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(54) Title: RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS

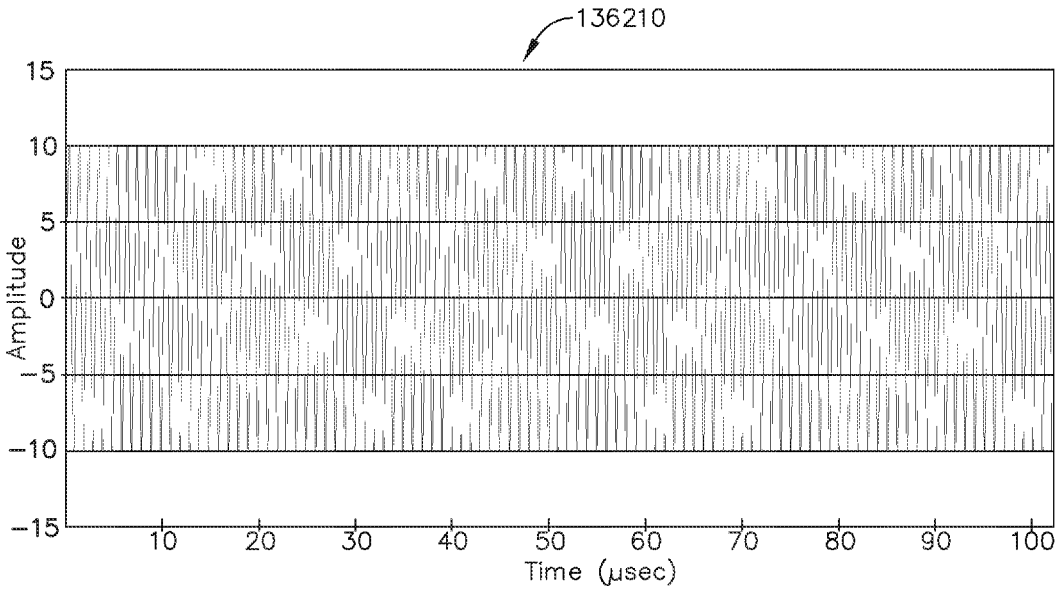


FIG. 34

(57) Abstract: An electrosurgical device may include a controller including an electrical generator, a surgical probe having a distal active electrode in electrical communication with an electrical source terminal of the electrical generator, and a return pad in electrical communication with an electrical return terminal of the electrical generator. The electrical generator may be configured to source an electrical current from the electrical source terminal, in which the electrical current combines characteristics of a therapeutic electrical signal and characteristics of an excitable tissue stimulating signal. The device may be configured to determine a distance from the electrode to an excitable tissue, based at least in part on an output signal generated by a sensing device in the pad. The device may also be configured to alter one or more characteristics of the therapeutic signal when the distance from the electrode to the tissue is less than a predetermined value.

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**Declarations under Rule 4.17:**

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

— *with information concerning request for restoration of the right of priority in respect of one or more priority claims (Rules 26bis.3 and 48.2(b)(vii))*

## TITLE

RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of U.S. Non-Provisional Patent Application Serial No. 16/115,233, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS, filed August 28, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0002]** The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/721,995, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION, filed on August 23, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0003]** The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/721,998, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS, filed on August 23, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0004]** The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/721,999, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING, filed on August 23, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0005]** The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/721,994, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY, filed on August 23, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0006]** The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/721,996, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS, filed on August 23, 2018, the disclosure of which is herein incorporated by reference in its entirety.

**[0007]** The present application also claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/692,747, titled SMART ACTIVATION OF AN ENERGY DEVICE BY ANOTHER DEVICE, filed on June 30, 2018, to U.S. Provisional Patent Application No. 62/692,748, titled SMART ENERGY ARCHITECTURE, filed on June 30, 2018, and to U.S. Provisional Patent Application No. 62/692,768, titled SMART ENERGY DEVICES, filed on June 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

**[0008]** This application also claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, and to U. S. Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC

END EFFECTOR AND CONTROL SYSTEM THEREFOR, filed March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

**[0009]** This application also claims the benefit of priority under 35 U.S.C. § 119(e) to U. S. Provisional Patent Application No. 62/650,898 filed on March 30, 2018, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS, to U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES, filed March 30, 2018, to U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, filed March 30, 2018, and to U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS, filed March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety.

**[0010]** This application also claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, to U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, and to U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety.

## BACKGROUND

**[0011]** In some surgical procedures, a medical professional may employ an electrosurgical device to seal or cut tissues such as blood vessels. Such devices effect a medical therapy by passing electrical energy, for example current at radiofrequencies (RF), through the tissue to be treated. Some electrosurgical devices are termed bipolar devices in that both an electrode to source the electrical energy (the active electrode) and a return electrode are housed in the same surgical probe. The electrosurgical device may include a generator to generate the electrical energy and supply the electrical energy to the active electrode in the surgical probe. The return electrode in the surgical probe may receive the current flowing through the patient's tissue and provide an electrical return path to the generator. Such bipolar devices may provide a short current path through the patient's tissue, and the medical professional can readily determine the tissues that may receive the electrical energy from the electrosurgical device.

**[0012]** Alternative devices may be termed monopolar devices. In such devices, only the active electrode is housed in the surgical probe. The electrical current entering the patient's tissue may return to the electrical energy generator via an electrical path through the gurney on which the patient reposes or through a specific return electrode pad. In some aspects, the patient may repose on the electrode pad, or the electrode pad may be placed on the patient at a location close to the surgical site where the surgical probe is deployed. It may be recognized that the current path through a patient undergoing a procedure using a monopolar device may be less well characterized

than the current path through a patient undergoing a procedure using a bipolar device. Consequently, some non-target tissue may be inadvertently cauterized, cut, or otherwise damaged by a monopolar electrosurgical device. Such non-target tissue may include electrically excitable tissue including, without limitation, ganglia, sensory nervous tissue, motor nervous tissue, and muscle tissue. Such unintended injury to excitable tissue may result in the patient experiencing muscle weakness, pain, numbness, paralysis and/or other undesired outcomes.

## SUMMARY

**[0013]** In an aspect, an electrosurgical device includes a controller having an electrical generator, a surgical probe including a distal active electrode, in which the active electrode is in electrical communication with an electrical source terminal of the electrical generator, and a return pad in electrical communication with an electrical return terminal of the electrical generator. The electrical generator is configured to source an electrical current from the electrical source terminal, and the electrical current sourced by the electrical generator combines characteristics of a therapeutic electrical signal and characteristics of an excitable tissue stimulating signal.

**[0014]** In one aspect of the electrosurgical device, the therapeutic electrical signal is a radiofrequency signal having a frequency greater than 200kHz and less than 5MHz.

**[0015]** In one aspect of the electrosurgical device, the excitable tissue stimulating signal is an AC signal having a frequency less than 200 kHz.

**[0016]** In one aspect of the electrosurgical device, the electrical current sourced by the electrical generator includes at least one alternating therapeutic electrical signal and at least one alternating excitable tissue stimulating signal.

**[0017]** In one aspect of the electrosurgical device, the electrical current sourced by the electrical generator includes a therapeutic electrical signal amplitude modulated by the excitable tissue stimulating signal.

**[0018]** In one aspect of the electrosurgical device, the electrical current sourced by the electrical generator includes a therapeutic electrical signal DC offset by the excitable tissue stimulating signal.

**[0019]** In one aspect of the electrosurgical device, the return pad further includes at least one sensing device having a sensing device output, and the sensing device is configured to determine a stimulation of an excitable tissue by the excitable tissue stimulating signal.

**[0020]** In one aspect of the electrosurgical device, the controller is configured to receive the sensing device output.

**[0021]** In one aspect of the electrosurgical device, the controller includes a processor and at least one memory component in data communication with the processor, in which the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to determine a distance of the active electrode from an excitable tissue based at least in part on the sensor output received by the controller.

**[0022]** In one aspect of the electrosurgical device, the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to alter a value of at least one characteristic of the therapeutic electrical signal when the distance of the active electrode from an excitable tissue is less than a predetermined value.

**[0023]** In an aspect, an electrosurgical system includes a processor and a memory coupled to the processor, in which the memory is configured to store instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal, cause the electrical generator to transmit the combination signal into a tissue of a patient through an active electrode in physical contact with the patient, and receive a sensing device output signal from a sensing device disposed within a return pad in physical contact with the patient.

**[0024]** In one aspect of the electrosurgical system, the memory is configured to further store instructions executable by the processor to determine, based at least in part on the sensing device output signal, a distance from the active electrode to an excitable tissue.

**[0025]** In one aspect of the electrosurgical system, the memory is configured to further store instructions executable by the processor to cause the controller to alter one or more characteristics of the therapeutic signal when the distance from the active electrode to the excitable tissue is less than a predetermined value.

**[0026]** In one aspect of the electrosurgical system, the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal includes instructions executable by the processor to cause the electrical generator to alternate the therapeutic signal and the excitable tissue stimulating signal.

**[0027]** In one aspect of the electrosurgical system, the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal includes instructions executable by the processor to cause the electrical generator to modulate an amplitude of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

**[0028]** In one aspect of the electrosurgical system, the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal includes instructions executable by the processor to cause the electrical generator to offset a DC value of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

**[0029]** In an aspect, an electrosurgical system includes a control circuit configured to control an electrical output of an electrical generator, in which the electrical output includes one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal, receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient, determine a distance between a location of

an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device, and alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

**[0030]** In one aspect of the electrosurgical system, the control circuit configured to alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value includes a control circuit configured to minimize the at least one characteristic of the therapeutic signal.

**[0031]** In an aspect, a non-transitory computer readable medium stores computer readable instructions which, when executed, cause a machine to control an electrical output of an electrical generator, in which the electrical output includes one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal, receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient, determine a distance between a location of an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device, and alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

## FIGURES

**[0032]** The features of various aspects are set forth with particularity in the appended claims. The various aspects, however, both as to organization and methods of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

**[0033]** FIG. 1 is a block diagram of a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

**[0034]** FIG. 2 is a surgical system being used to perform a surgical procedure in an operating room, in accordance with at least one aspect of the present disclosure.

**[0035]** FIG. 3 is a surgical hub paired with a visualization system, a robotic system, and an intelligent instrument, in accordance with at least one aspect of the present disclosure.

**[0036]** FIG. 4 is a partial perspective view of a surgical hub enclosure, and of a combo generator module slidably receivable in a drawer of the surgical hub enclosure, in accordance with at least one aspect of the present disclosure.

**[0037]** FIG. 5 is a perspective view of a combo generator module with bipolar, ultrasonic, and monopolar contacts and a smoke evacuation component, in accordance with at least one aspect of the present disclosure.

**[0038]** FIG. 6 illustrates a surgical data network comprising a modular communication hub configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to the cloud, in accordance with at least one aspect of the present disclosure.

**[0039]** FIG. 7 illustrates a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

**[0040]** FIG. 8 illustrates a surgical hub comprising a plurality of modules coupled to the modular control tower, in accordance with at least one aspect of the present disclosure.

**[0041]** FIG. 9 illustrates one aspect of a Universal Serial Bus (USB) network hub device, in accordance with at least one aspect of the present disclosure.

**[0042]** FIG. 10 illustrates a control circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

**[0043]** FIG. 11 illustrates a combinational logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

**[0044]** FIG. 12 illustrates a sequential logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

**[0045]** FIG. 13 is a system configured to execute adaptive ultrasonic blade control algorithms in a surgical data network comprising a modular communication hub, in accordance with at least one aspect of the present disclosure.

**[0046]** FIG. 14 illustrates an example of a generator, in accordance with at least one aspect of the present disclosure.

**[0047]** FIG. 15 is a surgical system comprising a generator and various surgical instruments usable therewith in accordance with at least one aspect of the present disclosure.

**[0048]** FIG. 16 is a diagram of the surgical system of FIG. 15 in accordance with at least one aspect of the present disclosure.

**[0049]** FIG. 17 is a structural view of a generator architecture in accordance with at least one aspect of the present disclosure.

**[0050]** FIGS. 18A-18C are functional views of a generator architecture in accordance with at least one aspect of the present disclosure.

**[0051]** FIGS. 19A-19B are structural and functional aspects of a generator in accordance with at least one aspect of the present disclosure.

**[0052]** FIG. 20 is a schematic diagram of a control circuit, in accordance with at least one aspect of the present disclosure.

**[0053]** FIG. 21 illustrates a generator circuit partitioned into multiple stages, in accordance with at least one aspect of the present disclosure.

**[0054]** FIG. 22 illustrates a generator circuit partitioned into multiple stages where a first stage circuit is common to the second stage circuit, in accordance with at least one aspect of the present disclosure.

**[0055]** FIG. 23 is a schematic diagram of one aspect of a drive circuit configured for driving a high-frequency current (RF), in accordance with at least one aspect of the present disclosure.

**[0056]** FIG. 24 is a schematic diagram of the transformer coupled to the RF drive circuit shown in FIG. 15, in accordance with at least one aspect of the present disclosure.

**[0057]** FIG. 25 is a schematic diagram of a circuit comprising separate power sources for high power energy/drive circuits and low power circuits, in accordance with at least one aspect of the resent disclosure.

**[0058]** FIG. 26 illustrates a control circuit that allows a dual generator system to switch between the RF generator and the ultrasonic generator energy modalities for a surgical instrument in accordance with at least one aspect of the resent disclosure.

**[0059]** FIG. 27 illustrates one aspect of a fundamental architecture for a digital synthesis circuit such as a direct digital synthesis (DDS) circuit configured to generate a plurality of wave shapes for the electrical signal waveform for use in a surgical instrument, in accordance with at least one aspect of the present disclosure.

**[0060]** FIG. 28 illustrates one aspect of direct digital synthesis (DDS) circuit configured to generate a plurality of wave shapes for the electrical signal waveform for use in surgical instrument, in accordance with at least one aspect of the present disclosure.

**[0061]** FIG. 29 illustrates one cycle of a discrete time digital electrical signal waveform, in accordance with at least one aspect of the present disclosure of an analog waveform (shown superimposed over a discrete time digital electrical signal waveform for comparison purposes), in accordance with at least one aspect of the present disclosure.

**[0062]** FIG. 30 depicts a surgical procedure using an electrosurgical system in accordance with at least one aspect of the present disclosure.

**[0063]** FIG. 31 illustrates a block diagram of the electrosurgical system used in FIG. 30 in accordance with at least one aspect of the present disclosure.

**[0064]** FIG. 32 illustrates a return pad of the electrosurgical system of FIG. 30 including a plurality of electrodes in accordance with at least one aspect of the present disclosure.

**[0065]** FIG. 33 illustrates an array of sensing devices in the return pad depicted in FIG. 31 in accordance with at least one aspect of the present disclosure.

**[0066]** FIG. 34 is a graphical representation of a therapeutic RF signal that may be used in an electrosurgical system in accordance with at least one aspect of the present disclosure.

**[0067]** FIG. 35 is a graphical representation of a nerve stimulation signal that may be incorporated in an electrosurgical system in accordance with at least one aspect of the present disclosure.

**[0068]** FIGS. 36A-36C are graphical representations of signals used by an electrosurgical system that may incorporate features of both the therapeutic RF signal of FIG. 34 and the nerve stimulation signal of FIG. 35 in accordance with at least one aspect of the present disclosure.

**[0069]** FIG. 37 summarizes a method in which such a control for a smart electrosurgical device may be effected in accordance with at least one aspect of the present disclosure.

**[0070]** FIG. 38 is a timeline depicting situational awareness of a surgical hub, in accordance with at least one aspect of the present disclosure.

## DESCRIPTION

**[0071]** Applicant of the present application owns the following U.S. Patent Applications, filed on August 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Docket No. END8536USNP2/180107-2, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;
- U.S. Patent Application Docket No. END8560USNP2/180106-2, titled TEMPERATURE CONTROL OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;
- U.S. Patent Application Docket No. END8563USNP1/180139-1, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION;
- U.S. Patent Application Docket No. END8563USNP2/180139-2, titled CONTROLLING ACTIVATION OF AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO THE PRESENCE OF TISSUE;
- U.S. Patent Application Docket No. END8563USNP3/180139-3, titled DETERMINING TISSUE COMPOSITION VIA AN ULTRASONIC SYSTEM;
- U.S. Patent Application Docket No. END8563USNP4/180139-4, titled DETERMINING THE STATE OF AN ULTRASONIC ELECTROMECHANICAL SYSTEM ACCORDING TO FREQUENCY SHIFT;
- U.S. Patent Application Docket No. END8563USNP5/180139-5, titled DETERMINING THE STATE OF AN ULTRASONIC END EFFECTOR;
- U.S. Patent Application Docket No. END8564USNP1/180140-1, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS;
- U.S. Patent Application Docket No. END8564USNP2/180140-2, titled MECHANISMS FOR CONTROLLING DIFFERENT ELECTROMECHANICAL SYSTEMS OF AN ELECTROSURGICAL INSTRUMENT;
- U.S. Patent Application Docket No. END8564USNP3/180140-3, titled DETECTION OF END EFFECTOR IMMERSION IN LIQUID;

- U.S. Patent Application Docket No. END8565USNP1/180142-1, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING;
- U.S. Patent Application Docket No. END8565USNP2/180142-2, titled INCREASING RADIO FREQUENCY TO CREATE PAD-LESS MONOPOLAR LOOP;
- U.S. Patent Application Docket No. END8566USNP1/180143-1, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY; and
- U.S. Patent Application Docket No. END8573USNP1/180145-1, titled ACTIVATION OF ENERGY DEVICES.

**[0072]** Applicant of the present application owns the following U.S. Patent Applications, filed on August 23, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/721,995, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION;
- U.S. Provisional Patent Application No. 62/721,998, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS;
- U.S. Provisional Patent Application No. 62/721,999, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING;
- U.S. Provisional Patent Application No. 62/721,994, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY; and
- U.S. Provisional Patent Application No. 62/721,996, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS.

**[0073]** Applicant of the present application owns the following U.S. Patent Applications, filed on June 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/692,747, titled SMART ACTIVATION OF AN ENERGY DEVICE BY ANOTHER DEVICE;
- U.S. Provisional Patent Application No. 62/692,748, titled SMART ENERGY ARCHITECTURE; and
- U.S. Provisional Patent Application No. 62/692,768, titled SMART ENERGY DEVICES.

**[0074]** Applicant of the present application owns the following U.S. Patent Applications, filed on June 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 16/024,090, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS;
- U.S. Patent Application Serial No. 16/024,057, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;
- U.S. Patent Application Serial No. 16/024,067, titled SYSTEMS FOR ADJUSTING END EFFECTOR PARAMETERS BASED ON PERIOPERATIVE INFORMATION;

- U.S. Patent Application Serial No. 16/024,075, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;
- U.S. Patent Application Serial No. 16/024,083, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;
- U.S. Patent Application Serial No. 16/024,094, titled SURGICAL SYSTEMS FOR DETECTING END EFFECTOR TISSUE DISTRIBUTION IRREGULARITIES;
- U.S. Patent Application Serial No. 16/024,138, titled SYSTEMS FOR DETECTING PROXIMITY OF SURGICAL END EFFECTOR TO CANCEROUS TISSUE;
- U.S. Patent Application Serial No. 16/024,150, titled SURGICAL INSTRUMENT CARTRIDGE SENSOR ASSEMBLIES;
- U.S. Patent Application Serial No. 16/024,160, titled VARIABLE OUTPUT CARTRIDGE SENSOR ASSEMBLY;
- U.S. Patent Application Serial No. 16/024,124, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;
- U.S. Patent Application Serial No. 16/024,132, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE CIRCUIT;
- U.S. Patent Application Serial No. 16/024,141, titled SURGICAL INSTRUMENT WITH A TISSUE MARKING ASSEMBLY;
- U.S. Patent Application Serial No. 16/024,162, titled SURGICAL SYSTEMS WITH PRIORITIZED DATA TRANSMISSION CAPABILITIES;
- U.S. Patent Application Serial No. 16/024,066, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;
- U.S. Patent Application Serial No. 16/024,096, titled SURGICAL EVACUATION SENSOR ARRANGEMENTS;
- U.S. Patent Application Serial No. 16/024,116, titled SURGICAL EVACUATION FLOW PATHS;
- U.S. Patent Application Serial No. 16/024,149, titled SURGICAL EVACUATION SENSING AND GENERATOR CONTROL;
- U.S. Patent Application Serial No. 16/024,180, titled SURGICAL EVACUATION SENSING AND DISPLAY;
- U.S. Patent Application Serial No. 16/024,245, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Patent Application Serial No. 16/024,258, titled SMOKE EVACUATION SYSTEM INCLUDING A SEGMENTED CONTROL CIRCUIT FOR INTERACTIVE SURGICAL PLATFORM;

- U.S. Patent Application Serial No. 16/024,265, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and
- U.S. Patent Application Serial No. 16/024,273, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

**[0075]** Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on June 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/691,228, titled A METHOD OF USING REINFORCED FLEX CIRCUITS WITH MULTIPLE SENSORS WITH ELECTROSURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/691,227, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;
- U.S. Provisional Patent Application Serial No. 62/691,230, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;
- U.S. Provisional Patent Application Serial No. 62/691,219, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;
- U.S. Provisional Patent Application Serial No. 62/691,257, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;
- U.S. Provisional Patent Application Serial No. 62/691,262, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and
- U.S. Provisional Patent Application Serial No. 62/691,251, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

**[0076]** Applicant of the present application owns the following U.S. Provisional Patent Application, filed on April 19, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/659,900, titled METHOD OF HUB COMMUNICATION.

**[0077]** Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 30, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U. S. Provisional Patent Application No. 62/650,898 filed on March 30, 2018, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS;
- U.S. Provisional Patent Application Serial No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES;

- U.S. Provisional Patent Application Serial No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM; and
- U.S. Provisional Patent Application Serial No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS

**[0078]** Applicant of the present application owns the following U.S. Patent Applications, filed on March 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Patent Application Serial No. 15/940,641, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,648, titled INTERACTIVE SURGICAL SYSTEMS WITH CONDITION HANDLING OF DEVICES AND DATA CAPABILITIES;
- U.S. Patent Application Serial No. 15/940,656, titled SURGICAL HUB COORDINATION OF CONTROL AND COMMUNICATION OF OPERATING ROOM DEVICES;
- U.S. Patent Application Serial No. 15/940,666, titled SPATIAL AWARENESS OF SURGICAL HUBS IN OPERATING ROOMS;
- U.S. Patent Application Serial No. 15/940,670, titled COOPERATIVE UTILIZATION OF DATA DERIVED FROM SECONDARY SOURCES BY INTELLIGENT SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,677, titled SURGICAL HUB CONTROL ARRANGEMENTS;
- U.S. Patent Application Serial No. 15/940,632, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Patent Application Serial No. 15/940,640, titled COMMUNICATION HUB AND STORAGE DEVICE FOR STORING PARAMETERS AND STATUS OF A SURGICAL DEVICE TO BE SHARED WITH CLOUD BASED ANALYTICS SYSTEMS;
- U.S. Patent Application Serial No. 15/940,645, titled SELF DESCRIBING DATA PACKETS GENERATED AT AN ISSUING INSTRUMENT;
- U.S. Patent Application Serial No. 15/940,649, titled DATA PAIRING TO INTERCONNECT A DEVICE MEASURED PARAMETER WITH AN OUTCOME;
- U.S. Patent Application Serial No. 15/940,654, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Patent Application Serial No. 15/940,663, titled SURGICAL SYSTEM DISTRIBUTED PROCESSING;
- U.S. Patent Application Serial No. 15/940,668, titled AGGREGATION AND REPORTING OF SURGICAL HUB DATA;
- U.S. Patent Application Serial No. 15/940,671, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Patent Application Serial No. 15/940,686, titled DISPLAY OF ALIGNMENT OF STAPLE CARTRIDGE TO PRIOR LINEAR STAPLE LINE;

- U.S. Patent Application Serial No. 15/940,700, titled STERILE FIELD INTERACTIVE CONTROL DISPLAYS;
- U.S. Patent Application Serial No. 15/940,629, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Patent Application Serial No. 15/940,704, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Patent Application Serial No. 15/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY; and
- U.S. Patent Application Serial No. 15/940,742, titled DUAL CMOS ARRAY IMAGING.
- U.S. Patent Application Serial No. 15/940,636, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Patent Application Serial No. 15/940,653, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL HUBS;
- U.S. Patent Application Serial No. 15/940,660, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Patent Application Serial No. 15/940,679, titled CLOUD-BASED MEDICAL ANALYTICS FOR LINKING OF LOCAL USAGE TRENDS WITH THE RESOURCE ACQUISITION BEHAVIORS OF LARGER DATA SET;
- U.S. Patent Application Serial No. 15/940,694, titled CLOUD-BASED MEDICAL ANALYTICS FOR MEDICAL FACILITY SEGMENTED INDIVIDUALIZATION OF INSTRUMENT FUNCTION;
- U.S. Patent Application Serial No. 15/940,634, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Patent Application Serial No. 15/940,706, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK; and
- U.S. Patent Application Serial No. 15/940,675, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES.
- U.S. Patent Application Serial No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,637, titled COMMUNICATION ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,642, titled CONTROLS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

- U.S. Patent Application Serial No. 15/940,680, titled CONTROLLERS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,683, titled COOPERATIVE SURGICAL ACTIONS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Patent Application Serial No. 15/940,690, titled DISPLAY ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Patent Application Serial No. 15/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

**[0079]** Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;
- U.S. Provisional Patent Application Serial No. 62/649,294, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;
- U.S. Provisional Patent Application Serial No. 62/649,300, titled SURGICAL HUB SITUATIONAL AWARENESS;
- U.S. Provisional Patent Application Serial No. 62/649,309, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;
- U.S. Provisional Patent Application Serial No. 62/649,310, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;
- U.S. Provisional Patent Application Serial No. 62/649,291, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;
- U.S. Provisional Patent Application Serial No. 62/649,296, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;
- U.S. Provisional Patent Application Serial No. 62/649,333, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;
- U.S. Provisional Patent Application Serial No. 62/649,327, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;
- U.S. Provisional Patent Application Serial No. 62/649,315, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;
- U.S. Provisional Patent Application Serial No. 62/649,313, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;

- U.S. Provisional Patent Application Serial No. 62/649,320, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. Provisional Patent Application Serial No. 62/649,307, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. Provisional Patent Application Serial No. 62/649,323, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

**[0080]** Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on March 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR; and
- U. S. Provisional Patent Application Serial No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR.

**[0081]** Applicant of the present application owns the following U.S. Provisional Patent Applications, filed on December 28, 2017, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application Serial No. U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM;
- U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS; and
- U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM.

**[0082]** Before explaining various aspects of surgical devices and generators in detail, it should be noted that the illustrative examples 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 examples may be implemented or incorporated in other aspects, 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 examples for the convenience of the reader and are not for the purpose of limitation thereof. Also, it will be appreciated that one or more of the following-described aspects, expressions of aspects, and/or examples, can be combined with any one or more of the other following-described aspects, expressions of aspects and/or examples.

**[0083]** Various aspects are directed to improved ultrasonic surgical devices, electrosurgical devices and generators for use therewith. Aspects of the ultrasonic surgical devices can be configured for transecting and/or coagulating tissue during surgical procedures, for example. Aspects of the electrosurgical devices can be configured for transecting, coagulating, scaling, welding and/or desiccating tissue during surgical procedures, for example.

**[0084]** Referring to FIG. 1, a computer-implemented interactive surgical system 100 includes one or more surgical systems 102 and a cloud-based system (e.g., the cloud 104 that may include a remote server 113 coupled to a storage device 105). Each surgical system 102 includes at least one surgical hub 106 in communication with the cloud 104 that may include a remote server 113. In one example, as illustrated in FIG. 1, the surgical system 102 includes a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112, which are configured to communicate with one another and/or the hub 106. In some aspects, a surgical system 102 may include an M number of hubs 106, an N number of visualization systems 108, an O number of robotic systems 110, and a P number of handheld intelligent surgical instruments 112, where M, N, O, and P are integers greater than or equal to one.

**[0085]** FIG. 2 depicts an example of a surgical system 102 being used to perform a surgical procedure on a patient who is lying down on an operating table 114 in a surgical operating room 116. A robotic system 110 is used in the surgical procedure as a part of the surgical system 102. The robotic system 110 includes a surgeon's console 118, a patient side cart 120 (surgical robot), and a surgical robotic hub 122. The patient side cart 120 can manipulate at least one removably coupled surgical tool 117 through a minimally invasive incision in the body of the patient while the surgeon views the surgical site through the surgeon's console 118. An image of the surgical site can be obtained by a medical imaging device 124, which can be manipulated by the patient side cart 120 to orient the imaging device 124. The robotic hub 122 can be used to process the images of the surgical site for subsequent display to the surgeon through the surgeon's console 118.

**[0086]** Other types of robotic systems can be readily adapted for use with the surgical system 102. Various examples of robotic systems and surgical tools that are suitable for use with the present disclosure are described in U.S. Provisional Patent Application Serial No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

**[0087]** Various examples of cloud-based analytics that are performed by the cloud 104, and are suitable for use with the present disclosure, are described in U.S. Provisional Patent Application Serial No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

**[0088]** In various aspects, the imaging device 124 includes at least one image sensor and one or more optical components. Suitable image sensors include, but are not limited to, Charge-Coupled Device (CCD) sensors and Complementary Metal-Oxide Semiconductor (CMOS) sensors.

**[0089]** The optical components of the imaging device 124 may include one or more illumination sources and/or one or more lenses. The one or more illumination sources may be directed to illuminate portions of the surgical field. The one or more image sensors may receive light reflected or refracted from the surgical field, including light reflected or refracted from tissue and/or surgical instruments.

**[0090]** The one or more illumination sources may be configured to radiate electromagnetic energy in the visible spectrum as well as the invisible spectrum. The visible spectrum, sometimes referred to as the optical spectrum or luminous spectrum, is that portion of the electromagnetic spectrum that is visible to (i.e., can be detected by) the human eye and may be referred to as visible light or simply light. A typical human eye will respond to wavelengths in air that are from about 380 nm to about 750 nm.

**[0091]** The invisible spectrum (i.e., the non-luminous spectrum) is that portion of the electromagnetic spectrum that lies below and above the visible spectrum (i.e., wavelengths below about 380 nm and above about 750 nm). The invisible spectrum is not detectable by the human eye. Wavelengths greater than about 750 nm are longer than the red visible spectrum, and they become invisible infrared (IR), microwave, and radio electromagnetic radiation. Wavelengths less than about 380 nm are shorter than the violet spectrum, and they become invisible ultraviolet, x-ray, and gamma ray electromagnetic radiation.

**[0092]** In various aspects, the imaging device 124 is configured for use in a minimally invasive procedure. Examples of imaging devices suitable for use with the present disclosure include, but not limited to, an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope, duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), endoscope, laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, and ureteroscope. Some aspects of spectral and multi-spectral imaging are described in greater detail under the heading “Advanced Imaging Acquisition Module” in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

**[0093]** It is axiomatic that strict sterilization of the operating room and surgical equipment is required during any surgery. The strict hygiene and sterilization conditions required in a “surgical theater,” i.e., an operating or treatment room, necessitate the highest possible sterility of all medical devices and equipment. Part of that sterilization process is the need to sterilize anything that comes in contact with the patient or penetrates the sterile field, including the imaging device 124 and its attachments and components. It will be appreciated that the sterile field may be considered a specified area, such as within a tray or on a sterile towel, that is considered free of microorganisms, or the sterile field may be considered an area, immediately around a patient, who has been prepared for a surgical procedure. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area.

**[0094]** In various aspects, the visualization system 108 includes one or more imaging sensors, one or more image-processing units, one or more storage arrays, and one or more displays that are strategically arranged with respect to the sterile field, as illustrated in FIG. 2. In one aspect, the visualization system 108 includes an interface for HL7, PACS, and EMR. Various components of the visualization system 108 are described under the heading “Advanced Imaging Acquisition Module” in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL

PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

**[0095]** As illustrated in FIG. 2, a primary display 119 is positioned in the sterile field to be visible to an operator at the operating table 114. In addition, a visualization tower 111 is positioned outside the sterile field. The visualization tower 111 includes a first non-sterile display 107 and a second non-sterile display 109, which face away from each other. The visualization system 108, guided by the hub 106, is configured to utilize the displays 107, 109, and 119 to coordinate information flow to operators inside and outside the sterile field. For example, the hub 106 may cause the visualization system 108 to display a snapshot of a surgical site, as recorded by an imaging device 124, on a non-sterile display 107 or 109, while maintaining a live feed of the surgical site on the primary display 119. The snapshot on the non-sterile display 107 or 109 can permit a non-sterile operator to perform a diagnostic step relevant to the surgical procedure, for example.

**[0096]** In one aspect, the hub 106 is also configured to route a diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 to the primary display 119 within the sterile field, where it can be viewed by a sterile operator at the operating table. In one example, the input can be in the form of a modification to the snapshot displayed on the non-sterile display 107 or 109, which can be routed to the primary display 119 by the hub 106.

**[0097]** Referring to FIG. 2, a surgical instrument 112 is being used in the surgical procedure as part of the surgical system 102. The hub 106 is also configured to coordinate information flow to a display of the surgical instrument 112. For example, in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. A diagnostic input or feedback entered by a non-sterile operator at the visualization tower 111 can be routed by the hub 106 to the surgical instrument display 115 within the sterile field, where it can be viewed by the operator of the surgical instrument 112. Example surgical instruments that are suitable for use with the surgical system 102 are described under the heading “Surgical Instrument Hardware” and in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, the disclosure of which is herein incorporated by reference in its entirety, for example.

**[0098]** Referring now to FIG. 3, a hub 106 is depicted in communication with a visualization system 108, a robotic system 110, and a handheld intelligent surgical instrument 112. The hub 106 includes a hub display 135, an imaging module 138, a generator module 140, a communication module 130, a processor module 132, and a storage array 134. In certain aspects, as illustrated in FIG. 3, the hub 106 further includes a smoke evacuation module 126 and/or a suction/irrigation module 128.

**[0099]** During a surgical procedure, energy application to tissue, for sealing and/or cutting, is generally associated with smoke evacuation, suction of excess fluid, and/or irrigation of the tissue. Fluid, power, and/or data lines from different sources are often entangled during the surgical

procedure. Valuable time can be lost addressing this issue during a surgical procedure. Detangling the lines may necessitate disconnecting the lines from their respective modules, which may require resetting the modules. The hub modular enclosure 136 offers a unified environment for managing the power, data, and fluid lines, which reduces the frequency of entanglement between such lines.

**[0100]** Aspects of the present disclosure present a surgical hub for use in a surgical procedure that involves energy application to tissue at a surgical site. The surgical hub includes a hub enclosure and a combo generator module slidably receivable in a docking station of the hub enclosure. The docking station includes data and power contacts. The combo generator module includes two or more of an ultrasonic energy generator component, a bipolar RF energy generator component, and a monopolar RF energy generator component that are housed in a single unit. In one aspect, the combo generator module also includes a smoke evacuation component, at least one energy delivery cable for connecting the combo generator module to a surgical instrument, at least one smoke evacuation component configured to evacuate smoke, fluid, and/or particulates generated by the application of therapeutic energy to the tissue, and a fluid line extending from the remote surgical site to the smoke evacuation component.

**[0101]** In one aspect, the fluid line is a first fluid line and a second fluid line extends from the remote surgical site to a suction and irrigation module slidably received in the hub enclosure. In one aspect, the hub enclosure comprises a fluid interface.

**[0102]** Certain surgical procedures may require the application of more than one energy type to the tissue. One energy type may be more beneficial for cutting the tissue, while another different energy type may be more beneficial for sealing the tissue. For example, a bipolar generator can be used to seal the tissue while an ultrasonic generator can be used to cut the sealed tissue. Aspects of the present disclosure present a solution where a hub modular enclosure 136 is configured to accommodate different generators, and facilitate an interactive communication therebetween. One of the advantages of the hub modular enclosure 136 is enabling the quick removal and/or replacement of various modules.

**[0103]** Aspects of the present disclosure present a modular surgical enclosure for use in a surgical procedure that involves energy application to tissue. The modular surgical enclosure includes a first energy-generator module, configured to generate a first energy for application to the tissue, and a first docking station comprising a first docking port that includes first data and power contacts, wherein the first energy-generator module is slidably movable into an electrical engagement with the power and data contacts and wherein the first energy-generator module is slidably movable out of the electrical engagement with the first power and data contacts,

**[0104]** Further to the above, the modular surgical enclosure also includes a second energy-generator module configured to generate a second energy, different than the first energy, for application to the tissue, and a second docking station comprising a second docking port that includes second data and power contacts, wherein the second energy-generator module is slidably movable into an electrical engagement with the power and data contacts, and wherein the second

energy-generator module is slidably movable out of the electrical engagement with the second power and data contacts.

**[0105]** In addition, the modular surgical enclosure also includes a communication bus between the first docking port and the second docking port, configured to facilitate communication between the first energy-generator module and the second energy-generator module.

**[0106]** Referring to FIGS. 3-5, aspects of the present disclosure are presented for a hub modular enclosure 136 that allows the modular integration of a generator module 140, a smoke evacuation module 126, and a suction/irrigation module 128. The hub modular enclosure 136 further facilitates interactive communication between the modules 140, 126, 128. As illustrated in FIG. 5, the generator module 140 can be a generator module with integrated monopolar, bipolar, and ultrasonic components supported in a single housing unit 139 slidably insertable into the hub modular enclosure 136. As illustrated in FIG. 5, the generator module 140 can be configured to connect to a monopolar device 146, a bipolar device 147, and an ultrasonic device 148. Alternatively, the generator module 140 may comprise a series of monopolar, bipolar, and/or ultrasonic generator modules that interact through the hub modular enclosure 136. The hub modular enclosure 136 can be configured to facilitate the insertion of multiple generators and interactive communication between the generators docked into the hub modular enclosure 136 so that the generators would act as a single generator.

**[0107]** In one aspect, the hub modular enclosure 136 comprises a modular power and communication backplane 149 with external and wireless communication headers to enable the removable attachment of the modules 140, 126, 128 and interactive communication therebetween.

**[0108]** In one aspect, the hub modular enclosure 136 includes docking stations, or drawers, 151, herein also referred to as drawers, which are configured to slidably receive the modules 140, 126, 128. FIG. 4 illustrates a partial perspective view of a surgical hub enclosure 136, and a combo generator module 145 slidably receivable in a docking station 151 of the surgical hub enclosure 136. A docking port 152 with power and data contacts on a rear side of the combo generator module 145 is configured to engage a corresponding docking port 150 with power and data contacts of a corresponding docking station 151 of the hub modular enclosure 136 as the combo generator module 145 is slid into position within the corresponding docking station 151 of the hub module enclosure 136. In one aspect, the combo generator module 145 includes a bipolar, ultrasonic, and monopolar module and a smoke evacuation module integrated together into a single housing unit 139, as illustrated in FIG. 5.

**[0109]** In various aspects, the smoke evacuation module 126 includes a fluid line 154 that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module 126. Vacuum suction originating from the smoke evacuation module 126 can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation

module 126. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module 126 that is received in the hub enclosure 136.

**[0110]** In various aspects, the smoke evacuation module 126 includes a fluid line 154 that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module 126. Vacuum suction originating from the smoke evacuation module 126 can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation module 126. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module 126 that is received in the hub enclosure 136.

**[0111]** In one aspect, the surgical tool includes a shaft having an end effector at a distal end thereof and at least one energy treatment associated with the end effector, an aspiration tube, and an irrigation tube. The aspiration tube can have an inlet port at a distal end thereof and the aspiration tube extends through the shaft. Similarly, an irrigation tube can extend through the shaft and can have an inlet port in proximity to the energy deliver implement. The energy deliver implement is configured to deliver ultrasonic and/or RF energy to the surgical site and is coupled to the generator module 140 by a cable extending initially through the shaft.

**[0112]** The irrigation tube can be in fluid communication with a fluid source, and the aspiration tube can be in fluid communication with a vacuum source. The fluid source and/or the vacuum source can be housed in the suction/irrigation module 128. In one example, the fluid source and/or the vacuum source can be housed in the hub enclosure 136 separately from the suction/irrigation module 128. In such example, a fluid interface can be configured to connect the suction/irrigation module 128 to the fluid source and/or the vacuum source.

**[0113]** In one aspect, the modules 140, 126, 128 and/or their corresponding docking stations on the hub modular enclosure 136 may include alignment features that are configured to align the docking ports of the modules into engagement with their counterparts in the docking stations of the hub modular enclosure 136. For example, as illustrated in FIG. 4, the combo generator module 145 includes side brackets 155 that are configured to slidably engage with corresponding brackets 156 of the corresponding docking station 151 of the hub modular enclosure 136. The brackets cooperate to guide the docking port contacts of the combo generator module 145 into an electrical engagement with the docking port contacts of the hub modular enclosure 136.

**[0114]** In some aspects, the drawers 151 of the hub modular enclosure 136 are the same, or substantially the same size, and the modules are adjusted in size to be received in the drawers 151. For example, the side brackets 155 and/or 156 can be larger or smaller depending on the size of the module. In other aspects, the drawers 151 are different in size and are each designed to accommodate a particular module.

**[0115]** Furthermore, the contacts of a particular module can be keyed for engagement with the contacts of a particular drawer to avoid inserting a module into a drawer with mismatching contacts.

**[0116]** As illustrated in FIG. 4, the docking port 150 of one drawer 151 can be coupled to the docking port 150 of another drawer 151 through a communications link 157 to facilitate an interactive communication between the modules housed in the hub modular enclosure 136. The docking ports 150 of the hub modular enclosure 136 may alternatively, or additionally, facilitate a wireless interactive communication between the modules housed in the hub modular enclosure 136. Any suitable wireless communication can be employed, such as for example Air Titan-Bluetooth.

**[0117]** Various image processors and imaging devices suitable for use with the present disclosure are described in U.S. Patent No. 7,995,045, titled COMBINED SBI AND CONVENTIONAL IMAGE PROCESSOR, which issued on August 9, 2011, which is herein incorporated by reference in its entirety. In addition, U.S. Patent No. 7,982,776, titled SBI MOTION ARTIFACT REMOVAL APPARATUS AND METHOD, which issued on July 19, 2011, which is herein incorporated by reference in its entirety, describes various systems for removing motion artifacts from image data. Such systems can be integrated with the imaging module 138. Furthermore, U.S. Patent Application Publication No. 2011/0306840, titled CONTROLLABLE MAGNETIC SOURCE TO FIXTURE INTRACORPOREAL APPARATUS, which published on December 15, 2011, and U.S. Patent Application Publication No. 2014/0243597, titled SYSTEM FOR PERFORMING A MINIMALLY INVASIVE SURGICAL PROCEDURE, which published on August 28, 2014, each of which is herein incorporated by reference in its entirety.

**[0118]** FIG. 6 illustrates a surgical data network 201 comprising a modular communication hub 203 configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to a cloud-based system (e.g., the cloud 204 that may include a remote server 213 coupled to a storage device 205). In one aspect, the modular communication hub 203 comprises a network hub 207 and/or a network switch 209 in communication with a network router. The modular communication hub 203 also can be coupled to a local computer system 210 to provide local computer processing and data manipulation. The surgical data network 201 may be configured as passive, intelligent, or switching. A passive surgical data network serves as a conduit for the data, enabling it to go from one device (or segment) to another and to the cloud computing resources. An intelligent surgical data network includes additional features to enable the traffic passing through the surgical data network to be monitored and to configure each port in the network hub 207 or network switch 209. An intelligent surgical data network may be referred to as a manageable hub or switch. A switching hub reads the destination address of each packet and then forwards the packet to the correct port.

**[0119]** Modular devices 1a-1n located in the operating theater may be coupled to the modular communication hub 203. The network hub 207 and/or the network switch 209 may be coupled to a network router 211 to connect the devices 1a-1n to the cloud 204 or the local computer system 210. Data associated with the devices 1a-1n may be transferred to cloud-based computers via the router for remote data processing and manipulation. Data associated with the devices 1a-1n may also be

transferred to the local computer system 210 for local data processing and manipulation. Modular devices 2a-2m located in the same operating theater also may be coupled to a network switch 209. The network switch 209 may be coupled to the network hub 207 and/or the network router 211 to connect to the devices 2a-2m to the cloud 204. Data associated with the devices 2a-2n may be transferred to the cloud 204 via the network router 211 for data processing and manipulation. Data associated with the devices 2a-2m may also be transferred to the local computer system 210 for local data processing and manipulation.

**[0120]** It will be appreciated that the surgical data network 201 may be expanded by interconnecting multiple network hubs 207 and/or multiple network switches 209 with multiple network routers 211. The modular communication hub 203 may be contained in a modular control tower configured to receive multiple devices 1a-1n/2a-2m. The local computer system 210 also may be contained in a modular control tower. The modular communication hub 203 is connected to a display 212 to display images obtained by some of the devices 1a-1n/2a-2m, for example during surgical procedures. In various aspects, the devices 1a-1n/2a-2m may include, for example, various modules such as an imaging module 138 coupled to an endoscope, a generator module 140 coupled to an energy-based surgical device, a smoke evacuation module 126, a suction/irrigation module 128, a communication module 130, a processor module 132, a storage array 134, a surgical device coupled to a display, and/or a non-contact sensor module, among other modular devices that may be connected to the modular communication hub 203 of the surgical data network 201.

**[0121]** In one aspect, the surgical data network 201 may comprise a combination of network hub(s), network switch(es), and network router(s) connecting the devices 1a-1n/2a-2m to the cloud. Any one of or all of the devices 1a-1n/2a-2m coupled to the network hub or network switch may collect data in real time and transfer the data to cloud computers for data processing and manipulation. It will be appreciated that cloud computing relies on sharing computing resources rather than having local servers or personal devices to handle software applications. The word “cloud” may be used as a metaphor for “the Internet,” although the term is not limited as such. Accordingly, the term “cloud computing” may be used herein to refer to “a type of Internet-based computing,” where different services—such as servers, storage, and applications—are delivered to the modular communication hub 203 and/or computer system 210 located in the surgical theater (e.g., a fixed, mobile, temporary, or field operating room or space) and to devices connected to the modular communication hub 203 and/or computer system 210 through the Internet. The cloud infrastructure may be maintained by a cloud service provider. In this context, the cloud service provider may be the entity that coordinates the usage and control of the devices 1a-1n/2a-2m located in one or more operating theaters. The cloud computing services can perform a large number of calculations based on the data gathered by smart surgical instruments, robots, and other computerized devices located in the operating theater. The hub hardware enables multiple devices or connections to be connected to a computer that communicates with the cloud computing resources and storage.

**[0122]** Applying cloud computer data processing techniques on the data collected by the devices 1a-1n/2a-2m, the surgical data network provides improved surgical outcomes, reduced costs, and improved patient satisfaction. At least some of the devices 1a-1n/2a-2m may be employed to view tissue states to assess leaks or perfusion of sealed tissue after a tissue sealing and cutting procedure. At least some of the devices 1a-1n/2a-2m may be employed to identify pathology, such as the effects of diseases, using the cloud-based computing to examine data including images of samples of body tissue for diagnostic purposes. This includes localization and margin confirmation of tissue and phenotypes. At least some of the devices 1a-1n/2a-2m may be employed to identify anatomical structures of the body using a variety of sensors integrated with imaging devices and techniques such as overlaying images captured by multiple imaging devices. The data gathered by the devices 1a-1n/2a-2m, including image data, may be transferred to the cloud 204 or the local computer system 210 or both for data processing and manipulation including image processing and manipulation. The data may be analyzed to improve surgical procedure outcomes by determining if further treatment, such as the application of endoscopic intervention, emerging technologies, a targeted radiation, targeted intervention, and precise robotics to tissue-specific sites and conditions, may be pursued. Such data analysis may further employ outcome analytics processing, and using standardized approaches may provide beneficial feedback to either confirm surgical treatments and the behavior of the surgeon or suggest modifications to surgical treatments and the behavior of the surgeon.

**[0123]** In one implementation, the operating theater devices 1a-1n may be connected to the modular communication hub 203 over a wired channel or a wireless channel depending on the configuration of the devices 1a-1n to a network hub. The network hub 207 may be implemented, in one aspect, as a local network broadcast device that works on the physical layer of the Open System Interconnection (OSI) model. The network hub provides connectivity to the devices 1a-1n located in the same operating theater network. The network hub 207 collects data in the form of packets and sends them to the router in half duplex mode. The network hub 207 does not store any media access control/Internet Protocol (MAC/IP) to transfer the device data. Only one of the devices 1a-1n can send data at a time through the network hub 207. The network hub 207 has no routing tables or intelligence regarding where to send information and broadcasts all network data across each connection and to a remote server 213 (FIG. 9) over the cloud 204. The network hub 207 can detect basic network errors such as collisions, but having all information broadcast to multiple ports can be a security risk and cause bottlenecks.

**[0124]** In another implementation, the operating theater devices 2a-2m may be connected to a network switch 209 over a wired channel or a wireless channel. The network switch 209 works in the data link layer of the OSI model. The network switch 209 is a multicast device for connecting the devices 2a-2m located in the same operating theater to the network. The network switch 209 sends data in the form of frames to the network router 211 and works in full duplex mode. Multiple devices

2a-2m can send data at the same time through the network switch 209. The network switch 209 stores and uses MAC addresses of the devices 2a-2m to transfer data.

**[0125]** The network hub 207 and/or the network switch 209 are coupled to the network router 211 for connection to the cloud 204. The network router 211 works in the network layer of the OSI model. The network router 211 creates a route for transmitting data packets received from the network hub 207 and/or network switch 211 to cloud-based computer resources for further processing and manipulation of the data collected by any one of or all the devices 1a-1n/2a-2m. The network router 211 may be employed to connect two or more different networks located in different locations, such as, for example, different operating theaters of the same healthcare facility or different networks located in different operating theaters of different healthcare facilities. The network router 211 sends data in the form of packets to the cloud 204 and works in full duplex mode. Multiple devices can send data at the same time. The network router 211 uses IP addresses to transfer data.

**[0126]** In one example, the network hub 207 may be implemented as a USB hub, which allows multiple USB devices to be connected to a host computer. The USB hub may expand a single USB port into several tiers so that there are more ports available to connect devices to the host system computer. The network hub 207 may include wired or wireless capabilities to receive information over a wired channel or a wireless channel. In one aspect, a wireless USB short-range, high-bandwidth wireless radio communication protocol may be employed for communication between the devices 1a-1n and devices 2a-2m located in the operating theater.

**[0127]** In other examples, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via Bluetooth wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area networks (PANs). In other aspects, the operating theater devices 1a-1n/2a-2m may communicate to the modular communication hub 203 via a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second communication module may be dedicated to longer-range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

**[0128]** The modular communication hub 203 may serve as a central connection for one or all of the operating theater devices 1a-1n/2a-2m and handles a data type known as frames. Frames carry the data generated by the devices 1a-1n/2a-2m. When a frame is received by the modular communication hub 203, it is amplified and transmitted to the network router 211, which transfers

the data to the cloud computing resources by using a number of wireless or wired communication standards or protocols, as described herein.

**[0129]** The modular communication hub 203 can be used as a standalone device or be connected to compatible network hubs and network switches to form a larger network. The modular communication hub 203 is generally easy to install, configure, and maintain, making it a good option for networking the operating theater devices 1a-1n/2a-2m.

**[0130]** FIG. 7 illustrates a computer-implemented interactive surgical system 200. The computer-implemented interactive surgical system 200 is similar in many respects to the computer-implemented interactive surgical system 100. For example, the computer-implemented interactive surgical system 200 includes one or more surgical systems 202, which are similar in many respects to the surgical systems 102. Each surgical system 202 includes at least one surgical hub 206 in communication with a cloud 204 that may include a remote server 213. In one aspect, the computer-implemented interactive surgical system 200 comprises a modular control tower 236 connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater. As shown in FIG. 8, the modular control tower 236 comprises a modular communication hub 203 coupled to a computer system 210. As illustrated in the example of FIG. 7, the modular control tower 236 is coupled to an imaging module 238 that is coupled to an endoscope 239, a generator module 240 that is coupled to an energy device 241, a smoke evacuator module 226, a suction/irrigation module 228, a communication module 230, a processor module 232, a storage array 234, a smart device/instrument 235 optionally coupled to a display 237, and a non-contact sensor module 242. The operating theater devices are coupled to cloud computing resources and data storage via the modular control tower 236. A robot hub 222 also may be connected to the modular control tower 236 and to the cloud computing resources. The devices/instruments 235, visualization systems 208, among others, may be coupled to the modular control tower 236 via wired or wireless communication standards or protocols, as described herein. The modular control tower 236 may be coupled to a hub display 215 (e.g., monitor, screen) to display and overlay images received from the imaging module, device/instrument display, and/or other visualization systems 208. The hub display also may display data received from devices connected to the modular control tower in conjunction with images and overlaid images.

**[0131]** FIG. 8 illustrates a surgical hub 206 comprising a plurality of modules coupled to the modular control tower 236. The modular control tower 236 comprises a modular communication hub 203, e.g., a network connectivity device, and a computer system 210 to provide local processing, visualization, and imaging, for example. As shown in FIG. 8, the modular communication hub 203 may be connected in a tiered configuration to expand the number of modules (e.g., devices) that may be connected to the modular communication hub 203 and transfer data associated with the modules to the computer system 210, cloud computing resources, or both. As shown in FIG. 8, each of the network hubs/switches in the modular communication hub 203 includes three downstream

ports and one upstream port. The upstream network hub/switch is connected to a processor to provide a communication connection to the cloud computing resources and a local display 217. Communication to the cloud 204 may be made either through a wired or a wireless communication channel.

**[0132]** The surgical hub 206 employs a non-contact sensor module 242 to measure the dimensions of the operating theater and generate a map of the surgical theater using either ultrasonic or laser-type non-contact measurement devices. An ultrasound-based non-contact sensor module scans the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off the perimeter walls of an operating theater as described under the heading "Surgical Hub Spatial Awareness Within an Operating Room" in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, which is herein incorporated by reference in its entirety, in which the sensor module is configured to determine the size of the operating theater and to adjust Bluetooth-pairing distance limits. A laser-based non-contact sensor module scans the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits, for example.

**[0133]** The computer system 210 comprises a processor 244 and a network interface 245. The processor 244 is coupled to a communication module 247, storage 248, memory 249, non-volatile memory 250, and input/output interface 251 via a system bus. The system bus can be any of several types of bus structure(s) including the memory bus or memory controller, a peripheral bus or external bus, and/or a local bus using any variety of available bus architectures including, but not limited to, 9-bit bus, Industrial Standard Architecture (ISA), Micro-Charmel Architecture (MSA), Extended ISA (EISA), Intelligent Drive Electronics (IDE), VESA Local Bus (VLB), Peripheral Component Interconnect (PCI), USB, Advanced Graphics Port (AGP), Personal Computer Memory Card International Association bus (PCMCIA), Small Computer Systems Interface (SCSI), or any other proprietary bus.

**[0134]** The processor 244 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), an internal read-only memory (ROM) loaded with StellarisWare® software, a 2 KB electrically erasable programmable read-only memory (EEPROM), and/or one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analogs, one or more 12-bit analog-to-digital converters (ADCs) with 12 analog input channels, details of which are available for the product datasheet.

**[0135]** In one aspect, the processor 244 may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

**[0136]** The system memory includes volatile memory and non-volatile memory. The basic input/output system (BIOS), containing the basic routines to transfer information between elements within the computer system, such as during start-up, is stored in non-volatile memory. For example, the non-volatile memory can include ROM, programmable ROM (PROM), electrically programmable ROM (EPROM), EEPROM, or flash memory. Volatile memory includes random-access memory (RAM), which acts as external cache memory. Moreover, RAM is available in many forms such as SRAM, dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM).

**[0137]** The computer system 210 also includes removable/non-removable, volatile/non-volatile computer storage media, such as for example disk storage. The disk storage includes, but is not limited to, devices like a magnetic disk drive, floppy disk drive, tape drive, Jaz drive, Zip drive, LS-60 drive, flash memory card, or memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), compact disc recordable drive (CD-R Drive), compact disc rewritable drive (CD-RW Drive), or a digital versatile disc ROM drive (DVD-ROM). To facilitate the connection of the disk storage devices to the system bus, a removable or non-removable interface may be employed.

**[0138]** It is to be appreciated that the computer system 210 includes software that acts as an intermediary between users and the basic computer resources described in a suitable operating environment. Such software includes an operating system. The operating system, which can be stored on the disk storage, acts to control and allocate resources of the computer system. System applications take advantage of the management of resources by the operating system through program modules and program data stored either in the system memory or on the disk storage. It is to be appreciated that various components described herein can be implemented with various operating systems or combinations of operating systems.

**[0139]** A user enters commands or information into the computer system 210 through input device(s) coupled to the I/O interface 251. The input devices include, but are not limited to, a pointing device such as a mouse, trackball, stylus, touch pad, keyboard, microphone, joystick, game pad, satellite dish, scanner, TV tuner card, digital camera, digital video camera, web camera, and the like. These and other input devices connect to the processor through the system bus via interface port(s). The interface port(s) include, for example, a serial port, a parallel port, a game port, and a USB. The output device(s) use some of the same types of ports as input device(s).

Thus, for example, a USB port may be used to provide input to the computer system and to output information from the computer system to an output device. An output adapter is provided to illustrate that there are some output devices like monitors, displays, speakers, and printers, among other output devices that require special adapters. The output adapters include, by way of illustration and not limitation, video and sound cards that provide a means of connection between the output device and the system bus. It should be noted that other devices and/or systems of devices, such as remote computer(s), provide both input and output capabilities.

**[0140]** The computer system 210 can operate in a networked environment using logical connections to one or more remote computers, such as cloud computer(s), or local computers. The remote cloud computer(s) can be a personal computer, server, router, network PC, workstation, microprocessor-based appliance, peer device, or other common network node, and the like, and typically includes many or all of the elements described relative to the computer system. For purposes of brevity, only a memory storage device is illustrated with the remote computer(s). The remote computer(s) is logically connected to the computer system through a network interface and then physically connected via a communication connection. The network interface encompasses communication networks such as local area networks (LANs) and wide area networks (WANs). LAN technologies include Fiber Distributed Data Interface (FDDI), Copper Distributed Data Interface (CDDI), Ethernet/IEEE 802.3, Token Ring/IEEE 802.5 and the like. WAN technologies include, but are not limited to, point-to-point links, circuit-switching networks like Integrated Services Digital Networks (ISDN) and variations thereon, packet-switching networks, and Digital Subscriber Lines (DSL).

**[0141]** In various aspects, the computer system 210 of FIG. 8, the imaging module 238 and/or visualization system 208, and/or the processor module 232 of FIGS. 7-8, may comprise an image processor, image-processing engine, media processor, or any specialized digital signal processor (DSP) used for the processing of digital images. The image processor may employ parallel computing with single instruction, multiple data (SIMD) or multiple instruction, multiple data (MIMD) technologies to increase speed and efficiency. The digital image-processing engine can perform a range of tasks. The image processor may be a system on a chip with multicore processor architecture.

**[0142]** The communication connection(s) refers to the hardware/software employed to connect the network interface to the bus. While the communication connection is shown for illustrative clarity inside the computer system, it can also be external to the computer system 210. The hardware/software necessary for connection to the network interface includes, for illustrative purposes only, internal and external technologies such as modems, including regular telephone-grade modems, cable modems, and DSL modems, ISDN adapters, and Ethernet cards.

**[0143]** FIG. 9 illustrates a functional block diagram of one aspect of a USB network hub 300 device, in accordance with at least one aspect of the present disclosure. In the illustrated aspect, the USB network hub device 300 employs a TUSB2036 integrated circuit hub by Texas Instruments.

The USB network hub 300 is a CMOS device that provides an upstream USB transceiver port 302 and up to three downstream USB transceiver ports 304, 306, 308 in compliance with the USB 2.0 specification. The upstream USB transceiver port 302 is a differential root data port comprising a differential data minus (DM0) input paired with a differential data plus (DP0) input. The three downstream USB transceiver ports 304, 306, 308 are differential data ports where each port includes differential data plus (DP1-DP3) outputs paired with differential data minus (DM1-DM3) outputs.

**[0144]** The USB network hub 300 device is implemented with a digital state machine instead of a microcontroller, and no firmware programming is required. Fully compliant USB transceivers are integrated into the circuit for the upstream USB transceiver port 302 and all downstream USB transceiver ports 304, 306, 308. The downstream USB transceiver ports 304, 306, 308 support both full-speed and low-speed devices by automatically setting the slew rate according to the speed of the device attached to the ports. The USB network hub 300 device may be configured either in bus-powered or self-powered mode and includes a hub power logic 312 to manage power.

**[0145]** The USB network hub 300 device includes a serial interface engine 310 (SIE). The SIE 310 is the front end of the USB network hub 300 hardware and handles most of the protocol described in chapter 8 of the USB specification. The SIE 310 typically comprehends signaling up to the transaction level. The functions that it handles could include: packet recognition, transaction sequencing, SOP, EOP, RESET, and RESUME signal detection/generation, clock/data separation, non-return-to-zero invert (NRZI) data encoding/decoding and bit-stuffing, CRC generation and checking (token and data), packet ID (PID) generation and checking/decoding, and/or serial-parallel/parallel-serial conversion. The 310 receives a clock input 314 and is coupled to a suspend/resume logic and frame timer 316 circuit and a hub repeater circuit 318 to control communication between the upstream USB transceiver port 302 and the downstream USB transceiver ports 304, 306, 308 through port logic circuits 320, 322, 324. The SIE 310 is coupled to a command decoder 326 via interface logic to control commands from a serial EEPROM via a serial EEPROM interface 330.

**[0146]** In various aspects, the USB network hub 300 can connect 127 functions configured in up to six logical layers (tiers) to a single computer. Further, the USB network hub 300 can connect to all peripherals using a standardized four-wire cable that provides both communication and power distribution. The power configurations are bus-powered and self-powered modes. The USB network hub 300 may be configured to support four modes of power management: a bus-powered hub, with either individual-port power management or ganged-port power management, and the self-powered hub, with either individual-port power management or ganged-port power management. In one aspect, using a USB cable, the USB network hub 300, the upstream USB transceiver port 302 is plugged into a USB host controller, and the downstream USB transceiver ports 304, 306, 308 are exposed for connecting USB compatible devices, and so forth.

Surgical Instrument Hardware Control

**[0147]** FIG. 10 illustrates a control circuit 500 configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The control circuit 500 can be configured to implement various processes described herein. The control circuit 500 may comprise a microcontroller comprising one or more processors 502 (e.g., microprocessor, microcontroller) coupled to at least one memory circuit 504. The memory circuit 504 stores machine-executable instructions that, when executed by the processor 502, cause the processor 502 to execute machine instructions to implement various processes described herein. The processor 502 may be any one of a number of single-core or multicore processors known in the art. The memory circuit 504 may comprise volatile and non-volatile storage media. The processor 502 may include an instruction processing unit 506 and an arithmetic unit 508. The instruction processing unit may be configured to receive instructions from the memory circuit 504 of this disclosure. FIG. 11 illustrates a combinational logic circuit 510 configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The combinational logic circuit 510 can be configured to implement various processes described herein. The combinational logic circuit 510 may comprise a finite state machine comprising a combinational logic 512 configured to receive data associated with the surgical instrument or tool at an input 514, process the data by the combinational logic 512, and provide an output 516.

**[0148]** FIG. 12 illustrates a sequential logic circuit 520 configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The sequential logic circuit 520 or the combinational logic 522 can be configured to implement various processes described herein. The sequential logic circuit 520 may comprise a finite state machine. The sequential logic circuit 520 may comprise a combinational logic 522, at least one memory circuit 524, and a clock 529, for example. The at least one memory circuit 524 can store a current state of the finite state machine. In certain instances, the sequential logic circuit 520 may be synchronous or asynchronous. The combinational logic 522 is configured to receive data associated with the surgical instrument or tool from an input 526, process the data by the combinational logic 522, and provide an output 528. In other aspects, the circuit may comprise a combination of a processor (e.g., processor 502, FIG. 10) and a finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of a combinational logic circuit (e.g., combinational logic circuit 510, FIG. 11) and the sequential logic circuit 520.

Generator Hardware

**[0149]** FIG. 13 is a system 800 configured to execute adaptive ultrasonic blade control algorithms in a surgical data network comprising a modular communication hub, in accordance with at least one aspect of the present disclosure. In one aspect, the generator module 240 is configured to execute one or more adaptive ultrasonic blade control algorithm(s). In another aspect, the device/instrument 235 is configured to execute the adaptive ultrasonic blade control algorithm(s). In

another aspect, both the device/instrument 235 and the device/instrument 235 are configured to execute the adaptive ultrasonic blade control algorithms.

**[0150]** The generator module 240 may comprise a patient isolated stage in communication with a non-isolated stage via a power transformer. A secondary winding of the power transformer is contained in the isolated stage and may comprise a tapped configuration (e.g., a center-tapped or a non-center-tapped configuration) to define drive signal outputs for delivering drive signals to different surgical instruments, such as, for example, an ultrasonic surgical instrument, an RF electrosurgical instrument, and a multifunction surgical instrument which includes ultrasonic and RF energy modes that can be delivered alone or simultaneously. In particular, the drive signal outputs may output an ultrasonic drive signal (e.g., a 420V root-mean-square (RMS) drive signal) to an ultrasonic surgical instrument 241, and the drive signal outputs may output an RF electrosurgical drive signal (e.g., a 100V RMS drive signal) to an RF electrosurgical instrument 241. Aspects of the generator module 240 are described herein with reference to FIGS. 14-19B.

**[0151]** The generator module 240 or the device/instrument 235 or both are coupled to the modular control tower 236 connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater, as described with reference to FIGS. 6-9, for example.

**[0152]** FIG. 14 illustrates an example of a generator 900, which is one form of a generator configured to couple to an ultrasonic instrument and further configured to execute adaptive ultrasonic blade control algorithms in a surgical data network comprising a modular communication hub as shown in FIG. 13. The generator 900 is configured to deliver multiple energy modalities to a surgical instrument. The generator 900 provides RF and ultrasonic signals for delivering energy to a surgical instrument either independently or simultaneously. The RF 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 900 comprises a processor 902 coupled to a waveform generator 904. The processor 902 and waveform generator 904 are configured to generate a variety of signal waveforms based on information stored in a memory coupled to the processor 902, not shown for clarity of disclosure. The digital information associated with a waveform is provided to the waveform generator 904 which includes one or more DAC circuits 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 906 is coupled to a power transformer 908. The signals are coupled across the power transformer 908 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 910 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.

**[0153]** A first voltage sensing circuit 912 is coupled across the terminals labeled ENERGY1 and the RETURN path to measure the output voltage therebetween. A second voltage sensing circuit 924 is coupled across the terminals labeled ENERGY2 and the RETURN path to measure the output voltage therebetween. A current sensing circuit 914 is disposed in series with the RETURN leg of the secondary side of the power transformer 908 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 912, 924 are provided to respective isolation transformers 916, 922 and the output of the current sensing circuit 914 is provided to another isolation transformer 918. The outputs of the isolation transformers 916, 928, 922 in the on the primary side of the power transformer 908 (non-patient isolated side) are provided to a one or more ADC circuit 926. The digitized output of the ADC circuit 926 is provided to the processor 902 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 902 and patient isolated circuits is provided through an interface circuit 920. Sensors also may be in electrical communication with the processor 902 by way of the interface circuit 920.

**[0154]** In one aspect, the impedance may be determined by the processor 902 by dividing the output of either the first voltage sensing circuit 912 coupled across the terminals labeled ENERGY1/RETURN or the second voltage sensing circuit 924 coupled across the terminals labeled ENERGY2/RETURN by the output of the current sensing circuit 914 disposed in series with the RETURN leg of the secondary side of the power transformer 908. The outputs of the first and second voltage sensing circuits 912, 924 are provided to separate isolations transformers 916, 922 and the output of the current sensing circuit 914 is provided to another isolation transformer 916. The digitized voltage and current sensing measurements from the ADC circuit 926 are provided the processor 902 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. 21 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 912 by the

current sensing circuit 914 and the tissue impedance may be measured by dividing the output of the second voltage sensing circuit 924 by the current sensing circuit 914.

**[0155]** As shown in FIG. 14, the generator 900 comprising at least one output port can include a power transformer 908 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 900 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 900 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 900 output would be preferably located between the output labeled ENERGY1 and RETURN as shown in FIG. 14. In one example, a connection of RF bipolar electrodes to the generator 900 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 surgical probe) to the ENERGY2 output and a suitable return pad connected to the RETURN output.

**[0156]** Additional details are disclosed in U.S. Patent Application Publication No. 2017/0086914, titled TECHNIQUES FOR OPERATING GENERATOR FOR DIGITALLY GENERATING ELECTRICAL SIGNAL WAVEFORMS AND SURGICAL INSTRUMENTS, which published on March 30, 2017, which is herein incorporated by reference in its entirety.

**[0157]** As used throughout this description, the term “wireless” and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some aspects they might not. The communication module may implement any of a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long term evolution (LTE), Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter range wireless communications such as Wi-Fi and Bluetooth and a second communication module may be dedicated to longer range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

**[0158]** As used herein a processor or processing unit is an electronic circuit which performs operations on some external data source, usually memory or some other data stream. The term is

used herein to refer to the central processor (central processing unit) in a system or computer systems (especially systems on a chip (SoCs)) that combine a number of specialized "processors."

**[0159]** As used herein, a system on a chip or system on chip (SoC or SOC) is an integrated circuit (also known as an "IC" or "chip") that integrates all components of a computer or other electronic systems. It may contain digital, analog, mixed-signal, and often radio-frequency functions—all on a single substrate. A SoC integrates a microcontroller (or microprocessor) with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or coprocessor. A SoC may or may not contain built-in memory.

**[0160]** As used herein, a microcontroller or controller is a system that integrates a microprocessor with peripheral circuits and memory. A microcontroller (or MCU for microcontroller unit) may be implemented as a small computer on a single integrated circuit. It may be similar to a SoC; an SoC may include a microcontroller as one of its components. A microcontroller may contain one or more core processing units (CPUs) along with memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers may be employed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

**[0161]** As used herein, the term controller or microcontroller may be a stand-alone IC or chip device that interfaces with a peripheral device. This may be a link between two parts of a computer or a controller on an external device that manages the operation of (and connection with) that device.

**[0162]** Any of the processors or microcontrollers described herein, may be implemented by any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, details of which are available for the product datasheet.

**[0163]** In one aspect, the processor may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

**[0164]** Modular devices include the modules (as described in connection with FIGS. 3 and 9, for example) that are receivable within a surgical hub and the surgical devices or instruments that can be connected to the various modules in order to connect or pair with the corresponding surgical hub. The modular devices include, for example, intelligent surgical instruments, medical imaging devices, suction/irrigation devices, smoke evacuators, energy generators, ventilators, insufflators, and displays. The modular devices described herein can be controlled by control algorithms. The control algorithms can be executed on the modular device itself, on the surgical hub to which the particular modular device is paired, or on both the modular device and the surgical hub (e.g., via a distributed computing architecture). In some exemplifications, the modular devices' control algorithms control the devices based on data sensed by the modular device itself (i.e., by sensors in, on, or connected to the modular device). This data can be related to the patient being operated on (e.g., tissue properties or insufflation pressure) or the modular device itself (e.g., the rate at which a knife is being advanced, motor current, or energy levels). For example, a control algorithm for a surgical stapling and cutting instrument can control the rate at which the instrument's motor drives its knife through tissue according to resistance encountered by the knife as it advances.

**[0165]** FIG. 15 illustrates one form of a surgical system 1000 comprising a generator 1100 and various surgical instruments 1104, 1106, 1108 usable therewith, where the surgical instrument 1104 is an ultrasonic surgical instrument, the surgical instrument 1106 is an RF electrosurgical instrument, and the multifunction surgical instrument 1108 is a combination ultrasonic/RF electrosurgical instrument. The generator 1100 is configurable for use with a variety of surgical instruments. According to various forms, the generator 1100 may be configurable for use with different surgical instruments of different types including, for example, ultrasonic surgical instruments 1104, RF electrosurgical instruments 1106, and multifunction surgical instruments 1108 that integrate RF and ultrasonic energies delivered simultaneously from the generator 1100. Although in the form of FIG. 15 the generator 1100 is shown separate from the surgical instruments 1104, 1106, 1108 in one form, the generator 1100 may be formed integrally with any of the surgical instruments 1104, 1106, 1108 to form a unitary surgical system. The generator 1100 comprises an input device 1110 located on a front panel of the generator 1100 console. The input device 1110 may comprise any suitable device that generates signals suitable for programming the operation of the generator 1100. The generator 1100 may be configured for wired or wireless communication

**[0166]** The generator 1100 is configured to drive multiple surgical instruments 1104, 1106, 1108. The first surgical instrument is an ultrasonic surgical instrument 1104 and comprises a handpiece 1105 (HP), an ultrasonic transducer 1120, a shaft 1126, and an end effector 1122. The end effector 1122 comprises an ultrasonic blade 1128 acoustically coupled to the ultrasonic transducer 1120 and a clamp arm 1140. The handpiece 1105 comprises a trigger 1143 to operate the clamp arm 1140 and a combination of the toggle buttons 1134a, 1134b, 1134c to energize and drive the ultrasonic blade 1128 or other function. The toggle buttons 1134a, 1134b, 1134c can be configured to energize the ultrasonic transducer 1120 with the generator 1100.

**[0167]** The generator 1100 also is configured to drive a second surgical instrument 1106. The second surgical instrument 1106 is an RF electrosurgical instrument and comprises a handpiece 1107 (HP), a shaft 1127, and an end effector 1124. The end effector 1124 comprises electrodes in clamp arms 1142a, 1142b and return through an electrical conductor portion of the shaft 1127. The electrodes are coupled to and energized by a bipolar energy source within the generator 1100. The handpiece 1107 comprises a trigger 1145 to operate the clamp arms 1142a, 1142b and an energy button 1135 to actuate an energy switch to energize the electrodes in the end effector 1124.

**[0168]** The generator 1100 also is configured to drive a multifunction surgical instrument 1108. The multifunction surgical instrument 1108 comprises a handpiece 1109 (HP), a shaft 1129, and an end effector 1125. The end effector 1125 comprises an ultrasonic blade 1149 and a clamp arm 1146. The ultrasonic blade 1149 is acoustically coupled to the ultrasonic transducer 1120. The handpiece 1109 comprises a trigger 1147 to operate the clamp arm 1146 and a combination of the toggle buttons 1137a, 1137b, 1137c to energize and drive the ultrasonic blade 1149 or other function. The toggle buttons 1137a, 1137b, 1137c can be configured to energize the ultrasonic transducer 1120 with the generator 1100 and energize the ultrasonic blade 1149 with a bipolar energy source also contained within the generator 1100. It will be appreciated that the handpiece 1105, 1107, 1109 may be replaced with a robotically controlled instrument. Accordingly, the term handpiece should not be limited in this context.

**[0169]** The generator 1100 is configurable for use with a variety of surgical instruments. According to various forms, the generator 1100 may be configurable for use with different surgical instruments of different types including, for example, the ultrasonic surgical instrument 1104, the RF electrosurgical instrument 1106, and the multifunction surgical instrument 1108 that integrates RF and ultrasonic energies delivered simultaneously from the generator 1100. Although in the form of FIG. 15 the generator 1100 is shown separate from the surgical instruments 1104, 1106, 1108, in another form the generator 1100 may be formed integrally with any one of the surgical instruments 1104, 1106, 1108 to form a unitary surgical system. As discussed above, the generator 1100 comprises an input device 1110 located on a front panel of the generator 1100 console. The input device 1110 may comprise any suitable device that generates signals suitable for programming the operation of the generator 1100. The generator 1100 also may comprise one or more output devices 1112. Further aspects of generators for digitally generating electrical signal waveforms and surgical instruments are described in US patent publication US-2017-0086914-A1, which is herein incorporated by reference in its entirety.

**[0170]** In various aspects, the generator 1100 may comprise several separate functional elements, such as modules and/or blocks, as shown in FIG. 16, a diagram of the surgical system 1000 of FIG. 15. Different functional elements or modules may be configured for driving the different kinds of surgical devices 1104, 1106, 1108. For example an ultrasonic generator module may drive an ultrasonic device, such as the ultrasonic device 1104. An electrosurgery/RF generator module may drive the electrosurgical device 1106. The modules may generate respective drive signals for

driving the surgical devices 1104, 1106, 1108. In various aspects, the ultrasonic generator module and/or the electrosurgery/RF generator module each may be formed integrally with the generator 1100. Alternatively, one or more of the modules may be provided as a separate circuit module electrically coupled to the generator 1100. (The modules are shown in phantom to illustrate this option.) Also, in some aspects, the electrosurgery/RF generator module may be formed integrally with the ultrasonic generator module, or vice versa.

**[0171]** In accordance with the described aspects, the ultrasonic generator module may produce a drive signal or signals of particular voltages, currents, and frequencies (e.g. 55,500 cycles per second, or Hz). The drive signal or signals may be provided to the ultrasonic device 1104, and specifically to the transducer 1120, which may operate, for example, as described above. In one aspect, the generator 1100 may be configured to produce a drive signal of a particular voltage, current, and/or frequency output signal that can be stepped with high resolution, accuracy, and repeatability.

**[0172]** In accordance with the described aspects, the electrosurgery/RF generator module 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 the electrodes of the electrosurgical device 1106, for example, as described above. Accordingly, the generator 1100 may be configured for therapeutic purposes by applying electrical energy to the tissue sufficient for treating the tissue (e.g., coagulation, cauterization, tissue welding, etc.).

**[0173]** The generator 1100 may comprise an input device 2150 (FIG. 18B) located, for example, on a front panel of the generator 1100 console. The input device 2150 may comprise any suitable device that generates signals suitable for programming the operation of the generator 1100. In operation, the user can program or otherwise control operation of the generator 1100 using the input device 2150. The input device 2150 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 1100 (e.g., operation of the ultrasonic generator module and/or electrosurgery/RF generator module). In various aspects, the input device 2150 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 aspects, the input device 2150 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 2150, 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 module and/or electrosurgery/RF generator module.

**[0174]** The generator 1100 may also comprise an output device 2140 (FIG. 18B) located, for example, on a front panel of the generator 1100 console. The output device 2140 includes one or more devices for providing a sensory feedback to a user. Such devices may comprise, for example,

visual feedback devices (e.g., an LCD display screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer) or tactile feedback devices (e.g., haptic actuators).

**[0175]** Although certain modules and/or blocks of the generator 1100 may be described by way of example, it can be appreciated that a greater or lesser number of modules and/or blocks may be used and still fall within the scope of the aspects. Further, although various aspects may be described in terms of modules and/or blocks to facilitate description, such modules 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.

**[0176]** In one aspect, the ultrasonic generator drive module and electrosurgery/RF drive module 1110 (FIG. 15) may comprise one or more embedded applications implemented as firmware, software, hardware, or any combination thereof. The modules 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).

**[0177]** In one aspect, the modules comprise a hardware component implemented as a processor for executing program instructions for monitoring various measurable characteristics of the devices 1104, 1106, 1108 and generating a corresponding output drive signal or signals for operating the devices 1104, 1106, 1108. In aspects in which the generator 1100 is used in conjunction with the device 1104, the drive signal may drive the ultrasonic transducer 1120 in cutting and/or coagulation operating modes. Electrical characteristics of the device 1104 and/or tissue may be measured and used to control operational aspects of the generator 1100 and/or provided as feedback to the user. In aspects in which the generator 1100 is used in conjunction with the device 1106, the drive signal may supply electrical energy (e.g., RF energy) to the end effector 1124 in cutting, coagulation and/or desiccation modes. Electrical characteristics of the device 1106 and/or tissue may be measured and used to control operational aspects of the generator 1100 and/or provided as feedback to the user. In various aspects, as previously discussed, the hardware components may be implemented as DSP, PLD, ASIC, circuits, and/or registers. In one aspect, the processor may be configured to store and execute computer software program instructions to generate the step function output signals for driving various components of the devices 1104, 1106, 1108, such as the ultrasonic transducer 1120 and the end effectors 1122, 1124, 1125.

**[0178]** FIG. 17 is a simplified block diagram of one aspect of the generator 1100 for providing inductorless tuning as described above, among other benefits. FIGS. 18A-18C illustrate an

architecture of the generator 1100 of FIG. 17 according to one aspect. With reference to FIG. 17, the generator 1100 may comprise a patient isolated stage 1520 in communication with a non-isolated stage 1540 via a power transformer 1560. A secondary winding 1580 of the power transformer 1560 is contained in the isolated stage 1520 and may comprise a tapped configuration (e.g., a center-tapped or non-center tapped configuration) to define drive signal outputs 1600a, 1600b, 1600c for outputting drive signals to different surgical devices, such as, for example, an ultrasonic surgical device 1104 and an electrosurgical device 1106. In particular, drive signal outputs 1600a, 1600b, 1600c may output a drive signal (e.g., a 420V RMS drive signal) to an ultrasonic surgical device 1104, and drive signal outputs 1600a, 1600b, 1600c may output a drive signal (e.g., a 100V RMS drive signal) to an electrosurgical device 1106, with output 1600b corresponding to the center tap of the power transformer 1560. The non-isolated stage 1540 may comprise a power amplifier 1620 having an output connected to a primary winding 1640 of the power transformer 1560. In certain aspects the power amplifier 1620 may comprise a push-pull amplifier, for example. The non-isolated stage 1540 may further comprise a programmable logic device 1660 for supplying a digital output to a digital-to-analog converter (DAC) 1680, which in turn supplies a corresponding analog signal to an input of the power amplifier 1620. In certain aspects the programmable logic device 1660 may comprise a field-programmable gate array (FPGA), for example. The programmable logic device 1660, by virtue of controlling the power amplifier's 1620 input via the DAC 1680, 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 1600a, 1600b, 1600c. In certain aspects and as discussed below, the programmable logic device 1660, in conjunction with a processor (e.g., processor 1740 discussed below), may implement a number of digital signal processing (DSP)-based and/or other control algorithms to control parameters of the drive signals output by the generator 1100.

**[0179]** Power may be supplied to a power rail of the power amplifier 1620 by a switch-mode regulator 1700. In certain aspects the switch-mode regulator 1700 may comprise an adjustable buck regulator, for example. As discussed above, the non-isolated stage 1540 may further comprise a processor 1740, which in one aspect may comprise a DSP processor such as an ADSP-21469 SHARC DSP, available from Analog Devices, Norwood, Mass., for example. In certain aspects the processor 1740 may control operation of the switch-mode power converter 1700 responsive to voltage feedback data received from the power amplifier 1620 by the processor 1740 via an analog-to-digital converter (ADC) 1760. In one aspect, for example, the processor 1740 may receive as input, via the ADC 1760, the waveform envelope of a signal (e.g., an RF signal) being amplified by the power amplifier 1620. The processor 1740 may then control the switch-mode regulator 1700 (e.g., via a pulse-width modulated (PWM) output) such that the rail voltage supplied to the power amplifier 1620 tracks the waveform envelope of the amplified signal. By dynamically modulating the rail voltage of the power amplifier 1620 based on the waveform envelope, the efficiency of the

power amplifier 1620 may be significantly improved relative to a fixed rail voltage amplifier scheme. The processor 1740 may be configured for wired or wireless communication.

**[0180]** In certain aspects and as discussed in further detail in connection with FIGS. 19A-19B, the programmable logic device 1660, in conjunction with the processor 1740, 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 1100. In one aspect, for example, the programmable logic device 1660 may implement a DDS control algorithm 2680 (FIG. 14A) 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 algorithm is particularly useful for ultrasonic applications in which an ultrasonic transducer, such as the ultrasonic transducer 1120, 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 1100 is impacted by various sources of distortion present in the output drive circuit (e.g., the power transformer 1560, the power amplifier 1620), voltage and current feedback data based on the drive signal may be input into an algorithm, such as an error control algorithm implemented by the processor 1740, 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 aspect, 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 aspects, 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.

**[0181]** The non-isolated stage 1540 may further comprise an ADC 1780 and an ADC 1800 coupled to the output of the power transformer 1560 via respective isolation transformers 1820, 1840 for respectively sampling the voltage and current of drive signals output by the generator 1100. In certain aspects, the ADCs 1780, 1800 may be configured to sample at high speeds (e.g., 80 Msps) to enable oversampling of the drive signals. In one aspect, for example, the sampling speed of the ADCs 1780, 1800 may enable approximately 200X (depending on drive frequency) oversampling of the drive signals. In certain aspects, the sampling operations of the ADCs 1780, 1800 may be performed by a single ADC receiving input voltage and current signals via a two-way multiplexer. The use of high-speed sampling in aspects of the generator 1100 may enable, among other things, calculation of the complex current flowing through the motional branch (which may be used in certain aspects to implement DDS-based waveform shape control described above),

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 1780, 1800 may be received and processed (e.g., FIFO buffering, multiplexing) by the programmable logic device 1660 and stored in data memory for subsequent retrieval by, for example, the processor 1740. As noted above, voltage and current feedback data may be used as input to an algorithm for pre-distorting or modifying LUT waveform samples on a dynamic and ongoing basis. In certain aspects, 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 programmable logic device 1660 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 algorithm.

**[0182]** In certain aspects, 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 aspect, for example, voltage and current feedback data may be used to determine impedance phase, e.g., the phase difference between the voltage and current drive signals. 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 harmonic distortion and correspondingly enhancing impedance phase measurement accuracy. The determination of phase impedance and a frequency control signal may be implemented in the processor 1740, for example, with the frequency control signal being supplied as input to a DDS control algorithm implemented by the programmable logic device 1660.

**[0183]** The impedance phase may be determined through Fourier analysis. In one aspect, the phase difference between the generator voltage $V_g(t)$ and generator current $I_g(t)$ driving signals may be determined using the Fast Fourier Transform (FFT) or the Discrete Fourier Transform (DFT) as follows:

$$V_g(t) = A_1\cos(2\pi f_0 t + \varphi_1)$$

$$I_g(t) = A_2\cos(2\pi f_0 t + \varphi_2)$$

$$V_g(f) = \frac{A_1}{2}\big(\delta(f - f_0) + \delta(f + f_0)\big)\exp(j2\pi f\frac{\varphi_1}{2\pi f_0})$$

$$I_g(f) = \frac{A_2}{2}\big(\delta(f - f_0) + \delta(f + f_0)\big)\exp(j2\pi f\frac{\varphi_2}{2\pi f_0})$$

**[0184]** Evaluating the Fourier Transform at the frequency of the sinusoid yields:

$$V_g(f_0) = \tfrac{A_1}{2}\delta(0)\exp(j\varphi_1) \qquad \arg V(f_0) = \varphi_1$$

$$I_g(f_0) = \tfrac{A_2}{2}\delta(0)\exp(j\varphi_2) \qquad \arg I(f_0) = \varphi_2$$

**[0185]** Other approaches include weighted least-squares estimation, Kalman filtering, and space-vector-based techniques. Virtually all of the processing in an FFT or DFT technique may be performed in the digital domain with the aid of the 2-channel high speed ADC 1780, 1800, for

example. In one technique, the digital signal samples of the voltage and current signals are Fourier transformed with an FFT or a DFT. The phase angle $\varphi$ at any point in time can be calculated by:

$$\varphi = 2\pi f t + \varphi_0$$

where $\varphi$ is the phase angle, $f$ is the frequency, $t$ is time, and $\varphi_0$ is the phase at $t = 0$.

**[0186]** Another technique for determining the phase difference between the voltage $V_g(t)$ and current $I_g(t)$ signals is the zero-crossing method and produces highly accurate results. For voltage $V_g(t)$ and current $I_g(t)$ signals having the same frequency, each negative to positive zero-crossing of voltage signal $V_g(t)$ triggers the start of a pulse, while each negative to positive zero-crossing of current signal $I_g(t)$ triggers the end of the pulse. The result is a pulse train with a pulse width proportional to the phase angle between the voltage signal and the current signal. In one aspect, the pulse train may be passed through an averaging filter to yield a measure of the phase difference. Furthermore, if the positive to negative zero crossings also are used in a similar manner, and the results averaged, any effects of DC and harmonic components can be reduced. In one implementation, the analog voltage $V_g(t)$ and current $I_g(t)$ signals are converted to digital signals that are high if the analog signal is positive and low if the analog signal is negative. High accuracy phase estimates require sharp transitions between high and low. In one aspect, a Schmitt trigger along with an RC stabilization network may be employed to convert the analog signals into digital signals. In other aspects, an edge triggered RS flip-flop and ancillary circuitry may be employed. In yet another aspect, the zero-crossing technique may employ an eXclusive OR (XOR) gate.

**[0187]** Other techniques for determining the phase difference between the voltage and current signals include Lissajous figures and monitoring the image; methods such as the three-voltmeter method, the crossed-coil method, vector voltmeter and vector impedance methods; and using phase standard instruments, phase-locked loops, and other techniques as described in Phase Measurement, Peter O'Shea, 2000 CRC Press LLC, <http://www.engnetbase.com>, which is incorporated herein by reference.

**[0188]** In another aspect, 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 aspects, control of the current amplitude may be implemented by control algorithm, such as, for example, a proportional-integral-derivative (PID) control algorithm, in the processor 1740. Variables controlled by the control algorithm to suitably control the current amplitude of the drive signal may include, for example, the scaling of the LUT waveform samples stored in the programmable logic device 1660 and/or the full-scale output voltage of the DAC 1680 (which supplies the input to the power amplifier 1620) via a DAC 1860.

**[0189]** The non-isolated stage 1540 may further comprise a processor 1900 for providing, among other things, user interface (UI) functionality. In one aspect, the processor 1900 may comprise an Atmel AT91 SAM9263 processor having an ARM 926EJ-S core, available from Atmel Corporation, San Jose, Calif., for example. Examples of UI functionality supported by the processor 1900 may

include audible and visual user feedback, communication with peripheral devices (e.g., via a Universal Serial Bus (USB) interface), communication with a foot switch 1430, communication with an input device 2150 (e.g., a touch screen display) and communication with an output device 2140 (e.g., a speaker). The processor 1900 may communicate with the processor 1740 and the programmable logic device (e.g., via a serial peripheral interface (SPI) bus). Although the processor 1900 may primarily support UI functionality, it may also coordinate with the processor 1740 to implement hazard mitigation in certain aspects. For example, the processor 1900 may be programmed to monitor various aspects of user input and/or other inputs (e.g., touch screen inputs 2150, foot switch 1430 inputs, temperature sensor inputs 2160) and may disable the drive output of the generator 1100 when an erroneous condition is detected.

**[0190]** In certain aspects, both the processor 1740 (FIG. 17, 18A) and the processor 1900 (FIG. 17, 18B) may determine and monitor the operating state of the generator 1100. For processor 1740, the operating state of the generator 1100 may dictate, for example, which control and/or diagnostic processes are implemented by the processor 1740. For processor 1900, the operating state of the generator 1100 may dictate, for example, which elements of a user interface (e.g., display screens, sounds) are presented to a user. The processors 1740, 1900 may independently maintain the current operating state of the generator 1100 and recognize and evaluate possible transitions out of the current operating state. The processor 1740 may function as the master in this relationship and determine when transitions between operating states are to occur. The processor 1900 may be aware of valid transitions between operating states and may confirm if a particular transition is appropriate. For example, when the processor 1740 instructs the processor 1900 to transition to a specific state, the processor 1900 may verify that the requested transition is valid. In the event that a requested transition between states is determined to be invalid by the processor 1900, the processor 1900 may cause the generator 1100 to enter a failure mode.

**[0191]** The non-isolated stage 1540 may further comprise a controller 1960 (FIG. 17, 18B) for monitoring input devices 2150 (e.g., a capacitive touch sensor used for turning the generator 1100 on and off, a capacitive touch screen). In certain aspects, the controller 1960 may comprise at least one processor and/or other controller device in communication with the processor 1900. In one aspect, for example, the controller 1960 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 aspect, the controller 1960 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.

**[0192]** In certain aspects, when the generator 1100 is in a “power off” state, the controller 1960 may continue to receive operating power (e.g., via a line from a power supply of the generator 1100, such as the power supply 2110 (FIG. 17) discussed below). In this way, the controller 1960 may continue to monitor an input device 2150 (e.g., a capacitive touch sensor located on a front panel of the generator 1100) for turning the generator 1100 on and off. When the generator 1100 is in the

"power off" state, the controller 1960 may wake the power supply (e.g., enable operation of one or more DC/DC voltage converters 2130 (FIG. 17) of the power supply 2110) if activation of the "on/off" input device 2150 by a user is detected. The controller 1960 may therefore initiate a sequence for transitioning the generator 1100 to a "power on" state. Conversely, the controller 1960 may initiate a sequence for transitioning the generator 1100 to the "power off" state if activation of the "on/off" input device 2150 is detected when the generator 1100 is in the "power on" state. In certain aspects, for example, the controller 1960 may report activation of the "on/off" input device 2150 to the processor 1900, which in turn implements the necessary process sequence for transitioning the generator 1100 to the "power off" state. In such aspects, the controller 1960 may have no independent ability for causing the removal of power from the generator 1100 after its "power on" state has been established.

**[0193]** In certain aspects, the controller 1960 may cause the generator 1100 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.

**[0194]** In certain aspects, the isolated stage 1520 may comprise an instrument interface circuit 1980 to, for example, provide a communication interface between a control circuit of a surgical device (e.g., a control circuit comprising handpiece switches) and components of the non-isolated stage 1540, such as, for example, the programmable logic device 1660, the processor 1740 and/or the processor 1900. The instrument interface circuit 1980 may exchange information with components of the non-isolated stage 1540 via a communication link that maintains a suitable degree of electrical isolation between the stages 1520, 1540, such as, for example, an infrared (IR)-based communication link. Power may be supplied to the instrument interface circuit 1980 using, for example, a low-dropout voltage regulator powered by an isolation transformer driven from the non-isolated stage 1540.

**[0195]** In one aspect, the instrument interface circuit 1980 may comprise a programmable logic device 2000 (e.g., an FPGA) in communication with a signal conditioning circuit 2020 (FIG. 17 and FIG. 18C). The signal conditioning circuit 2020 may be configured to receive a periodic signal from the programmable logic device 2000 (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 1100 to the surgical device) and monitored to determine a state or configuration of the control circuit. For example, 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 discernible based on the one or more characteristics. In one aspect, for example, the signal conditioning circuit 2020 may comprise an ADC for generating samples of a voltage signal

appearing across inputs of the control circuit resulting from passage of interrogation signal therethrough. The programmable logic device 2000 (or a component of the non-isolated stage 1540) may then determine the state or configuration of the control circuit based on the ADC samples.

**[0196]** In one aspect, the instrument interface circuit 1980 may comprise a first data circuit interface 2040 to enable information exchange between the programmable logic device 2000 (or other element of the instrument interface circuit 1980) and a first data circuit disposed in or otherwise associated with a surgical device. In certain aspects, for example, a first data circuit 2060 may be disposed in a cable integrally attached to a surgical device handpiece, or in an adaptor for interfacing a specific surgical device type or model with the generator 1100. In certain aspects, the first data circuit may comprise a non-volatile storage device, such as an electrically erasable programmable read-only memory (EEPROM) device. In certain aspects and referring again to FIG. 17, the first data circuit interface 2040 may be implemented separately from the programmable logic device 2000 and comprise suitable circuitry (e.g., discrete logic devices, a processor) to enable communication between the programmable logic device 2000 and the first data circuit. In other aspects, the first data circuit interface 2040 may be integral with the programmable logic device 2000.

**[0197]** In certain aspects, the first data circuit 2060 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 1980 (e.g., by the programmable logic device 2000), transferred to a component of the non-isolated stage 1540 (e.g., to programmable logic device 1660, processor 1740 and/or processor 1900) for presentation to a user via an output device 2140 and/or for controlling a function or operation of the generator 1100. Additionally, any type of information may be communicated to first data circuit 2060 for storage therein via the first data circuit interface 2040 (e.g., using the programmable logic device 2000). 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.

**[0198]** As discussed previously, a surgical instrument may be detachable from a handpiece (e.g., instrument 1106 may be detachable from handpiece 1107) to promote instrument interchangeability and/or disposability. In such cases, known 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, it may be impractical to design a surgical device to maintain backward compatibility with generators that lack the requisite data reading functionality due to, for example, differing signal schemes, design complexity and cost. Other aspects of instruments 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.

**[0199]** Additionally, aspects of the generator 1100 may enable communication with instrument-based data circuits. For example, the generator 1100 may be configured to communicate with a second data circuit (e.g., a data circuit) contained in an instrument (e.g., instrument 1104, 1106 or 1108) of a surgical device. The instrument interface circuit 1980 may comprise a second data circuit interface 2100 to enable this communication. In one aspect, the second data circuit interface 2100 may comprise a tri-state digital interface, although other interfaces may also be used. In certain aspects, the second data circuit may generally be any circuit for transmitting and/or receiving data. In one aspect, 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. Additionally or alternatively, any type of information may be communicated to the second data circuit for storage therein via the second data circuit interface 2100 (e.g., using the programmable logic device 2000). 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 aspects, the second data circuit may transmit data acquired by one or more sensors (e.g., an instrument-based temperature sensor). In certain aspects, the second data circuit may receive data from the generator 1100 and provide an indication to a user (e.g., an LED indication or other visible indication) based on the received data.

**[0200]** In certain aspects, the second data circuit and the second data circuit interface 2100 may be configured such that communication between the programmable logic device 2000 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 handpiece to the generator 1100). In one aspect, for example, information may be communicated to and from the second data circuit using a one-wire bus communication scheme implemented on existing cabling, such as one of the conductors used transmit interrogation signals from the signal conditioning circuit 2020 to a control circuit in a handpiece. 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 can be implemented over a common physical channel (either with or without frequency-band separation), 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.

**[0201]** In certain aspects, the isolated stage 1520 may comprise at least one blocking capacitor 2960-1 (FIG. 18C) connected to the drive signal output 1600b 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 aspect, a second blocking capacitor

2960-2 may be provided in series with the blocking capacitor 2960-1, with current leakage from a point between the blocking capacitors 2960-1, 2960-2 being monitored by, for example, an ADC 2980 for sampling a voltage induced by leakage current. The samples may be received by the programmable logic device 2000, for example. Based on changes in the leakage current (as indicated by the voltage samples in the aspect of FIG. 17), the generator 1100 may determine when at least one of the blocking capacitors 2960-1, 2960-2 has failed. Accordingly, the aspect of FIG. 17 may provide a benefit over single-capacitor designs having a single point of failure.

**[0202]** In certain aspects, the non-isolated stage 1540 may comprise a power supply 2110 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. As discussed above, the power supply 2110 may further comprise one or more DC/DC voltage converters 2130 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 1100. As discussed above in connection with the controller 1960, one or more of the DC/DC voltage converters 2130 may receive an input from the controller 1960 when activation of the "on/off" input device 2150 by a user is detected by the controller 1960 to enable operation of, or wake, the DC/DC voltage converters 2130.

**[0203]** FIGS. 19A-19B illustrate certain functional and structural aspects of one aspect of the generator 1100. Feedback indicating current and voltage output from the secondary winding 1580 of the power transformer 1560 is received by the ADCs 1780, 1800, respectively. As shown, the ADCs 1780, 1800 may be implemented as a 2-channel ADC and may sample the feedback signals at a high speed (e.g., 80 Msps) to enable oversampling (e.g., approximately 200x oversampling) of the drive signals. The current and voltage feedback signals may be suitably conditioned in the analog domain (e.g., amplified, filtered) prior to processing by the ADCs 1780, 1800. Current and voltage feedback samples from the ADCs 1780, 1800 may be individually buffered and subsequently multiplexed or interleaved into a single data stream within block 2120 of the programmable logic device 1660. In the aspect of FIGS. 19A-19B, the programmable logic device 1660 comprises an FPGA.

**[0204]** The multiplexed current and voltage feedback samples may be received by a parallel data acquisition port (PDAP) implemented within block 2144 of the processor 1740. The PDAP may comprise a packing unit for implementing any of a number of methodologies for correlating the multiplexed feedback samples with a memory address. In one aspect, for example, feedback samples corresponding to a particular LUT sample output by the programmable logic device 1660 may be stored at one or more memory addresses that are correlated or indexed with the LUT address of the LUT sample. In another aspect, feedback samples corresponding to a particular LUT sample output by the programmable logic device 1660 may be stored, along with the LUT address of the LUT sample, at a common memory location. In any event, the feedback samples may be stored such that the address of the LUT sample from which a particular set of feedback samples originated may be subsequently ascertained. As discussed above, synchronization of the LUT

sample addresses and the feedback samples in this way contributes to the correct timing and stability of the pre-distortion algorithm. A direct memory access (DMA) controller implemented at block 2166 of the processor 1740 may store the feedback samples (and any LUT sample address data, where applicable) at a designated memory location 2180 of the processor 1740 (e.g., internal RAM).

**[0205]** Block 2200 of the processor 1740 may implement a pre-distortion algorithm for pre-distorting or modifying the LUT samples stored in the programmable logic device 1660 on a dynamic, ongoing basis. As discussed above, pre-distortion of the LUT samples may compensate for various sources of distortion present in the output drive circuit of the generator 1100. The pre-distorted LUT samples, when processed through the drive circuit, will therefore result in a drive signal having the desired waveform shape (e.g., sinusoidal) for optimally driving the ultrasonic transducer.

**[0206]** At block 2220 of the pre-distortion algorithm, the current through the motional branch of the ultrasonic transducer is determined. The motional branch current may be determined using Kirchhoff's Current Law based on, for example, the current and voltage feedback samples stored at memory location 2180(which, when suitably scaled, may be representative of Ig and Vg in the model of FIG. 25 discussed above), a value of the ultrasonic transducer static capacitance $C_0$ (measured or known a priori) and a known value of the drive frequency. A motional branch current sample for each set of stored current and voltage feedback samples associated with a LUT sample may be determined.

**[0207]** At block 2240 of the pre-distortion algorithm, each motional branch current sample determined at block 2220 is compared to a sample of a desired current waveform shape to determine a difference, or sample amplitude error, between the compared samples. For this determination, the sample of the desired current waveform shape may be supplied, for example, from a waveform shape LUT 2260 containing amplitude samples for one cycle of a desired current waveform shape. The particular sample of the desired current waveform shape from the LUT 2260 used for the comparison may be dictated by the LUT sample address associated with the motional branch current sample used in the comparison. Accordingly, the input of the motional branch current to block 2240 may be synchronized with the input of its associated LUT sample address to block 2240. The LUT samples stored in the programmable logic device 1660 and the LUT samples stored in the waveform shape LUT 2260 may therefore be equal in number. In certain aspects, the desired current waveform shape represented by the LUT samples stored in the waveform shape LUT 2260 may be a fundamental sine wave. Other waveform shapes may be desirable. For example, it is contemplated that a fundamental sine wave for driving main longitudinal motion of an ultrasonic transducer superimposed with one or more other drive signals at other frequencies, such as a third order harmonic for driving at least two mechanical resonances for beneficial vibrations of transverse or other modes, could be used.

**[0208]** Each value of the sample amplitude error determined at block 2240 may be transmitted to the LUT of the programmable logic device 1660 (shown at block 2280 in FIG. 19A) along with an indication of its associated LUT address. Based on the value of the sample amplitude error and its associated address (and, optionally, values of sample amplitude error for the same LUT address previously received), the LUT 2280 (or other control block of the programmable logic device 1660) may pre-distort or modify the value of the LUT sample stored at the LUT address such that the sample amplitude error is reduced or minimized. It will be appreciated that such pre-distortion or modification of each LUT sample in an iterative manner across the entire range of LUT addresses will cause the waveform shape of the generator's output current to match or conform to the desired current waveform shape represented by the samples of the waveform shape LUT 2260.

**[0209]** Current and voltage amplitude measurements, power measurements and impedance measurements may be determined at block 2300 of the processor 1740 based on the current and voltage feedback samples stored at memory location 2180. Prior to the determination of these quantities, the feedback samples may be suitably scaled and, in certain aspects, processed through a suitable filter 2320 to remove noise resulting from, for example, the data acquisition process and induced harmonic components. The filtered voltage and current samples may therefore substantially represent the fundamental frequency of the generator's drive output signal. In certain aspects, the filter 2320 may be a finite impulse response (FIR) filter applied in the frequency domain. Such aspects may use the Fast Fourier Transform (FFT) of the output drive signal current and voltage signals. In certain aspects, the resulting frequency spectrum may be used to provide additional generator functionality. In one aspect, for example, the ratio of the second and/or third order harmonic component relative to the fundamental frequency component may be used as a diagnostic indicator.

**[0210]** At block 2340 (FIG. 19B), a root mean square (RMS) calculation may be applied to a sample size of the current feedback samples representing an integral number of cycles of the drive signal to generate a measurement $I_{rms}$ representing the drive signal output current.

**[0211]** At block 2360, a root mean square (RMS) calculation may be applied to a sample size of the voltage feedback samples representing an integral number of cycles of the drive signal to determine a measurement $V_{rms}$ representing the drive signal output voltage.

**[0212]** At block 2380, the current and voltage feedback samples may be multiplied point by point, and a mean calculation is applied to samples representing an integral number of cycles of the drive signal to determine a measurement $P_r$ of the generator's real output power.

**[0213]** At block 2400, measurement $P_a$ of the generator's apparent output power may be determined as the product $V_{rms} \cdot I_{rms}$.

**[0214]** At block 2420, measurement $Z_m$ of the load impedance magnitude may be determined as the quotient $V_{rms}/I_{rms}$.

**[0215]** In certain aspects, the quantities $I_{rms}$, $V_{rms}$, $P_r$, $P_a$ and $Z_m$ determined at blocks 2340, 2360, 2380, 2400 and 2420 may be used by the generator 1100 to implement any of a number of control

and/or diagnostic processes. In certain aspects, any of these quantities may be communicated to a user via, for example, an output device 2140 integral with the generator 1100 or an output device 2140 connected to the generator 1100 through a suitable communication interface (e.g., a USB interface). Various diagnostic processes may include, without limitation, handpiece integrity, instrument integrity, instrument attachment integrity, instrument overload, approaching instrument overload, frequency lock failure, over-voltage condition, over-current condition, over-power condition, voltage sense failure, current sense failure, audio indication failure, visual indication failure, short circuit condition, power delivery failure, or blocking capacitor failure, for example.

**[0216]** Block 2440 of the processor 1740 may implement a phase control algorithm for determining and controlling the impedance phase of an electrical load (e.g., the ultrasonic transducer) driven by the generator 1100. As discussed above, by controlling the frequency of the drive signal to minimize or reduce the difference between the determined impedance phase and an impedance phase setpoint (e.g., 0°), the effects of harmonic distortion may be minimized or reduced, and the accuracy of the phase measurement increased.

**[0217]** The phase control algorithm receives as input the current and voltage feedback samples stored in the memory location 2180. Prior to their use in the phase control algorithm, the feedback samples may be suitably scaled and, in certain aspects, processed through a suitable filter 2460 (which may be identical to filter 2320) to remove noise resulting from the data acquisition process and induced harmonic components, for example. The filtered voltage and current samples may therefore substantially represent the fundamental frequency of the generator's drive output signal.

**[0218]** At block 2480 of the phase control algorithm, the current through the motional branch of the ultrasonic transducer is determined. This determination may be identical to that described above in connection with block 2220 of the pre-distortion algorithm. The output of block 2480 may thus be, for each set of stored current and voltage feedback samples associated with a LUT sample, a motional branch current sample.

**[0219]** At block 2500 of the phase control algorithm, impedance phase is determined based on the synchronized input of motional branch current samples determined at block 2480 and corresponding voltage feedback samples. In certain aspects, the impedance phase is determined as the average of the impedance phase measured at the rising edge of the waveforms and the impedance phase measured at the falling edge of the waveforms.

**[0220]** At block 2520 of the of the phase control algorithm, the value of the impedance phase determined at block 2220 is compared to phase setpoint 2540 to determine a difference, or phase error, between the compared values.

**[0221]** At block 2560 (FIG. 19A) of the phase control algorithm, based on a value of phase error determined at block 2520 and the impedance magnitude determined at block 2420, a frequency output for controlling the frequency of the drive signal is determined. The value of the frequency output may be continuously adjusted by the block 2560 and transferred to a DDS control block 2680 (discussed below) in order to maintain the impedance phase determined at block 2500 at the phase

setpoint (e.g., zero phase error). In certain aspects, the impedance phase may be regulated to a 0° phase setpoint. In this way, any harmonic distortion will be centered about the crest of the voltage waveform, enhancing the accuracy of phase impedance determination.

**[0222]** Block 2580 of the processor 1740 may implement an algorithm for modulating the current amplitude of the drive signal in order to control the drive signal current, voltage and power in accordance with user specified setpoints, or in accordance with requirements specified by other processes or algorithms implemented by the generator 1100. Control of these quantities may be realized, for example, by scaling the LUT samples in the LUT 2280 and/or by adjusting the full-scale output voltage of the DAC 1680 (which supplies the input to the power amplifier 1620) via a DAC 1860. Block 2600 (which may be implemented as a PID controller in certain aspects) may receive, as input, current feedback samples (which may be suitably scaled and filtered) from the memory location 2180. The current feedback samples may be compared to a "current demand" $I_d$ value dictated by the controlled variable (e.g., current, voltage or power) to determine if the drive signal is supplying the necessary current. In aspects in which drive signal current is the control variable, the current demand $I_d$ may be specified directly by a current setpoint 2620A ($I_{sp}$). For example, an RMS value of the current feedback data (determined as in block 2340) may be compared to user-specified RMS current setpoint $I_{sp}$ to determine the appropriate controller action. If, for example, the current feedback data indicates an RMS value less than the current setpoint $I_{sp}$, LUT scaling and/or the full-scale output voltage of the DAC 1680 may be adjusted by the block 2600 such that the drive signal current is increased. Conversely, block 2600 may adjust LUT scaling and/or the full-scale output voltage of the DAC 1680 to decrease the drive signal current when the current feedback data indicates an RMS value greater than the current setpoint $I_{sp}$.

**[0223]** In aspects in which the drive signal voltage is the control variable, the current demand $I_d$ may be specified indirectly, for example, based on the current required to maintain a desired voltage setpoint 2620B ($V_{sp}$) given the load impedance magnitude $Z_m$ measured at block 2420 (e.g. $I_d=V_{sp}/Z_m$). Similarly, in aspects in which drive signal power is the control variable, the current demand $I_d$ may be specified indirectly, for example, based on the current required to maintain a desired power setpoint 2620C ($P_{sp}$) given the voltage $V_{rms}$ measured at blocks 2360 (e.g. $I_d=P_{sp}/V_{rms}$).

**[0224]** Block 2680 (FIG. 19A) may implement a DDS control algorithm for controlling the drive signal by recalling LUT samples stored in the LUT 2280. In certain aspects, the DDS control algorithm may be a numerically-controlled oscillator (NCO) algorithm for generating samples of a waveform at a fixed clock rate using a point (memory location)-skipping technique. The NCO algorithm may implement a phase accumulator, or frequency-to-phase converter, that functions as an address pointer for recalling LUT samples from the LUT 2280. In one aspect, the phase accumulator may be a D step size, modulo N phase accumulator, where D is a positive integer representing a frequency control value, and N is the number of LUT samples in the LUT 2280. A frequency control value of D=1, for example, may cause the phase accumulator to sequentially point

to every address of the LUT 2280, resulting in a waveform output replicating the waveform stored in the LUT 2280. When D>1, the phase accumulator may skip addresses in the LUT 2280, resulting in a waveform output having a higher frequency. Accordingly, the frequency of the waveform generated by the DDS control algorithm may therefore be controlled by suitably varying the frequency control value. In certain aspects, the frequency control value may be determined based on the output of the phase control algorithm implemented at block 2440. The output of block 2680 may supply the input of DAC 1680, which in turn supplies a corresponding analog signal to an input of the power amplifier 1620.

**[0225]** Block 2700 of the processor 1740 may implement a switch-mode converter control algorithm for dynamically modulating the rail voltage of the power amplifier 1620 based on the waveform envelope of the signal being amplified, thereby improving the efficiency of the power amplifier 1620. In certain aspects, characteristics of the waveform envelope may be determined by monitoring one or more signals contained in the power amplifier 1620. In one aspect, for example, characteristics of the waveform envelope may be determined by monitoring the minima of a drain voltage (e.g., a MOSFET drain voltage) that is modulated in accordance with the envelope of the amplified signal. A minima voltage signal may be generated, for example, by a voltage minima detector coupled to the drain voltage. The minima voltage signal may be sampled by ADC 1760, with the output minima voltage samples being received at block 2720 of the switch-mode converter control algorithm. Based on the values of the minima voltage samples, block 2740 may control a PWM signal output by a PWM generator 2760, which, in turn, controls the rail voltage supplied to the power amplifier 1620 by the switch-mode regulator 1700. In certain aspects, as long as the values of the minima voltage samples are less than a minima target 2780 input into block 2720, the rail voltage may be modulated in accordance with the waveform envelope as characterized by the minima voltage samples. When the minima voltage samples indicate low envelope power levels, for example, block 2740 may cause a low rail voltage to be supplied to the power amplifier 1620, with the full rail voltage being supplied only when the minima voltage samples indicate maximum envelope power levels. When the minima voltage samples fall below the minima target 2780, block 2740 may cause the rail voltage to be maintained at a minimum value suitable for ensuring proper operation of the power amplifier 1620.

**[0226]** In some aspects, an electrical circuit can be used to drive both ultrasonic transducers and RF electrodes interchangeably If driven simultaneously, filter circuits may be provided to select either the ultrasonic waveform or the RF waveform. Such filtering techniques are described in commonly owned U.S. Pat. Pub. No. US-2017-0086910-A1, titled TECHNIQUES FOR CIRCUIT TOPOLOGIES FOR COMBINED GENERATOR, which is herein incorporated by reference in its entirety.

**[0227]** FIG. 20 is a schematic diagram of a control circuit 3200, such as control circuit 3212, in accordance with at least one aspect of the present disclosure. The control circuit 3200 is located within a housing of the battery assembly. The battery assembly is the energy source for a variety of

local power supplies 3215. The control circuit comprises a main processor 3214 coupled via an interface master 3218 to various downstream circuits by way of outputs SCL-A and SDA-A, SCL-B and SDA-B, SCL-C and SDA-C, for example. In one aspect, the interface master 3218 is a general purpose serial interface such as an $I^2C$ serial interface. The main processor 3214 also is configured to drive switches 3224 through general purposes input/output (GPIO) 3220, a display 3226 (e.g., and LCD display), and various indicators 3228 through GPIO 3222. A watchdog processor 3216 is provided to control the main processor 3214. A switch 3230 is provided in series with a battery 3211 to activate the control circuit 3212 upon insertion of the battery assembly into a handle assembly of a surgical instrument.

**[0228]** The main processor 3214 comprises a memory for storing tables of digitized drive signals or waveforms that are transmitted to an electrical circuit that may be used for driving an ultrasonic transducer, for example. In other aspects, the main processor 3214 may generate a digital waveform and transmit it to the electrical circuit or may store the digital waveform for later transmission to the electrical circuit. The main processor 3214 also may provide RF drive by way of output terminals SCL-B, SDA-B and various sensors (e.g., Hall-effect sensors, magneto-rheological fluid (MRF) sensors, etc.) by way of output terminals SCL-C, SDA-C. In one aspect, the main processor 3214 is configured to sense the presence of ultrasonic drive circuitry and/or RF drive circuitry to enable appropriate software and user interface functionality.

**[0229]** In one aspect, the main processor 3214 may be an LM 4F230H5QR, available from Texas Instruments, for example. In at least one example, the Texas Instruments LM4F230H5QR is an ARM Cortex-M4F Processor Core comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), internal read-only memory (ROM) loaded with StellarisWare® software, 2 KB electrically erasable programmable read-only memory (EEPROM), one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QED analog, one or more 12-bit Analog-to-Digital Converters (ADC) with 12 analog input channels, among other features that are readily available from the product datasheet. Other processors may be readily substituted and, accordingly, the present disclosure should not be limited in this context.

Modular Battery Powered Handheld Surgical Instrument With Multistage Generator Circuits

**[0230]** In another aspect, the present disclosure provides a modular battery powered handheld surgical instrument with multistage generator circuits. Disclosed is a surgical instrument that includes a battery assembly, a handle assembly, and a shaft assembly where the battery assembly and the shaft assembly are configured to mechanically and electrically connect to the handle assembly. The battery assembly includes a control circuit configured to generate a digital waveform. The handle assembly includes a first stage circuit configured to receive the digital waveform, convert the digital waveform into an analog waveform, and amplify the analog waveform. The shaft

assembly includes a second stage circuit coupled to the first stage circuit to receive, amplify, and apply the analog waveform to a load.

**[0231]** In one aspect, the present disclosure provides a surgical instrument, comprising: a battery assembly, comprising a control circuit comprising a battery, a memory coupled to the battery, and a processor coupled to the memory and the battery, wherein the processor is configured to generate a digital waveform; a handle assembly comprising a first stage circuit coupled to the processor, the first stage circuit comprising a digital-to-analog (DAC) converter and a first stage amplifier circuit, wherein the DAC is configured to receive the digital waveform and convert the digital waveform into an analog waveform, wherein the first stage amplifier circuit is configured to receive and amplify the analog waveform; and a shaft assembly comprising a second stage circuit coupled to the first stage amplifier circuit to receive the analog waveform, amplify the analog waveform, and apply the analog waveform to a load; wherein the battery assembly and the shaft assembly are configured to mechanically and electrically connect to the handle assembly.

**[0232]** The load may comprise any one of an ultrasonic transducer, an electrode, or a sensor, or any combinations thereof. The first stage circuit may comprise a first stage ultrasonic drive circuit and a first stage high-frequency current drive circuit. The control circuit may be configured to drive the first stage ultrasonic drive circuit and the first stage high-frequency current drive circuit independently or simultaneously. The first stage ultrasonic drive circuit may be configured to couple to a second stage ultrasonic drive circuit. The second stage ultrasonic drive circuit may be configured to couple to an ultrasonic transducer. The first stage high-frequency current drive circuit may be configured to couple to a second stage high-frequency drive circuit. The second stage high-frequency drive circuit may be configured to couple to an electrode.

**[0233]** The first stage circuit may comprise a first stage sensor drive circuit. The first stage sensor drive circuit may be configured to a second stage sensor drive circuit. The second stage sensor drive circuit may be configured to couple to a sensor.

**[0234]** In another aspect, the present disclosure provides a surgical instrument, comprising: a battery assembly, comprising a control circuit comprising a battery, a memory coupled to the battery, and a processor coupled to the memory and the battery, wherein the processor is configured to generate a digital waveform; a handle assembly comprising a common first stage circuit coupled to the processor, the common first stage circuit comprising a digital-to-analog (DAC) converter and a common first stage amplifier circuit, wherein the DAC is configured to receive the digital waveform and convert the digital waveform into an analog waveform, wherein the common first stage amplifier circuit is configured to receive and amplify the analog waveform; and a shaft assembly comprising a second stage circuit coupled to the common first stage amplifier circuit to receive the analog waveform, amplify the analog waveform, and apply the analog waveform to a load; wherein the battery assembly and the shaft assembly are configured to mechanically and electrically connect to the handle assembly.

**[0235]** The load may comprise any one of an ultrasonic transducer, an electrode, or a sensor, or any combinations thereof. The common first stage circuit may be configured to drive ultrasonic, high-frequency current, or sensor circuits. The common first stage drive circuit may be configured to couple to a second stage ultrasonic drive circuit, a second stage high-frequency drive circuit, or a second stage sensor drive circuit. The second stage ultrasonic drive circuit may be configured to couple to an ultrasonic transducer, the second stage high-frequency drive circuit is configured to couple to an electrode, and the second stage sensor drive circuit is configured to couple to a sensor.

**[0236]** In another aspect, the present disclosure provides a surgical instrument, comprising a control circuit comprising a memory coupled to a processor, wherein the processor is configured to generate a digital waveform; a handle assembly comprising a common first stage circuit coupled to the processor, the common first stage circuit configured to receive the digital waveform, convert the digital waveform into an analog waveform, and amplify the analog waveform; and a shaft assembly comprising a second stage circuit coupled to the common first stage circuit to receive and amplify the analog waveform; wherein the shaft assembly is configured to mechanically and electrically connect to the handle assembly.

**[0237]** The common first stage circuit may be configured to drive ultrasonic, high-frequency current, or sensor circuits. The common first stage drive circuit may be configured to couple to a second stage ultrasonic drive circuit, a second stage high-frequency drive circuit, or a second stage sensor drive circuit. The second stage ultrasonic drive circuit may be configured to couple to an ultrasonic transducer, the second stage high-frequency drive circuit is configured to couple to an electrode, and the second stage sensor drive circuit is configured to couple to a sensor.

**[0238]** FIG. 21 illustrates a generator circuit 3400 partitioned into a first stage circuit 3404 and a second stage circuit 3406, in accordance with at least one aspect of the present disclosure. In one aspect, the surgical instruments of surgical system 1000 described herein may comprise a generator circuit 3400 partitioned into multiple stages. For example, surgical instruments of surgical system 1000 may comprise the generator circuit 3400 partitioned into at least two circuits: the first stage circuit 3404 and the second stage circuit 3406 of amplification enabling operation of RF energy only, ultrasonic energy only, and/or a combination of RF energy and ultrasonic energy. A combination modular shaft assembly 3414 may be powered by the common first stage circuit 3404 located within a handle assembly 3412 and the modular second stage circuit 3406 integral to the modular shaft assembly 3414. As previously discussed throughout this description in connection with the surgical instruments of surgical system 1000, a battery assembly 3410 and the shaft assembly 3414 are configured to mechanically and electrically connect to the handle assembly 3412. The end effector assembly is configured to mechanically and electrically connect the shaft assembly 3414.

**[0239]** Turning now to FIG. 21, the generator circuit 3400 is partitioned into multiple stages located in multiple modular assemblies of a surgical instrument, such as the surgical instruments of

surgical system 1000 described herein. In one aspect, a control stage circuit 3402 may be located in the battery assembly 3410 of the surgical instrument. The control stage circuit 3402 is a control circuit 3200 as described in connection with FIG. 20. The control circuit 3200 comprises a processor 3214, which includes internal memory 3217 (FIG. 21) (e.g., volatile and non-volatile memory), and is electrically coupled to a battery 3211. The battery 3211 supplies power to the first stage circuit 3404, the second stage circuit 3406, and a third stage circuit 3408, respectively. As previously discussed, the control circuit 3200 generates a digital waveform 4300 (FIG. 29) using circuits and techniques described in connection with FIGS. 27 and 28. Returning to FIG. 21, the digital waveform 4300 may be configured to drive an ultrasonic transducer, high-frequency (e.g., RF) electrodes, or a combination thereof either independently or simultaneously. If driven simultaneously, filter circuits may be provided in the corresponding first stage circuits 3404 to select either the ultrasonic waveform or the RF waveform. Such filtering techniques are described in commonly owned U.S. Pat. Pub. No. US-2017-0086910-A1, titled TECHNIQUES FOR CIRCUIT TOPOLOGIES FOR COMBINED GENERATOR, which is herein incorporated by reference in its entirety.

**[0240]** The first stage circuits 3404 (e.g., the first stage ultrasonic drive circuit 3420, the first stage RF drive circuit 3422, and the first stage sensor drive circuit 3424) are located in a handle assembly 3412 of the surgical instrument. The control circuit 3200 provides the RF drive signal to the first stage RF drive circuit 3422 via outputs SCL-B, SDA-B of the control circuit 3200. The first stage RF drive circuit 3422 is described in detail in connection with FIG. 23. The control circuit 3200 provides the sensor drive signal to the first stage sensor drive circuit 3424 via outputs SCL-C, SDA-C of the control circuit 3200. Generally, each of the first stage circuits 3404 includes a digital-to-analog (DAC) converter and a first stage amplifier section to drive the second stage circuits 3406. The outputs of the first stage circuits 3404 are provided to the inputs of the second stage circuits 3406.

**[0241]** The control circuit 3200 is configured to detect which modules are plugged into the control circuit 3200. For example, the control circuit 3200 is configured to detect whether the first stage ultrasonic drive circuit 3420, the first stage RF drive circuit 3422, or the first stage sensor drive circuit 3424 located in the handle assembly 3412 is connected to the battery assembly 3410. Likewise, each of the first stage circuits 3404 can detect which second stage circuits 3406 are connected thereto and that information is provided back to the control circuit 3200 to determine the type of signal waveform to generate. Similarly, each of the second stage circuits 3406 can detect which third stage circuits 3408 or components are connected thereto and that information is provided back to the control circuit 3200 to determine the type of signal waveform to generate.

**[0242]** In one aspect, the second stage circuits 3406 (e.g., the ultrasonic drive second stage circuit 3430, the RF drive second stage circuit 3432, and the sensor drive second stage circuit 3434) are located in the shaft assembly 3414 of the surgical instrument. The first stage ultrasonic drive circuit 3420 provides a signal to the second stage ultrasonic drive circuit 3430 via outputs US-Left/US-Right. In addition to a transformer, the second stage ultrasonic drive circuit 3430 also may

include filter, amplifier, and signal conditioning circuits. The first stage high-frequency (RF) current drive circuit 3422 provides a signal to the second stage RF drive circuit 3432 via outputs RF-Left/RF-Right. In addition to a transformer and blocking capacitors, the second stage RF drive circuit 3432 also may include filter, amplifier, and signal conditioning circuits. The first stage sensor drive circuit 3424 provides a signal to the second stage sensor drive circuit 3434 via outputs Sensor-1/Sensor-2. The second stage sensor drive circuit 3434 may include filter, amplifier, and signal conditioning circuits depending on the type of sensor. The outputs of the second stage circuits 3406 are provided to the inputs of the third stage circuits 3408.

**[0243]** In one aspect, the third stage circuits 3408 (e.g., the ultrasonic transducer 1120, the RF electrodes 3074a, 3074b, and the sensors 3440) may be located in various assemblies 3416 of the surgical instruments. In one aspect, the second stage ultrasonic drive circuit 3430 provides a drive signal to the ultrasonic transducer 1120 piezoelectric stack. In one aspect, the ultrasonic transducer 1120 is located in the ultrasonic transducer assembly of the surgical instrument. In other aspects, however, the ultrasonic transducer 1120 may be located in the handle assembly 3412, the shaft assembly 3414, or the end effector. In one aspect, the second stage RF drive circuit 3432 provides a drive signal to the RF electrodes 3074a, 3074b, which are generally located in the end effector portion of the surgical instrument. In one aspect, the second stage sensor drive circuit 3434 provides a drive signal to various sensors 3440 located throughout the surgical instrument.

**[0244]** FIG. 22 illustrates a generator circuit 3500 partitioned into multiple stages where a first stage circuit 3504 is common to the second stage circuit 3506, in accordance with at least one aspect of the present disclosure. In one aspect, the surgical instruments of surgical system 1000 described herein may comprise generator circuit 3500 partitioned into multiple stages. For example, the surgical instruments of surgical system 1000 may comprise the generator circuit 3500 partitioned into at least two circuits: the first stage circuit 3504 and the second stage circuit 3506 of amplification enabling operation of high-frequency (RF) energy only, ultrasonic energy only, and/or a combination of RF energy and ultrasonic energy. A combination modular shaft assembly 3514 may be powered by a common first stage circuit 3504 located within the handle assembly 3512 and a modular second stage circuit 3506 integral to the modular shaft assembly 3514. As previously discussed throughout this description in connection with the surgical instruments of surgical system 1000, a battery assembly 3510 and the shaft assembly 3514 are configured to mechanically and electrically connect to the handle assembly 3512. The end effector assembly is configured to mechanically and electrically connect the shaft assembly 3514.

**[0245]** As shown in the example of FIG. 22, the battery assembly 3510 portion of the surgical instrument comprises a first control circuit 3502, which includes the control circuit 3200 previously described. The handle assembly 3512, which connects to the battery assembly 3510, comprises a common first stage drive circuit 3420. As previously discussed, the first stage drive circuit 3420 is configured to drive ultrasonic, high-frequency (RF) current, and sensor loads. The output of the common first stage drive circuit 3420 can drive any one of the second stage circuits 3506 such as

the second stage ultrasonic drive circuit 3430, the second stage high-frequency (RF) current drive circuit 3432, and/or the second stage sensor drive circuit 3434. The common first stage drive circuit 3420 detects which second stage circuit 3506 is located in the shaft assembly 3514 when the shaft assembly 3514 is connected to the handle assembly 3512. Upon the shaft assembly 3514 being connected to the handle assembly 3512, the common first stage drive circuit 3420 determines which one of the second stage circuits 3506 (e.g., the second stage ultrasonic drive circuit 3430, the second stage RF drive circuit 3432, and/or the second stage sensor drive circuit 3434) is located in the shaft assembly 3514. The information is provided to the control circuit 3200 located in the handle assembly 3512 in order to supply a suitable digital waveform 4300 (FIG. 29) to the second stage circuit 3506 to drive the appropriate load, e.g., ultrasonic, RF, or sensor. It will be appreciated that identification circuits may be included in various assemblies 3516 in third stage circuit 3508 such as the ultrasonic transducer 1120, the electrodes 3074a, 3074b, or the sensors 3440. Thus, when a third stage circuit 3508 is connected to a second stage circuit 3506, the second stage circuit 3506 knows the type of load that is required based on the identification information.

**[0246]** FIG. 23 is a schematic diagram of one aspect of an electrical circuit 3600 configured to drive a high-frequency current (RF), in accordance with at least one aspect of the present disclosure. The electrical circuit 3600 comprises an analog multiplexer 3680. The analog multiplexer 3680 multiplexes various signals from the upstream channels SCL-A, SDA-A such as RF, battery, and power control circuit. A current sensor 3682 is coupled in series with the return or ground leg of the power supply circuit to measure the current supplied by the power supply. A field effect transistor (FET) temperature sensor 3684 provides the ambient temperature. A pulse width modulation (PWM) watchdog timer 3688 automatically generates a system reset if the main program neglects to periodically service it. It is provided to automatically reset the electrical circuit 3600 when it hangs or freezes because of a software or hardware fault. It will be appreciated that the electrical circuit 3600 may be configured for driving RF electrodes or for driving the ultrasonic transducer 1120 as described in connection with FIG. 29, for example. Accordingly, with reference now back to FIG. 23, the electrical circuit 3600 can be used to drive both ultrasonic and RF electrodes interchangeably.

**[0247]** A drive circuit 3686 provides Left and Right RF energy outputs. A digital signal that represents the signal waveform is provided to the SCL-A, SDA-A inputs of the analog multiplexer 3680 from a control circuit, such as the control circuit 3200 (FIG. 20). A digital-to-analog converter 3690 (DAC) converts the digital input to an analog output to drive a PWM circuit 3692 coupled to an oscillator 3694. The PWM circuit 3692 provides a first signal to a first gate drive circuit 3696a coupled to a first transistor output stage 3698a to drive a first RF+ (Left) energy output. The PWM circuit 3692 also provides a second signal to a second gate drive circuit 3696b coupled to a second transistor output stage 3698b to drive a second RF- (Right) energy output. A voltage sensor 3699 is coupled between the RF Left/RF output terminals to measure the output voltage. The drive circuit 3686, the first and second drive circuits 3696a, 3696b, and the first and second transistor output

stages 3698a, 3698b define a first stage amplifier circuit. In operation, the control circuit 3200 (FIG. 20) generates a digital waveform 4300 (FIG. 29) employing circuits such as direct digital synthesis (DDS) circuits 4100, 4200 (FIGS. 27 and 28). The DAC 3690 receives the digital waveform 4300 and converts it into an analog waveform, which is received and amplified by the first stage amplifier circuit.

**[0248]** FIG. 24 is a schematic diagram of the transformer 3700 coupled to the electrical circuit 3600 shown in FIG. 23, in accordance with at least one aspect of the present disclosure. The RF+ /RF input terminals (primary winding) of the transformer 3700 are electrically coupled to the RF Left/RF output terminals of the electrical circuit 3600. One side of the secondary winding is coupled in series with first and second blocking capacitors 3706, 3708. The second blocking capacitor is coupled to the second stage RF drive circuit 3774a positive terminal. The other side of the secondary winding is coupled to the second stage RF drive circuit 3774b negative terminal. The second stage RF drive circuit 3774a positive output is coupled to the ultrasonic blade and the second stage RF drive circuit 3774b negative ground terminal is coupled to an outer tube. In one aspect, a transformer has a turns-ratio of $n_1$:$n_2$ of 1:50.

**[0249]** FIG. 25 is a schematic diagram of a circuit 3800 comprising separate power sources for high power energy/drive circuits and low power circuits, in accordance with at least one aspect of the present disclosure. A power supply 3812 includes a primary battery pack comprising first and second primary batteries 3815, 3817 (e.g., Li-ion batteries) that are connected into the circuit 3800 by a switch 3818 and a secondary battery pack comprising a secondary battery 3820 that is connected into the circuit by a switch 3823 when the power supply 3812 is inserted into the battery assembly. The secondary battery 3820 is a sag preventing battery that has componentry resistant to gamma or other radiation sterilization. For instance, a switch mode power supply 3827 and optional charge circuit within the battery assembly can be incorporated to allow the secondary battery 3820 to reduce the voltage sag of the primary batteries 3815, 3817. This guarantees full charged cells at the beginning of a surgery that are easy to introduce into the sterile field. The primary batteries 3815, 3817 can be used to power motor control circuits 3826 and energy circuits 3832 directly. The motor control circuits 3826 are configured to control a motor, such as motor 3829. The power supply/battery pack 3812 may comprise a dual type battery assembly including primary Li-ion batteries 3815, 3817 and secondary NiMH batteries 3820 with dedicated energy cells 3820 to control handle electronics circuits 3830 from dedicated energy cells 3815, 3817 to run the motor control circuits 3826 and the energy circuits 3832. In this case the circuit 3810 pulls from the secondary batteries 3820 involved in driving the handle electronics circuits 3830 when the primary batteries 3815, 3817 involved in driving the energy circuits 3832 and/or motor control circuits 3826 are dropping low. In one various aspect, the circuit 3810 may include a one way diode that would not allow for current to flow in the opposite direction (e.g., from the batteries involved in driving the energy and/or motor control circuits to the batteries involved in driving the electronics circuits).

**[0250]** Additionally, a gamma friendly charge circuit may be provided that includes a switch mode power supply 3827 using diodes and vacuum tube components to minimize voltage sag at a predetermined level. With the inclusion of a minimum sag voltage that is a division of the NiMH voltages (3 NiMH cells) the switch mode power supply 3827 could be eliminated. Additionally a modular system may be provided wherein the radiation hardened components are located in a module, making the module sterilizable by radiation sterilization. Other non-radiation hardened components may be included in other modular components and connections made between the modular components such that the componentry operates together as if the components were located together on the same circuit board. If only two NiMH cells are desired the switch mode power supply 3827 based on diodes and vacuum tubes allows for sterilizable electronics within the disposable primary battery pack.

**[0251]** Turning now to FIG. 26, there is shown a control circuit 3900 for operating a battery 3901 powered RF generator circuit 3902 for use with a surgical instrument, in accordance with at least one aspect of the present disclosure. The surgical instrument is configured to use both ultrasonic vibration and high-frequency current to carry out surgical coagulation/cutting treatments on living tissue, and uses high-frequency current to carry out a surgical coagulation treatment on living tissue.

**[0252]** FIG. 26 illustrates the control circuit 3900 that allows a dual generator system to switch between the RF generator circuit 3902 and the ultrasonic generator circuit 3920 energy modalities for a surgical instrument of the surgical system 1000. In one aspect, a current threshold in an RF signal is detected. When the impedance of the tissue is low the high-frequency current through tissue is high when RF energy is used as the treatment source for the tissue. In accordance with at least one aspect, a visual indicator 3912 or light located on the surgical instrument of surgical system 1000 may be configured to be in an on-state during this high current period. When the current falls below a threshold, the visual indicator 3912 is in an off-state. Accordingly, a phototransistor 3914 may be configured to detect the transition from an on-state to an off-state and disengages the RF energy as shown in the control circuit 3900 shown in FIG. 26. Therefore, when the energy button is released and an energy switch 3926 is opened, the control circuit 3900 is reset and both the RF and ultrasonic generator circuits 3902, 3920 are held off.

**[0253]** With reference to FIG.26, in one aspect, a method of managing an RF generator circuit 3902 and ultrasound generator circuit 3920 is provided. The RF generator circuit 3902 and/or the ultrasound generator circuit 3920 may be located in the handle assembly 1109, the ultrasonic transducer/RF generator assembly 1120, the battery assembly, the shaft assembly 1129, and/or the nozzle, of the multifunction electrosurgical instrument 1108, for example. The control circuit 3900 is held in a reset state if the energy switch 3926 is off (e.g., open). Thus, when the energy switch 3926 is opened, the control circuit 3900 is reset and both the RF and ultrasonic generator circuits 3902, 3920 are turned off. When the energy switch 3926 is squeezed and the energy switch 3926 is engaged (e.g., closed), RF energy is delivered to the tissue and the visual indicator 3912 operated

by a current sensing step-up transformer 3904 will be lit while the tissue impedance is low. The light from the visual indicator 3912 provides a logic signal to keep the ultrasonic generator circuit 3920 in the off state. Once the tissue impedance increases above a threshold and the high-frequency current through the tissue decreases below a threshold, the visual indicator 3912 turns off and the light transitions to an off-state. A logic signal generated by this transition turns off a relay 3908, whereby the RF generator circuit 3902 is turned off and the ultrasonic generator circuit 3920 is turned on, to complete the coagulation and cut cycle.

**[0254]** Still with reference to FIG. 26, in one aspect, the dual generator circuit configuration employs the on-board RF generator circuit 3902, which is battery 3901 powered, for one modality and a second, on-board ultrasound generator circuit 3920, which may be on-board in the handle assembly 1109, battery assembly, shaft assembly 1129, nozzle, and/or the ultrasonic transducer/RF generator assembly 1120 of the multifunction electrosurgical instrument 1108, for example. The ultrasonic generator circuit 3920 also is battery 3901 operated. In various aspects, the RF generator circuit 3902 and the ultrasonic generator circuit 3920 may be an integrated or separable component of the handle assembly 1109. According to various aspects, having the dual RF/ultrasonic generator circuits 3902, 3920 as part of the handle assembly 1109 may eliminate the need for complicated wiring. The RF/ultrasonic generator circuits 3902, 3920 may be configured to provide the full capabilities of an existing generator while utilizing the capabilities of a cordless generator system simultaneously.

**[0255]** Either type of system can have separate controls for the modalities that are not communicating with each other. The surgeon activates the RF and Ultrasonic separately and at their discretion. Another approach would be to provide fully integrated communication schemes that share buttons, tissue status, instrument operating parameters (such as jaw closure, forces, etc.) and algorithms to manage tissue treatment. Various combinations of this integration can be implemented to provide the appropriate level of function and performance.

**[0256]** As discussed above, in one aspect, the control circuit 3900 includes the battery 3901 powered RF generator circuit 3902 comprising a battery as an energy source. As shown, RF generator circuit 3902 is coupled to two electrically conductive surfaces referred to herein as electrodes 3906a, 3906b (i.e., active electrode 3906a and return electrode 3906b) and is configured to drive the electrodes 3906a, 3906b with RF energy (e.g., high-frequency current). A first winding 3910a of the step-up transformer 3904 is connected in series with one pole of the bipolar RF generator circuit 3902 and the return electrode 3906b. In one aspect, the first winding 3910a and the return electrode 3906b are connected to the negative pole of the bipolar RF generator circuit 3902. The other pole of the bipolar RF generator circuit 3902 is connected to the active electrode 3906a through a switch contact 3909 of the relay 3908, or any suitable electromagnetic switching device comprising an armature which is moved by an electromagnet 3936 to operate the switch contact 3909. The switch contact 3909 is closed when the electromagnet 3936 is energized and the switch contact 3909 is open when the electromagnet 3936 is de-energized. When the switch contact

is closed, RF current flows through conductive tissue (not shown) located between the electrodes 3906a, 3906b. It will be appreciated, that in one aspect, the active electrode 3906a is connected to the positive pole of the bipolar RF generator circuit 3902.

**[0257]** A visual indicator circuit 3905 comprises the step-up transformer 3904, a series resistor R2, and the visual indicator 3912. The visual indicator 3912 can be adapted for use with the surgical instrument 1108 and other electrosurgical systems and tools, such as those described herein. The first winding 3910a of the step-up transformer 3904 is connected in series with the return electrode 3906b and the second winding 3910b of the step-up transformer 3904 is connected in series with the resistor R2 and the visual indicator 3912 comprising a type NE-2 neon bulb, for example.

**[0258]** In operation, when the switch contact 3909 of the relay 3908 is open, the active electrode 3906a is disconnected from the positive pole of the bipolar RF generator circuit 3902 and no current flows through the tissue, the return electrode 3906b, and the first winding 3910a of the step-up transformer 3904. Accordingly, the visual indicator 3912 is not energized and does not emit light. When the switch contact 3909 of the relay 3908 is closed, the active electrode 3906a is connected to the positive pole of the bipolar RF generator circuit 3902 enabling current to flow through tissue, the return electrode 3906b, and the first winding 3910a of the step-up transformer 3904 to operate on tissue, for example cut and cauterize the tissue.

**[0259]** A first current flows through the first winding 3910a as a function of the impedance of the tissue located between the active and return electrodes 3906a, 3906b providing a first voltage across the first winding 3910a of the step-up transformer 3904. A stepped up second voltage is induced across the second winding 3910b of the step-up transformer 3904. The secondary voltage appears across the resistor R2 and energizes the visual indicator 3912 causing the neon bulb to light when the current through the tissue is greater than a predetermined threshold. It will be appreciated that the circuit and component values are illustrative and not limited thereto. When the switch contact 3909 of the relay 3908 is closed, current flows through the tissue and the visual indicator 3912 is turned on.

**[0260]** Turning now to the energy switch 3926 portion of the control circuit 3900, when the energy switch 3926 is open position, a logic high is applied to the input of a first inverter 3928 and a logic low is applied of one of the two inputs of the AND gate 3932. Thus, the output of the AND gate 3932 is low and a transistor 3934 is off to prevent current from flowing through the winding of the electromagnet 3936. With the electromagnet 3936 in the de-energized state, the switch contact 3909 of the relay 3908 remains open and prevents current from flowing through the electrodes 3906a, 3906b. The logic low output of the first inverter 3928 also is applied to a second inverter 3930 causing the output to go high and resetting a flip-flop 3918 (e.g., a D-Type flip-flop). At which time, the $Q$ output goes low to turn off the ultrasound generator circuit 3920 circuit and the $\overline{Q}$ output goes high and is applied to the other input of the AND gate 3932.

**[0261]** When the user presses the energy switch 3926 on the instrument handle to apply energy to the tissue between the electrodes 3906a, 3906b, the energy switch 3926 closes and applies a

logic low at the input of the first inverter 3928, which applies a logic high to other input of the AND gate 3932 causing the output of the AND gate 3932 to go high and turns on the transistor 3934. In the on state, the transistor 3934 conducts and sinks current through the winding of the electromagnet 3936 to energize the electromagnet 3936 and close the switch contact 3909 of the relay 3908. As discussed above, when the switch contact 3909 is closed, current can flow through the electrodes 3906a, 3906b and the first winding 3910a of the step-up transformer 3904 when tissue is located between the electrodes 3906a, 3906b.

**[0262]** As discussed above, the magnitude of the current flowing through the electrodes 3906a, 3906b depends on the impedance of the tissue located between the electrodes 3906a, 3906b. Initially, the tissue impedance is low and the magnitude of the current high through the tissue and the first winding 3910a. Consequently, the voltage impressed on the second winding 3910b is high enough to turn on the visual indicator 3912. The light emitted by the visual indicator 3912 turns on the phototransistor 3914, which pulls the input of an inverter 3916 low and causes the output of the inverter 3916 to go high. A high input applied to the *CLK* of the flip-flop 3918 has no effect on the *Q* or the $\overline{Q}$ outputs of the flip-flop 3918 and *Q* output remains low and the $\overline{Q}$ output remains high. Accordingly, while the visual indicator 3912 remains energized, the ultrasound generator circuit 3920 is turned OFF and an ultrasonic transducer 3922 and an ultrasonic blade 3924 of the multifunction electrosurgical instrument are not activated.

**[0263]** As the tissue between the electrodes 3906a, 3906b dries up, due to the heat generated by the current flowing through the tissue, the impedance of the tissue increases and the current therethrough decreases. When the current through the first winding 3910a decreases, the voltage across the second winding 3910b also decreases and when the voltage drops below a minimum threshold required to operate the visual indicator 3912, the visual indicator 3912 and the phototransistor 3914 turn off. When the phototransistor 3914 turns off, a logic high is applied to the input of the inverter 3916 and a logic low is applied to the *CLK* input of the flip-flop 3918 to clock a logic high to the *Q* output and a logic low to the $\overline{Q}$ output. The logic high at the *Q* output turns on the ultrasound generator circuit 3920 to activate the ultrasonic transducer 3922 and the ultrasonic blade 3924 to initiate cutting the tissue located between the electrodes 3906a, 3906a. Simultaneously or near simultaneously with the ultrasound generator circuit 3920 turning on, the $\overline{Q}$ output of the flip-flop 3918 goes low and causes the output of the AND gate 3932 to go low and turn off the transistor 3934, thereby de-energizing the electromagnet 3936 and opening the switch contact 3909 of the relay 3908 to cut off the flow of current through the electrodes 3906a, 3906b.

**[0264]** While the switch contact 3909 of the relay 3908 is open, no current flows through the electrodes 3906a, 3906b, tissue, and the first winding 3910a of the step-up transformer 3904. Therefore, no voltage is developed across the second winding 3910b and no current flows through the visual indicator 3912.

**[0265]** The state of the *Q* and the $\overline{Q}$ outputs of the flip-flop 3918 remain the same while the user squeezes the energy switch 3926 on the instrument handle to maintain the energy switch 3926

closed. Thus, the ultrasonic blade 3924 remains activated and continues cutting the tissue between the jaws of the end effector while no current flows through the electrodes 3906a, 3906b from the bipolar RF generator circuit 3902. When the user releases the energy switch 3926 on the instrument handle, the energy switch 3926 opens and the output of the first inverter 3928 goes low and the output of the second inverter 3930 goes high to reset the flip-flop 3918 causing the *Q* output to go low and turn off the ultrasound generator circuit 3920. At the same time, the $\overline{Q}$ output goes high and the circuit is now in an off state and ready for the user to actuate the energy switch 3926 on the instrument handle to close the energy switch 3926, apply current to the tissue located between the electrodes 3906a, 3906b, and repeat the cycle of applying RF energy to the tissue and ultrasonic energy to the tissue as described above.

**[0266]** In one aspect, the ultrasonic or high-frequency current generators of the surgical system 1000 may be configured to generate the electrical signal waveform digitally such that the desired using a predetermined number of phase points stored in a lookup table to digitize the wave shape. The phase points may be stored in a table defined in a memory, a field programmable gate array (FPGA), or any suitable non-volatile memory. FIG. 27 illustrates one aspect of a fundamental architecture for a digital synthesis circuit such as a direct digital synthesis (DDS) circuit 4100 configured to generate a plurality of wave shapes for the electrical signal waveform. The generator software and digital controls may command the FPGA to scan the addresses in the lookup table 4104 which in turn provides varying digital input values to a DAC circuit 4108 that feeds a power amplifier. The addresses may be scanned according to a frequency of interest. Using such a lookup table 4104 enables generating various types of wave shapes that can be fed into tissue or into a transducer, an RF electrode, multiple transducers simultaneously, multiple RF electrodes simultaneously, or a combination of RF and ultrasonic instruments. Furthermore, multiple lookup tables 4104 that represent multiple wave shapes can be created, stored, and applied to tissue from a generator.

**[0267]** The waveform signal may be configured to control at least one of an output current, an output voltage, or an output power of an ultrasonic transducer and/or an RF electrode, or multiples thereof (e.g. two or more ultrasonic transducers and/or two or more RF electrodes). Further, where the surgical instrument comprises an ultrasonic components, the waveform signal may be configured to drive at least two vibration modes of an ultrasonic transducer of the at least one surgical instrument. Accordingly, a generator may be configured to provide a waveform signal to at least one surgical instrument wherein the waveform signal corresponds to at least one wave shape of a plurality of wave shapes in a table. Further, the waveform signal provided to the two surgical instruments may comprise two or more wave shapes. The table may comprise information associated with a plurality of wave shapes and the table may be stored within the generator. In one aspect or example, the table may be a direct digital synthesis table, which may be stored in an FPGA of the generator. The table may be addressed by anyway that is convenient for categorizing wave shapes. In accordance with at least one aspect, the table, which may be a direct digital

synthesis table, is addressed according to a frequency of the waveform signal. Additionally, the information associated with the plurality of wave shapes may be stored as digital information in the table.

**[0268]** The analog electrical signal waveform may be configured to control at least one of an output current, an output voltage, or an output power of an ultrasonic transducer and/or an RF electrode, or multiples thereof (e.g., two or more ultrasonic transducers and/or two or more RF electrodes). Further, where the surgical instrument comprises ultrasonic components, the analog electrical signal waveform may be configured to drive at least two vibration modes of an ultrasonic transducer of the at least one surgical instrument. Accordingly, the generator circuit may be configured to provide an analog electrical signal waveform to at least one surgical instrument wherein the analog electrical signal waveform corresponds to at least one wave shape of a plurality of wave shapes stored in a lookup table 4104. Further, the analog electrical signal waveform provided to the two surgical instruments may comprise two or more wave shapes. The lookup table 4104 may comprise information associated with a plurality of wave shapes and the lookup table 4104 may be stored either within the generator circuit or the surgical instrument. In one aspect or example, the lookup table 4104 may be a direct digital synthesis table, which may be stored in an FPGA of the generator circuit or the surgical instrument. The lookup table 4104 may be addressed by anyway that is convenient for categorizing wave shapes. In accordance with at least one aspect, the lookup table 4104, which may be a direct digital synthesis table, is addressed according to a frequency of the desired analog electrical signal waveform. Additionally, the information associated with the plurality of wave shapes may be stored as digital information in the lookup table 4104.

**[0269]** With the widespread use of digital techniques in instrumentation and communications systems, a digitally-controlled method of generating multiple frequencies from a reference frequency source has evolved and is referred to as direct digital synthesis. The basic architecture is shown in FIG. 27. In this simplified block diagram, a DDS circuit is coupled to a processor, controller, or a logic device of the generator circuit and to a memory circuit located in the generator circuit of the surgical system 1000. The DDS circuit 4100 comprises an address counter 4102, lookup table 4104, a register 4106, a DAC circuit 4108, and a filter 4112. A stable clock $f_c$ is received by the address counter 4102 and the register 4106 drives a programmable-read-only-memory (PROM) which stores one or more integral number of cycles of a sinewave (or other arbitrary waveform) in a lookup table 4104. As the address counter 4102 steps through memory locations, values stored in the lookup table 4104 are written to the register 4106, which is coupled to the DAC circuit 4108. The corresponding digital amplitude of the signal at the memory location of the lookup table 4104 drives the DAC circuit 4108, which in turn generates an analog output signal 4110. The spectral purity of the analog output signal 4110 is determined primarily by the DAC circuit 4108. The phase noise is basically that of the reference clock $f_c$. The first analog output signal 4110 output from the DAC circuit 4108 is filtered by the filter 4112 and a second analog output signal 4114 output by the filter

4112 is provided to an amplifier having an output coupled to the output of the generator circuit. The second analog output signal has a frequency $f_{out}$.

**[0270]** Because the DDS circuit 4100 is a sampled data system, issues involved in sampling must be considered: quantization noise, aliasing, filtering, etc. For instance, the higher order harmonics of the DAC circuit 4108 output frequencies fold back into the Nyquist bandwidth, making them unfilterable, whereas, the higher order harmonics of the output of phase-locked-loop (PLL) based synthesizers can be filtered. The lookup table 4104 contains signal data for an integral number of cycles. The final output frequency $f_{out}$ can be changed changing the reference clock frequency $f_c$ or by reprogramming the PROM.

**[0271]** The DDS circuit 4100 may comprise multiple lookup tables 4104 where the lookup table 4104 stores a waveform represented by a predetermined number of samples, wherein the samples define a predetermined shape of the waveform. Thus multiple waveforms having a unique shape can be stored in multiple lookup tables 4104 to provide different tissue treatments based on instrument settings or tissue feedback. Examples of waveforms include high crest factor RF electrical signal waveforms for surface tissue coagulation, low crest factor RF electrical signal waveform for deeper tissue penetration, and electrical signal waveforms that promote efficient touch-up coagulation. In one aspect, the DDS circuit 4100 can create multiple wave shape lookup tables 4104 and during a tissue treatment procedure (e.g., “on-the-fly” or in virtual real time based on user or sensor inputs) switch between different wave shapes stored in separate lookup tables 4104 based on the tissue effect desired and/or tissue feedback. Accordingly, switching between wave shapes can be based on tissue impedance and other factors, for example. In other aspects, the lookup tables 4104 can store electrical signal waveforms shaped to maximize the power delivered into the tissue per cycle (i.e., trapezoidal or square wave). In other aspects, the lookup tables 4104 can store wave shapes synchronized in such way that they make maximizing power delivery by the multifunction surgical instrument of surgical system 1000 while delivering RF and ultrasonic drive signals. In yet other aspects, the lookup tables 4104 can store electrical signal waveforms to drive ultrasonic and RF therapeutic, and/or sub-therapeutic, energy simultaneously while maintaining ultrasonic frequency lock. Custom wave shapes specific to different instruments and their tissue effects can be stored in the non-volatile memory of the generator circuit or in the non-volatile memory (e.g., EEPROM) of the surgical system 1000 and be fetched upon connecting the multifunction surgical instrument to the generator circuit. An example of an exponentially damped sinusoid, as used in many high crest factor "coagulation" waveforms is shown in FIG. 29.

**[0272]** A more flexible and efficient implementation of the DDS circuit 4100 employs a digital circuit called a Numerically Controlled Oscillator (NCO). A block diagram of a more flexible and efficient digital synthesis circuit such as a DDS circuit 4200 is shown in FIG. 28. In this simplified block diagram, a DDS circuit 4200 is coupled to a processor, controller, or a logic device of the generator and to a memory circuit located either in the generator or in any of the surgical instruments of surgical system 1000. The DDS circuit 4200 comprises a load register 4202, a

parallel delta phase register 4204, an adder circuit 4216, a phase register 4208, a lookup table 4210 (phase-to-amplitude converter), a DAC circuit 4212, and a filter 4214. The adder circuit 4216 and the phase register 4208 form part of a phase accumulator 4206. A clock frequency $f_c$ is applied to the phase register 4208 and a DAC circuit 4212. The load register 4202 receives a tuning word that specifies output frequency as a fraction of the reference clock frequency signal $f_c$. The output of the load register 4202 is provided to the parallel delta phase register 4204 with a tuning word M.

**[0273]** The DDS circuit 4200 includes a sample clock that generates the clock frequency $f_c$, the phase accumulator 4206, and the lookup table 4210 (e.g., phase to amplitude converter). The content of the phase accumulator 4206 is updated once per clock cycle $f_c$. When time the phase accumulator 4206 is updated, the digital number, M, stored in the parallel delta phase register 4204 is added to the number in the phase register 4208 by the adder circuit 4216. Assuming that the number in the parallel delta phase register 4204 is 00...01 and that the initial contents of the phase accumulator 4206 is 00...00. The phase accumulator 4206 is updated by 00...01 per clock cycle. If the phase accumulator 4206 is 32-bits wide, 232 clock cycles (over 4 billion) are required before the phase accumulator 4206 returns to 00...00, and the cycle repeats.

**[0274]** A truncated output 4218 of the phase accumulator 4206 is provided to a phase-to amplitude converter lookup table 4210 and the output of the lookup table 4210 is coupled to a DAC circuit 4212. The truncated output 4218 of the phase accumulator 4206 serves as the address to a sine (or cosine) lookup table. An address in the lookup table corresponds to a phase point on the sinewave from 0° to 360°. The lookup table 4210 contains the corresponding digital amplitude information for one complete cycle of a sinewave. The lookup table 4210 therefore maps the phase information from the phase accumulator 4206 into a digital amplitude word, which in turn drives the DAC circuit 4212. The output of the DAC circuit is a first analog signal 4220 and is filtered by a filter 4214. The output of the filter 4214 is a second analog signal 4222, which is provided to a power amplifier coupled to the output of the generator circuit.

**[0275]** In one aspect, the electrical signal waveform may be digitized into 1024 (210) phase points, although the wave shape may be digitized is any suitable number of 2n phase points ranging from 256 (28) to 281,474,976,710,656 (248), where n is a positive integer, as shown in TABLE 1. The electrical signal waveform may be expressed as $A_n(\theta_n)$, where a normalized amplitude $A_n$ at a point n is represented by a phase angle $\theta_n$ is referred to as a phase point at point n. The number of discrete phase points n determines the tuning resolution of the DDS circuit 4200 (as well as the DDS circuit 4100 shown in FIG. 21).

**[0276]** TABLE 1 specifies the electrical signal waveform digitized into a number of phase points.

TABLE 1

| N | Number of Phase Points $2^n$ |
|---|---|
| 8 | 256 |

| N | Number of Phase Points $2^n$ |
|---|---|
| 10 | 1,024 |
| 12 | 4,096 |
| 14 | 16,384 |
| 16 | 65,536 |
| 18 | 262,144 |
| 20 | 1,048,576 |
| 22 | 4,194,304 |
| 24 | 16,777,216 |
| 26 | 67,108,864 |
| 28 | 268,435,456 |
| ... | ... |
| 32 | 4,294,967,296 |
| ... | ... |
| 48 | 281,474,976,710,656 |
| ... | ... |

**[0277]** The generator circuit algorithms and digital control circuits scan the addresses in the lookup table 4210, which in turn provides varying digital input values to the DAC circuit 4212 that feeds the filter 4214 and the power amplifier. The addresses may be scanned according to a frequency of interest. Using the lookup table enables generating various types of shapes that can be converted into an analog output signal by the DAC circuit 4212, filtered by the filter 4214, amplified by the power amplifier coupled to the output of the generator circuit, and fed to the tissue in the form of RF energy or fed to an ultrasonic transducer and applied to the tissue in the form of ultrasonic vibrations which deliver energy to the tissue in the form of heat. The output of the amplifier can be applied to an RF electrode, multiple RF electrodes simultaneously, an ultrasonic transducer, multiple ultrasonic transducers simultaneously, or a combination of RF and ultrasonic transducers, for example. Furthermore, multiple wave shape tables can be created, stored, and applied to tissue from a generator circuit.

**[0278]** With reference back to FIG. 21, for n = 32, and M = 1, the phase accumulator 4206 steps through 232 possible outputs before it overflows and restarts. The corresponding output wave frequency is equal to the input clock frequency divided by 232. If M = 2, then the phase register

1708 “rolls over" twice as fast, and the output frequency is doubled. This can be generalized as follows.

**[0279]** For a phase accumulator 4206 configured to accumulate n-bits (n generally ranges from 24 to 32 in most DDS systems, but as previously discussed n may be selected from a wide range of options), there are $2^n$ possible phase points. The digital word in the delta phase register, M, represents the amount the phase accumulator is incremented per clock cycle. If $f_c$ is the clock frequency, then the frequency of the output sinewave is equal to:

$$f_0 = \frac{M \cdot f_c}{2^n}$$

**[0280]** The above equation is known as the DDS is known as the DDS "tuning equation." Note that the frequency resolution of the system is equal to $\frac{f_o}{2^n}$. For n = 32, the resolution is greater than one part in four billion. In one aspect of the DDS circuit 4200, not all of the bits out of the phase accumulator 4206 are passed on to the lookup table 4210, but are truncated, leaving only the first 13 to 15 most significant bits (MSBs), for example. This reduces the size of the lookup table 4210 and does not affect the frequency resolution. The phase truncation only adds a small but acceptable amount of phase noise to the final output.

**[0281]** The electrical signal waveform may be characterized by a current, voltage, or power at a predetermined frequency. Further, where any one of the surgical instruments of surgical system 1000 comprises ultrasonic components, the electrical signal waveform may be configured to drive at least two vibration modes of an ultrasonic transducer of the at least one surgical instrument. Accordingly, the generator circuit may be configured to provide an electrical signal waveform to at least one surgical instrument wherein the electrical signal waveform is characterized by a predetermined wave shape stored in the lookup table 4210 (or lookup table 4104 FIG. 27). Further, the electrical signal waveform may be a combination of two or more wave shapes. The lookup table 4210 may comprise information associated with a plurality of wave shapes. In one aspect or example, the lookup table 4210 may be generated by the DDS circuit 4200 and may be referred to as a direct digital synthesis table. DDS works by first storing a large repetitive waveform in onboard memory. A cycle of a waveform (sine, triangle, square, arbitrary) can be represented by a predetermined number of phase points as shown in TABLE 1 and stored into memory. Once the waveform is stored into memory, it can be generated at very precise frequencies. The direct digital synthesis table may be stored in a non-volatile memory of the generator circuit and/or may be implemented with a FPGA circuit in the generator circuit. The lookup table 4210 may be addressed by any suitable technique that is convenient for categorizing wave shapes. According to one aspect, the lookup table 4210 is addressed according to a frequency of the electrical signal waveform. Additionally, the information associated with the plurality of wave shapes may be stored as digital information in a memory or as part of the lookup table 4210.

**[0282]** In one aspect, the generator circuit may be configured to provide electrical signal waveforms to at least two surgical instruments simultaneously. The generator circuit also may be

configured to provide the electrical signal waveform, which may be characterized two or more wave shapes, via an output channel of the generator circuit to the two surgical instruments simultaneously. For example, in one aspect the electrical signal waveform comprises a first electrical signal to drive an ultrasonic transducer (e.g., ultrasonic drive signal), a second RF drive signal, and/or a combination thereof. In addition, an electrical signal waveform may comprise a plurality of ultrasonic drive signals, a plurality of RF drive signals, and/or a combination of a plurality of ultrasonic and RF drive signals.

**[0283]** In addition, a method of operating the generator circuit according to the present disclosure comprises generating an electrical signal waveform and providing the generated electrical signal waveform to any one of the surgical instruments of surgical system 1000, where generating the electrical signal waveform comprises receiving information associated with the electrical signal waveform from a memory. The generated electrical signal waveform comprises at least one wave shape. Furthermore, providing the generated electrical signal waveform to the at least one surgical instrument comprises providing the electrical signal waveform to at least two surgical instruments simultaneously.

**[0284]** The generator circuit as described herein may allow for the generation of various types of direct digital synthesis tables. Examples of wave shapes for RF/Electrosurgery signals suitable for treating a variety of tissue generated by the generator circuit include RF signals with a high crest factor (which may be used for surface coagulation in RF mode), a low crest factor RF signals (which may be used for deeper tissue penetration), and waveforms that promote efficient touch-up coagulation. The generator circuit also may generate multiple wave shapes employing a direct digital synthesis lookup table 4210 and, on the fly, can switch between particular wave shapes based on the desired tissue effect. Switching may be based on tissue impedance and/or other factors.

**[0285]** In addition to traditional sine /cosine wave shapes, the generator circuit may be configured to generate wave shape(s) that maximize the power into tissue per cycle (i.e., trapezoidal or square wave). The generator circuit may provide wave shape(s) that are synchronized to maximize the power delivered to the load when driving RF and ultrasonic signals simultaneously and to maintain ultrasonic frequency lock, provided that the generator circuit includes a circuit topology that enables simultaneously driving RF and ultrasonic signals. Further, custom wave shapes specific to instruments and their tissue effects can be stored in a non-volatile memory (NVM) or an instrument EEPROM and can be fetched upon connecting any one of the surgical instruments of surgical system 1000 to the generator circuit.

**[0286]** The DDS circuit 4200 may comprise multiple lookup tables 4104 where the lookup table 4210 stores a waveform represented by a predetermined number of phase points (also may be referred to as samples), wherein the phase points define a predetermined shape of the waveform. Thus multiple waveforms having a unique shape can be stored in multiple lookup tables 4210 to provide different tissue treatments based on instrument settings or tissue feedback. Examples of

waveforms include high crest factor RF electrical signal waveforms for surface tissue coagulation, low crest factor RF electrical signal waveform for deeper tissue penetration, and electrical signal waveforms that promote efficient touch-up coagulation. In one aspect, the DDS circuit 4200 can create multiple wave shape lookup tables 4210 and during a tissue treatment procedure (e.g., "on-the-fly" or in virtual real time based on user or sensor inputs) switch between different wave shapes stored in different lookup tables 4210 based on the tissue effect desired and/or tissue feedback. Accordingly, switching between wave shapes can be based on tissue impedance and other factors, for example. In other aspects, the lookup tables 4210 can store electrical signal waveforms shaped to maximize the power delivered into the tissue per cycle (i.e., trapezoidal or square wave). In other aspects, the lookup tables 4210 can store wave shapes synchronized in such way that they make maximizing power delivery by any one of the surgical instruments of surgical system 1000 when delivering RF and ultrasonic drive signals. In yet other aspects, the lookup tables 4210 can store electrical signal waveforms to drive ultrasonic and RF therapeutic, and/or sub-therapeutic, energy simultaneously while maintaining ultrasonic frequency lock. Generally, the output wave shape may be in the form of a sine wave, cosine wave, pulse wave, square wave, and the like. Nevertheless, the more complex and custom wave shapes specific to different instruments and their tissue effects can be stored in the non-volatile memory of the generator circuit or in the non-volatile memory (e.g., EEPROM) of the surgical instrument and be fetched upon connecting the surgical instrument to the generator circuit. One example of a custom wave shape is an exponentially damped sinusoid as used in many high crest factor "coagulation" waveforms, as shown in FIG. 23.

**[0287]** FIG. 29 illustrates one cycle of a discrete time digital electrical signal waveform 4300, in accordance with at least one aspect of the present disclosure of an analog waveform 4304 (shown superimposed over the discrete time digital electrical signal waveform 4300 for comparison purposes). The horizontal axis represents Time (t) and the vertical axis represents digital phase points. The digital electrical signal waveform 4300 is a digital discrete time version of the desired analog waveform 4304, for example. The digital electrical signal waveform 4300 is generated by storing an amplitude phase point 4302 that represents the amplitude per clock cycle $T_{clk}$ over one cycle or period $T_o$. The digital electrical signal waveform 4300 is generated over one period $T_o$ by any suitable digital processing circuit. The amplitude phase points are digital words stored in a memory circuit. In the example illustrated in FIGS. 27, 28, the digital word is a six-bit word that is capable of storing the amplitude phase points with a resolution of 26 or 64 bits. It will be appreciated that the examples shown in FIGS. 27, 28 is for illustrative purposes and in actual implementations the resolution can be much higher. The digital amplitude phase points 4302 over one cycle $T_o$ are stored in the memory as a string of string words in a lookup table 4104, 4210 as described in connection with FIGS. 27, 28, for example. To generate the analog version of the analog waveform 4304, the amplitude phase points 4302 are read sequentially from the memory from 0 to $T_o$ per clock cycle $T_{clk}$ and are converted by a DAC circuit 4108, 4212, also described in connection with FIGS. 27, 28. Additional cycles can be generated by repeatedly reading the amplitude phase points

4302 of the digital electrical signal waveform 4300 the from 0 to $T_o$ for as many cycles or periods as may be desired. The smooth analog version of the analog waveform 4304 is achieved by filtering the output of the DAC circuit 4108, 4212 by a filter 4112, 4214 (FIGS. 27 and 28). The filtered analog output signal 4114, 4222 (FIGS. 27 and 28) is applied to the input of a power amplifier.

Advanced RF Energy Device Including Nerve Stimulation Signal with Therapeutic Waveforms

**[0288]** As disclosed above, in some surgical procedures, a medical professional may employ an electrosurgical device to seal or cut tissues such as blood vessels. Such devices effect a medical therapy by passing electrical energy, for example current at radiofrequencies (RF), through the tissue to be treated. Some electrosurgical devices are termed bipolar devices in that both an electrode to source the electrical energy (the active electrode) and a return electrode are housed in the same surgical probe. It will be appreciated that a surgical probe may comprise a handpiece or a robotically controlled instrument or a combination thereof.

**[0289]** Alternative devices may be termed monopolar devices. In such devices, only the active electrode is housed in the surgical probe. The electrical current entering the patient's tissue may return to the electrical energy generator via an electrical path through the gurney on which the patient reposes or through a specific return electrode pad. In some aspects, the patient may repose on the electrode pad, or the electrode pad may be placed on the patient at a location close to the surgical site where the surgical probe is deployed. It may be recognized that the current path through a patient undergoing a procedure using a monopolar device may be less well characterized than the current path through a patient undergoing a procedure using a bipolar device. Consequently, some non-target tissue may be inadvertently cauterized, cut, or otherwise damaged by a monopolar electrosurgical device. Such unintended injury to excitable tissue may result in the patient experiencing muscle weakness, pain, numbness, paralysis and/or other undesired outcomes.

**[0290]** It is therefore desirable that a monopolar electrosurgical device incorporate features to determine if the device is close enough to excitable tissue to cause inadvertent injury. Such features may be used by one or more subsystems of the electrosurgical device as a basis for notifying the medical professional of the proximity of such tissue to the monopolar electrode. Additionally, such features may be used by one or more subsystems of an intelligent electrosurgical device to reduce or eliminate the amount of therapeutic energy delivered to tissue deemed to close to non-target excitable tissue. In some intelligent medical devices that combine electrosurgical (RF) with ultrasonic therapeutic modes, features to determine if the device is close enough to excitable tissue to cause inadvertent injury when the device is operating in the electrosurgical (RF) mode may result in the device switching to the ultrasonic mode.

**[0291]** 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 surgical probe, 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 located at a distal end of the surgical probe 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.

**[0292]** FIG. 30 depicts a typical monopolar electrosurgical system 136000. The electrosurgical system 136000 can include a controller 136010, a generator 136012, an electrosurgical instrument 136015, and a return pad 136020 which includes one or more return electrodes. Typically, the generator 136012 may source an electrical signal to the electrosurgical instrument 136015 along a first conducting electrical path 136017 and may receive a return signal from the one or more return electrodes along a second conducting electrical path 136023. FIG. 30 depicts an example of a health care professional 136025 treating a patient 136027 using an electrosurgical instrument 136015 such as an active monopolar electrode.

**[0293]** FIG. 31 is a schematic block diagram of the patient and electrical components depicted in FIG. 30. The generator 136012 may be a separate component from the controller 136010 or the controller 136010 may include the electrical generator 136012. The controller 136010 may control the operation of the generator 136012, including controlling an electrical output thereof. As disclosed below, the controller 136010 may control one or more output waveforms of the electrical generator 136012 including the control of a variety of characteristics including amplitude characteristics, frequency characteristics, and phase characteristics of the output signal of the electrical generator 136012. The controller 136010 may further receive signals from any number of additional components including, without limitation, manual control actuators (switches, push buttons, slides, and similar), sensors, or data signals transmitted by any number of communication devices, computers, smart surgical devices, and imaging systems. The controller 136010 may be composed of any type or types of computer processor devices, one or more memory components (static and/or dynamic memory components), and communication components configured to transmit and/or receive data signals (analog or digital) as may be required for the functioning of the controller. The memory components of the controller 136010 may contain one or more instructions that, when read by the one or more computer processor devices, may direct the operation of the controller. Examples of such instructions and their intended results are disclosed below.

**[0294]** Electrical energy may be sourced by the electrical generator 136012 and received by a surgical instrument 136015 such as an active monopolar electrode. In some aspects, the active electrode may be in electrical communication with an electrical source terminal of the electrical

generator 136012 to receive the electrical energy. In some aspects, the surgical instrument 136015 may receive an electrical signal over a first conducting electrical path 136017 such as a wire or other cabling.

**[0295]** During the procedure, the patient 136027 may lie supine on a return pad 136020. The return pad 136020 may be in electrical communication with the electrical generator 136012 via an electrical return terminal, and the electrical energy sourced into the patient 136027 by the electrosurgical instrument 136015, such as an active electrode, may be returned to the electrical generator 136012 through the return pad 136020. In some aspects, the return pad 136020 may be in electrical communication with the electrical return terminal over a second conducting electrical path 136023, such as a wire or other cabling.

**[0296]** In some aspects, the generator 136012 may supply alternating current at radiofrequency levels to the electrosurgical instrument 136015. In some alternative aspects, the electrosurgical instrument 136015 may also incorporate features for ultrasonic therapeutic modes, and the generator 136012 may also be configured to generate power to drive one or more ultrasonic therapeutic components. The electrosurgical instrument 136015, which typically includes an electrode tip (i.e., an active electrode) which can be positioned at a target tissue of a patient 136027, receives the alternating current from the generator 136012 and delivers the alternating current to the target tissue via the electrode tip. The alternating current received by the electrode tip may be from the generator 136012 via a first conducting electrical path 136017. The alternating current is received at the target tissue, and the resistance from the tissue creates heat which provides the desired effect (e.g., sealing and/or cutting) at the surgical site. The alternating current received at the target tissue is conducted through the patient's body and ultimately is received by the one or more return electrodes of the return pad 136020. The alternating current received by the return pad 136020 may be conducted back to the generator via a second conducting electrical path 136023 to complete the closed path followed by the alternating current. The one or more return electrodes are configured to carry the amount of current introduced by the electrode tip. The return pad 136020 may be attached to the patient's body or may be separated a small distance from the patient's body (i.e., capacitive coupling). The alternating current received by the one or more return electrodes is passed back to the generator 136012 to complete the closed path followed by the alternating current.

**[0297]** For an electrosurgical system 136000 which utilizes capacitive coupling to complete the current path between the patient's body and the return electrode, the patient's body effectively acts as a first capacitive plate of a capacitor and the return electrode pad effectively acts as a second capacitive plate of a capacitor.

**[0298]** In some aspects, the return pad 136020 may include a single return electrode which incorporates an array of multiple sensing devices. In some alternative aspects, the return pad 136020 may include an array of return electrodes, where an array of sensing devices may be incorporated into the array of return electrodes. In one non-limiting example, the return pad 136020

may include multiple return electrodes in which each of the return electrodes includes a sensing device.

**[0299]** By incorporating an array of sensing devices into the return electrode pad 136020, the sensing devices may be used to detect either a nerve control signal applied to the patient or a movement of an anatomical feature of the patient resulting from an application of the nerve control signal. The sensing devices may include, without limitation, one or more pressure sensors, one or more accelerometers, or combinations thereof. In some non-limiting aspects, a sensing device may be configured to output a signal indicative of the detected nerve control signal and/or the detected movement of an anatomical feature of the patient. Using Coulomb's law and the respective locations of the active electrode, the patient's body and the sensing devices, the detected nerve control signal and/or movement of an anatomical feature of the patient can be analyzed to determine the location of a nerve within the patient's body.

**[0300]** In some aspects, for example as depicted in FIG. 32, a return pad 136120 may include a plurality of electrodes 136125 which can be capacitively coupled to the patient's body and collectively are configured to carry the amount of current introduced into the patient's body by the electrosurgical instrument. For this capacitive coupling, the patient's body effectively acts as one plate of a capacitor and collectively the plurality of electrodes 136125 of the return pad 136120 effectively act together as the other plate of the capacitor. A more detailed description of capacitive coupling can be found, for example, in U.S. Patent No. 6,214,000, titled CAPACITIVE REUSABLE ELECTROSURGICAL RETURN ELECTRODE, issued April 10, 2001 and in U.S. Patent No. 6,582,424, titled CAPACITIVE REUSABLE ELECTROSURGICAL RETURN ELECTRODE, issued June 24, 2003, the entire contents of which are each incorporated herein by reference and in their respective entireties.

**[0301]** FIG. 31 illustrates a plurality of electrodes 136125a-d of the return pad of FIG. 30, in accordance with at least one aspect of the present disclosure. Although four electrodes 136215a-d are shown in FIG. 31, it will be appreciated that the return pad 136120 may include any number of electrodes 136125. For example, according to various aspects, the return pad 136120 may include two electrodes, eight electrodes, sixteen electrodes, or any number of electrodes that may be fabricated in the return pad 136120. It should be recognized that the number of electrodes may be an even integer or an odd integer. Also, although the individual electrodes 136125a-d are shown in FIG. 31 as being substantially rectangular, it will be appreciated that the individual electrodes can be of any suitable shape.

**[0302]** The electrodes 136125a-d of the return pad 136120 may serve as the return electrodes of the electrosurgical system of FIGS. 30 and 31, and can also be considered to be segmented electrodes as the electrodes 136125a-d can be selectively decoupled from the patient's body and/or the generator. In some aspects, the electrodes 136125a-d of the return pad 136120 can be coupled together to effectively act as one large electrode. For example, according to various aspects, each of the electrodes 136125a-d of the return pad 136120 can be connected by respective conductive

members 136130a-d to inputs of a switching device 136135 as shown in FIG. 32. When the switching device 136135 is in an open position, as shown in FIG. 32, the respective electrodes 136125a-d of the return pad 136120 are decoupled from one another as well as from the patient's body and/or the generator. In contrast, when the switching device 136135 is in a closed position, the respective electrodes 136125a-d of the return pad 136120 are coupled together to effectively act as a single large electrode. It may be recognized that differing combinations of electrodes 136125a-d may be coupled together by the switching device 136135 to form any group or groups of electrodes. For example, if a patient is disposed in a supine position on the return pad 136120 with the patient's head proximate to the switching device 136135, electrodes 136125a and 136125c may be coupled together and electrodes 136125b and 136125d may be coupled together thereby sensing electrical currents flowing through the lower torso and upper torso, respectively. Alternatively, if a patient is disposed in a supine position on the return pad 136120 with the patient's head proximate to the switching device 136135, electrodes 136125a and 136125b may be coupled together and electrodes 136125c and 136125d may be coupled together thereby sensing electrical currents flowing through the right torso and left torso, respectively.

**[0303]** The switching device 136135 can be controlled by a processing circuit (e.g., a processing circuit of the generator of the electrosurgical system, of a hub of an electrosurgical system, etc.). For purposes of simplicity, the processing circuit is not shown in FIG. 32. According to various aspects, the switching device 136135 can be incorporated into the return pad 136120. According to other aspects, the switching device 136135 can be incorporated into the second conducting electrical path of the electrosurgical system of FIGS. 30 and 31. The return pad136120 can also include a plurality of sensing devices.

**[0304]** FIG. 33 illustrates an array of sensing devices 136140a-d of the return pad in accordance with at least one aspect of the present disclosure. According to various aspects, the number of sensing devices 36140a-d may correspond to the number of electrodes 36125a-d such that there is one sensing device for each electrode (for example, sensing device 36140a with electrode 136125a, sensing device 36140b with electrode 136125b, sensing device 36140c with electrode 136125c, and sensing device 36140d with electrode 136125d). Each sensing device 36140a-d may be mounted to or integrated with a corresponding electrode 136125a-d, respectively. However, although the number of sensing devices 36140a-d associated with the corresponding electrodes 136125a-d may correspond to the number of electrodes, it will be appreciated that the return pad may include any number of sensing devices. For example, for aspects of the return pad which include sixteen electrodes, the return pad may only include four or eight sensing devices. Although the sensing devices 136140a-d are shown in FIG. 33 as being centered on the corresponding electrodes 136125a-d, respectively, it will be appreciated that the sensing devices 136140a-d can be positioned on any portion of the corresponding electrodes 136125a-d. It may be further understood that the position of a particular sensing device on a particular electrode is independent of a position of any other sensing device on its respective electrode.

**[0305]** The sensing devices 136140a-d are configured to detect a monopolar nerve control signal applied to the patient and/or a movement of an anatomical feature of the patient (e.g., a muscle twitch) resulting from application of the nerve control signal. The monopolar nerve control signal may be applied by the surgical instrument of the electrosurgical system of FIGS. 30 and 31, or may be applied by a different surgical instrument which is coupled to a different generator. Each sensing device 136140a-d may include, for example, a pressure sensor, an accelerometer, or combinations thereof, and is configured to output a signal indicative of the detected nerve control signal and/or the detected movement of an anatomical feature of the patient. In some non-limiting examples, a sensing device composed of a pressure sensor may include for example, a piezoresistive strain gauge, a capacitive pressure sensor, an electromagnetic pressure sensor, and/or a piezoelectric pressure sensor either alone or in combination. In some non-limiting examples, a sensing device composed of an accelerometer may include, for example, a mechanical accelerometer, a capacitive accelerometer, a piezoelectric accelerometer, an electromagnetic accelerometer, and/or a microelectromechanical system (MEMS) accelerometer either alone or in combination. The respective output signals of the respective sensing devices 136140a-d may be in the form of analog signals and/or digital signals.

**[0306]** Using Coulomb's law and the respective locations of the active electrode of the surgical instrument, the patient's body and the respective sensing devices, the respective output signals of the respected sensing devices 136140a-d, which are indicative of a detected nerve control signal and/or movement of an anatomical feature of the patient, can be analyzed to determine the location of a nerve within the patient's body. Coulomb's law states that $E=K(Q/r^2)$, where E is the threshold current required at a nerve to stimulate the nerve, K is a constant, Q is the minimal current from the nerve stimulation electrode and r is the distance from the nerve. The further the nerve stimulation electrode is from the nerve (r increases), the current required to stimulate the nerve is proportionately greater. Thus, the amount of stimulation of an excitable tissue as measured by a sensing device 136150a-d may be related to the distance of the nerve stimulation electrode to the excitable tissue at constant current stimulation. In some aspects, an output signal of a sensing device 136140a-d may also be dependent on the distance of the excitable tissue to the sensing device 136140a-d. It may be recognized that multiple sensing devices 136140a-d may be used to triangulate the position of an electrically stimulated excitable tissue based on the geometry and position of the multiple sensing devices 136140a-d. A constant current stimulus can thus be utilized to estimate the distance from the nerve stimulation electrode to the nerve. Alternatively, current stimulus composed of varying amounts of current may be used to improve the determination of the position of the excitable tissue through the triangulation method associated with multiple sensing devices 136140a-d. In general, the respective strengths of the output signals of the respective sensing devices are indicative of how close or far the respective sensing devices are from the stimulated nerve of the patient.

**[0307]** According to various aspects, the analysis of the respective output signals of the respective sensing devices can be performed by a processing circuit of the generator of the electrosurgical system of FIGS. 30 and 31, by a processing circuit of a nerve monitoring system which is separate from the generator of the electrosurgical system thereof, by a processing circuit of a hub of an electrosurgical system, etc. The analysis can be performed in real time or in near-real time. According to various aspects, the respective output signals serve as inputs to a monopolar nerve stimulation algorithm which is executed by the processing circuit.

**[0308]** As shown in FIG. 33, according to various aspects, the output signals of the respective sensing devices 136140a-d can be input into a multiple input - single output switching device 136137 (e.g., a multiplexer) via respective conductive members 136142a-d, respectively. By controlling the selection signals S0, S1 to the multiple input - single output switching device 136137, the multiple input - single output switching device 136137 can be controlled to output only one of the output signals of the respective sensing devices 136140a-d at a time for the above-described analysis. As one non-limiting example, with reference to FIG. 33, by setting the selection signals S0, S1 to 0,0, the output signal from the sensing device 136140c can be output by the multiple input - single output switching device 136137 for analysis by the applicable processing circuit. In another non-limiting example, setting the selection signals S0, S1 to 0,1, the output signal from the sensing device 136140a can be output by the multiple input - single output switching device 136137 for analysis by the applicable processing circuit. Similarly, by setting the selection signals S0, S1 to 1,0, the output signal from the sensing device 136140d can be output by the multiple input - single output switching device 136137 for analysis by the applicable processing circuit. And, by extension, by setting the selection signals S0, S1 to 1,1, the output signal from the sensing device 136140b can be output by the multiple input - single output switching device 136137 for analysis by the applicable processing circuit.

**[0309]** The selection signals S0, S1 can be provided to the multiple input - single output switching device 136137 by a processing circuit such as, as non-limiting examples, a processing circuit of the generator of the electrosurgical system of FIGS. 30 and 31, a processing circuit of a nerve monitoring system which is separate from the generator of the electrosurgical system, by a processing circuit of a hub of an electrosurgical system, and similar. For purposes of simplicity, the processing circuit is not shown in FIG. 33. By providing the various selection signals at a fast enough rate, the output signals of the respective sensing devices 136125a-d can effectively be scanned at a rate which allows for the timely analysis of all of the output signals of the respective sensing devices 136125a-d to determine the position of the stimulated nerve.

**[0310]** According to various aspects, the multiple input - single output switching device 136137 can be incorporated into the return pad. According to other aspects, the multiple input - single output switching device 136137can be incorporated into the second conducting electrical path 136023 of the electrosurgical system 136000 of FIG. 30.

**[0311]** The control of the multiple input - single output switching device 136137 as disclosed in FIG. 33 may be in the context of a four input-one output switching device, corresponding to the four sensing devices 136140a-d depicted in FIG. 33. It will be appreciated that for aspects in which there are more than four sensing devices (e.g., sixteen sensing devices), the output signals of the more than more than four sensing devices may serve as inputs to a multiple input - single output switching device having more than two selection signals (e.g., S0, S1, S2 and S3).

**[0312]** For aspects where the output signals of the sensing devices (for example 136140a-d are analog signals, the output of the multiple input - single output switching device 136137 can be converted into a corresponding digital signal by an analog-to-digital converter 136145 prior to the performance of the analysis of the output signals by the applicable processing circuit.

**[0313]** Returning to FIG. 30, according to various aspects, the detection of the nerve control signal and/or the movement of an anatomical feature of the patient by the sensing devices can be performed while the electrodes 136125a-d of the return pad 136120 are coupled to one another or while the electrodes 136125a-d are uncoupled from one another. For example, with regard to performing the detection when the respective electrodes 136125a-d of the return pad 136120 are uncoupled from one another, after positioning the patient on the operating table but before starting a surgical procedure, the return pad 136120 can be placed in a “sensing mode” by controlling the switching device 136135 to uncouple the respective electrodes 136125a-d of the return pad 136120 from one another. While the respective electrodes 136125a-d are uncoupled from one another, a nerve and/or a nerve bundle can be stimulated with an electrosurgical instrument as described above, and the respective output signals of the sensing devices of the return pad136120 can be analyzed as described above to identify where the nerve, nerve bundle and/or nerve nexuses associated therewith are located. The locations of the nerve, nerve bundle and/or nerve nexuses may be input into a monopolar nerve stimulation algorithm profile. Once the locations of the nerve, nerve bundle and/or nerve nexuses are input into the monopolar nerve stimulation algorithm profile, the locations of the nerve, nerve bundle and/or nerve nexuses may be effectively isolated from the capacitive operation of the electrodes of the return pad 136120. The locations of the nerve, nerve bundle and/or nerve nexuses may be used as sensing nodes of the monopolar nerve stimulation algorithm profile to inform the surgeon as the surgeon approaches a nerve and/or a nerve bundle while performing a tissue cutting procedure. According to various aspects, the surgeon may be informed of the nearby location of the nerve and/or nerve bundle via an audible warning, a visual warning, a tactile (such as vibratory) warning, etc.

**[0314]** Returning to FIG. 31, with regard to performing the detection when the respective electrodes of the return pad 136015 are coupled with one another, according to various aspects, the generator 136012 of the electrosurgical system can generate a high frequency waveform (the alternating current at radio frequency) which may be modulated on a carrier wave having a sufficiently low frequency to stimulate a nerve of the patient. This modulation may allow for the sensing of the nerve control signal and/or the movement of an anatomical feature concurrently with

the capacitive coupling of the respective electrodes of the return pad 136020 with the patient's body 136027. By applying a specific waveform to the patient 136027 and sensing a specific response, there is a high level of confidence that the movement of the anatomical feature may be correlated with the applied waveform and not due to random patient motion. The modulation can be adjusted over time to stimulate different nerve sizes. According to various aspects, the modulation can be varied in amplitude over time in order to allow the applicable processing circuit to determine the distance the nerve and/or nerve bundle is from the signal without having to constantly stimulate the nerve and/or nerve bundle.

**[0315]** The electrical energy applied by a surgical probe of an electrosurgical device to the tissue may be in the form of radio frequency (RF) energy that may be in a frequency range described in EN 60601-2-2:2009+A11:2011, Definition 201.3.218—HIGH FREQUENCY. For example, the frequencies in monopolar RF applications are typically restricted to less than 5 MHz. Frequencies above 200 kHz can be typically used for MONOPOLAR applications in order to avoid the unwanted stimulation of nerves and muscles which would result from the use of low frequency current. Lower frequencies may be used for BIPOLAR techniques 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. However, higher frequencies may be used in the case of BIPOLAR techniques. It is generally recognized that 10 mA is the lower threshold of thermal effects on tissue.

**[0316]** It may be recognized that an electrosurgical device may take advantage of the response of excitable tissue to electrical frequencies below 200 kHz in order to determine if such excitable tissue is sufficiently proximate to the end effector of the electrosurgical device to be potentially damaged thereby. FIG. 34 illustrates an RF signal 136210 that may be used in an electrosurgical device to cut or cauterize tissue. Such an RF signal 136210 may be termed a therapeutic signal because it has a frequency that may effect a therapeutic result such as cauterizing or cutting tissue. For purely illustrative purposes, the x-axis may represent time wherein each division represents 10 μsecs, and the y-axis (amplitude) has an arbitrary value. The RF signal 136210 depicted in FIG. 34 may therefore have a frequency of about 1 MHz. It may be understood that an RF therapeutic signal may have any frequency, amplitude, and/or phase characteristics sufficient to effect a therapeutic application such as sealing, cauterizing, ablating, or cutting a tissue.

**[0317]** FIG. 35 depicts a signal 136220 that may be used to stimulate excitable tissue such as nerves or muscle. Again, solely for illustrative purposes, the signal 136220 depicted in FIG. 35 may extend over about 20 μsecs, and, if repeated, would constitute a waveform having a frequency of about 50 kHz. Such an electrical signal 136220 may be termed a stimulating signal because it has a frequency that may simulate excitable tissues such as nerve or muscle tissue. It may be understood that a waveform of a stimulating signal may differ from the signal 136220 presented in FIG.35 in any aspect such as duration, frequency, or amplitude. In general, a stimulating signal 136220 may have any appropriate waveform or amplitude while having a frequency within a range that is capable of

stimulating such excitable tissue. As indicated, such waveforms as depicted in FIGS. 34 and 35 are illustrative only. In one alternative example, a therapeutic RF signal may have a frequency of about 330 kHz and a waveform to stimulate excitable tissue may have a frequency of about 2 kHz.

**[0318]** It may be understood that an intelligent electrosurgical device may be configured to emit either a therapeutic signal or a stimulating signal or a combination thereof. FIGS. 36A-36C present examples of combinations of therapeutic signals and stimulating signals. The electrical generator may source an output current composed of any number or combination of characteristics of the therapeutic signal and characteristics of a tissue stimulating signal. Non-limiting examples of characteristics of a therapeutic signal may include a therapeutic signal frequency, a therapeutic signal amplitude, and a therapeutic signal phase. Non-limiting examples of characteristics of a tissue stimulating signal may include a stimulating signal frequency, a stimulating signal amplitude, and a stimulating signal phase. It may be recognized that a therapeutic signal may be characterized by any number of frequencies, phases, and amplitudes. Additionally, it may be recognized that a tissue stimulating signal may be characterized by any number of frequencies, phases, and amplitudes. In some aspects, the controller may be configured to control an electrical generator to provide an electrical output composed of a combination or combinations of characteristics of a therapeutic signal and characteristics of a tissue stimulating signal.

**[0319]** FIG. 36A depicts a non-limiting example of a first combination signal 136230 composed of a first therapeutic signal 136212a , a stimulating signal 136222, and a second therapeutic signal 136212b. As depicted, one or more stimulating signals (such as signal 136220, FIG. 35) may alternate with one or more therapeutic signals (such as signal 136210, FIG. 34). It may be understood that the length of time for the application of the one or more therapeutic signals (such as 136212a,b) may be arbitrary and may depend on the length of time that a medical professional may wish to apply it. It may also be understood that the stimulating signal 136222 may be transmitted at any time during the application of a therapeutic signal. It may be further understood that one or more zero-amplitude signals may be interspersed between one or more therapeutic signals and one or more stimulating signals. Multiple stimulating signals may be transmitted in succession before a subsequent therapeutic signal is transmitted.

**[0320]** FIG. 36B presents a non-limiting example of a second combination signal 136240 of a therapeutic signal and a stimulating signal. In FIG. 36B, the stimulating signal (136220 depicted in FIG. 35) may be used to modulate the amplitude of the therapeutic signal (136210 depicted in FIG. 34). In some aspects, the stimulating signal 136220 may be applied directly to an amplitude modulation circuit to modulate the amplitude of a therapeutic signal 136210. In alternative aspects, the stimulating signal 136220 may be offset and scaled before being used to modulate the amplitude of the therapeutic signal 136210. As an example, the stimulating signal 136220 in FIG. 35 may be offset by +4.5 V and the resulting signal may be scaled by 4.5 V so that the amplitude of the therapeutic signal 136210 is modulated by a positive-valued modulation signal that may range in value from about 0.1V to about 2V. One may readily recognize that any simple transformation of a

stimulating signal 136220 may be used to modulate the amplitude of a therapeutic signal 136210. It may be recognized that the amplitude of the therapeutic signal 136210 may be modulated by the stimulating signal 136220 at any time or for any number of times during the application of the therapeutic signal. The amplitude of the therapeutic signal 136210 may be modulated in the same manner over the course of multiple periods of modulation. Alternative, each amplitude modulation may differ according to the offset and/or scaling transformation of the stimulating signal 136220.

**[0321]** FIG. 36C presents a non-limiting example of a third combination signal 136250 of a therapeutic signal and a stimulating signal. In FIG. 36C the stimulating signal (136220 depicted in FIG. 35) may be used as a DC offset to the therapeutic signal (136210 depicted in FIG. 34). It may be recognized that the stimulating signal 136220 may also be altered according to any offset or scaling transformation before being applied as a DC offset to the therapeutic signal 136210. It may be recognized that a DC offset based on the stimulating signal 136220 may be applied at any time to the therapeutic signal 136210 and may be applied multiple times over the course of the application of the therapeutic signal 136210. The DC offset applied to the therapeutic signal 136210 may be the same over the course of multiple periods of offset application. Alternative, each DC offset to the therapeutic signal 136210 may differ according to the offset and/or scaling transformation of the stimulating signal

**[0322]** It may be understood that the combination of a stimulating signal with a therapeutic signal is not limited to the examples disclosed above and depicted in FIGS. 36A-36C. A stimulating signal may be combined with a therapeutic signal in the same manner throughout an electrosurgical procedure. Alternatively, a stimulating signal may be combined with a therapeutic signal in any of a number of different ways throughout the electrosurgical procedure. In some aspects, a stimulating signal may be combined with a therapeutic signal based on a choice made by a health care professional during the electrosurgical procedure. For example, the surgical probe may include one or more controls to permit the operator of the electrosurgical device to choose a mode of combination of the stimulating signal with the therapeutic signal. The surgical probe may also include one or more controls to permit the operator of the electrosurgical device to choose when the stimulating signal may be applied. In some alternative aspects, the surgical probe may include controls to permit a user to vary one or more characteristics of the therapeutic signal and/or the stimulating signal. Non-limiting examples of such signal characteristics may include one or more frequencies, one or more phases, and one or more amplitudes. In some alternative aspects, the control or controls of the stimulating signal and the therapeutic signal, their respective characteristics, or their combination may be located on the control unit of the electrosurgical device, or may be incorporated in a foot-operated controller.

**[0323]** In some aspects, a smart electrosurgical device may include a processor, memory components, and instructions resident in the memory components for adjusting a therapeutic signal output based on a distance of the active electrode from excitable tissues. In some aspects, such processor, memory components, and instructions may form components of the controller. In some

aspects, such processor, memory components, and instructions may form components of the electrical generator. In some aspects, such processor, memory components, and instructions may form components of a computer system separate from the smart electrosurgical device.

**[0324]** FIG. 37 summarizes a one non-limiting method 136300 in which such a control may be effected. A controller may configure a generator to combine 136310 a stimulating signal with a therapeutic signal to form an electrode emitted signal. The controller may then cause an electrode to transmit 136320 the electrode emitted signal from an active electrode into a patient tissue. The controller may then receive 136330 a signal from a return signal pad in electrical communication with at least a portion of the patient. The signal returned by the return signal pad may include a signal generated by any one or more sensing devices disposed within the return pad. The controller may analyze 136340 the return signal from the return signal pad. It may be recognized that the analysis 136340 may include any one or more pre-processing methods including, without limitation, noise filtering, signal extraction, baseline adjustment, or any other method that may permit the controller to identify the return signal from the patient. Based on the return signal or any suitable manipulation of the return signal, the controller may determine 136350 that an excitable tissue has been stimulated by the emitted electrode signal. When the controller has determined 136350 that an excitable tissue has been stimulated by the emitted electrode signal, the controller may determine 136360 a distance of the excitable tissue from the active electrode. The controller may then adjust 136370 an amplitude of the therapeutic signal when the distance of the excitable tissue from the active electrode is less than a threshold value. In some aspects, the threshold value may be determined by a user of the electrosurgical system. In some other aspects, the threshold value may be based on a plurality of data acquired by the electrosurgical system or a HUB system of which the electrosurgical system is a part. In some aspects, the threshold value may be based on one or more mathematical models, physiological models (such as animal models), or on data acquired during an electrosurgical procedure on the patient.

**[0325]** In some further aspects, a smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor associated with a control unit to combine a stimulating signal with a therapeutic signal. Such instructions may include, without limitation: determining the type of stimulating signal (for example, amplitude, duration, and waveform); determining the type of signal combination (for example alternating, amplitude modulation, DC offset, or other type of combination); determining the timing of the signal combination (that is, when, during a therapeutic activity, the therapeutic signal and the stimulating signals are combined, for example periodically, randomly, or at a single time); or determining types of signal transformations of the stimulating signal before being combined with the therapeutic signal.

**[0326]** In some aspects, the smart electrosurgical device may include processor readable instructions stored within a memory component that, when executed by a processor, may cause the processor within the control unit to cause an active monopolar electrode to emit a therapeutic signal,

a combined therapeutic signal and stimulating signal, or a stimulating signal upon contact with a patient's tissue. In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to combine a therapeutic signal and a stimulating signal, to form an electrode emitted signal and to transmit the emitted signal from the active electrode into a patient tissue. In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to receive one or more return signals from the patient, the return signals comprising electrical current returned from the current emitted by the active monopolar electrode and received by a return signal pad. In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to receive one or more output signals of the one or more sensing devices associated with a return pad in contact with the patient. In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to analyze the one or more output signals received from the one or more sensing devices associated with a return pad in contact with the patient.

**[0327]** In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to determine that an excitable tissue had been stimulated by the stimulating signal. In some examples, the one or more sensing devices may include an accelerometer associated with the return pad. In one non-limiting example, an output of an accelerometer may reflect to motion of a muscle in contact therewith which is activated by the stimulating signal. The amount of muscle motion may result at least in part from the amount of stimulating current received by either the muscle tissue or a nerve enervating the muscle. Because tissue may act as a resistive element to the propagation of the stimulating signal, the amount of muscle activation may indicate a distance of the active electrode from either the muscle or the enervating nerves.

**[0328]** In some aspects, the patient may rest in a supine position on the return pad, and the sensor outputs of the return pad, such as one or more accelerometers, may indicate an amount of muscle motion of a patient's back muscles in contact with the return pad. In an alternative aspect, a return pad may be placed on a muscle or muscle group proximal to the position of the surgical site wherein the electrosurgical device may be operated. In some examples, the return pad may be place on a portion of superficial abdominal muscles (such as the rectus abdominis muscles) for an abdominal surgery. In some examples, the return pad may be placed on a side portion of the abdomen to monitor stimulation of the external oblique or the anterior serratus muscles.

**[0329]** In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the

processor within the control unit to calculate or determine a distance of an excitable tissue from a distal end of the active electrode based at least in part on a return signal or one or more output signals from the one or more sensing devices associated with a return pad in contact with the patient. In some aspects, the smart electrosurgical device may include processor readable instructions within a memory component that, when executed by a processor, may cause the processor within the control unit to adjust one or more of an amplitude, a frequency, and a phase of a therapeutic signal based at least in part on a distance of an excitable tissue from the distal end of the active electrode. In some aspects, the amplitude, frequency, and/or phase of a therapeutic signal may be adjusted when the distance of an excitable tissue from the active electrode is less than a first pre-determined value. In some aspects, adjusting the amplitude, frequency, or phase of a therapeutic signal may result in the electrosurgical systems emitting no therapeutic signal when the distance of an excitable tissue from the active electrode is less than a second pre-determined value.

**[0330]** In some additional aspects, the active electrode of a surgical probe of the electrosurgical device may be applied to a tissue solely to determine a distance of excitable tissue from the active electrode. In such a use, the medical professional using the device may operate it solely in a stimulating mode, without applying therapeutic signals to the active electrode. In a stimulating mode, the user of the device may operate one or more controls configured to ramp a characteristic of the stimulating signal to determine under which conditions an excitable tissues is stimulated thereby. For example, a user may operate controls configured to ramp a voltage or current amplitude of the stimulating signal from a low value to a high value. When a signal is received from a sensor (for example, an accelerometer sensing muscle movement), the electrosurgical device may then calculate an approximate distance from the active electrode to the excitable tissue based at least in part on the amplitude of the stimulating signal. In another example, a user may operate controls configured to ramp a frequency of the stimulating signal from a low value to a high value. When a signal is received from a sensor (for example, an accelerometer sensing muscle movement), the electrosurgical device may then calculate an approximate distance from the active electrode to the excitable tissue based at least in part on the frequency of the stimulating signal.

**[0331]** In some aspects, an electrosurgical device or a smart electrosurgical device may be incorporated into a surgical HUB system. The HUB system may incorporate a number of hand-held medical devices, robotic medical devices, image acquisition devices, image display devices, communication devices, processing devices, networking devices, and other electronic devices that may operate in a concerted and coordinated fashion. In some aspects, the HUB may include such devices located within a single surgical suite, located within a plurality of surgical suites, or located within any number of computer server locations. The computer memory modules, instructions, and processors disclosed above in the context of the control of a smart, stand-alone electrosurgical device may be distributed among any of the components of the surgical HUB system as may be appropriate.

**[0332]** In some aspects, additional information that may be acquired by the components of the surgical HUB system may be used to improve the operation of a smart electrosurgical device. For example, cameras and imaging systems directed at a surgical site may provide imaging information that can be used to determine the location of the distal end of the active electrode with respect to tissue in the surgical site. The image-based location of the distal end of the active electrode may be used with the return pad sensor output to refine the distance between the active electrode and any excitable tissue in the patient. In some alternative examples, the HUB system may include data comprising anatomical models related to the location of nerve and muscle tissue. Such model information may also be used along with the image-based localization of the active electrode and the return pad sensor output to better determine the proximity of the active electrode to known excitable tissue.

**[0333]** Although the functions and devices disclosed above may be related solely to an electrosurgical device, it may be recognized that such functions and deices may also be incorporated into multi-mode surgical devices that include functions associated with an electrosurgical device. For example, a multi-mode surgical device may incorporate features associated with an electrosurgical device along with features associated with an ultrasonic surgical device. In addition to the functions disclosed above regarding altering the properties of an electrosurgical therapeutic signal, a multi-mode device may include other functions. For example, a surgical device may use either RF energy or ultrasound for a therapeutic effect, for example cutting a tissue. In such a multi-mode device, RF energy may be initially applied to a tissue for purposes of cutting material, but the multi-mode device may be configured to switch to an ultrasound mode if the end effector of the multi-mode device is determined to be too close to excitable tissue.

Situational Awareness

**[0334]** Referring now to FIG. 38, a timeline 5200 depicting situational awareness of a hub, such as the surgical hub 106 or 206, for example, is depicted. The timeline 5200 is an illustrative surgical procedure and the contextual information that the surgical hub 106, 206 can derive from the data received from the data sources at each step in the surgical procedure. The timeline 5200 depicts the typical steps that would be taken by the nurses, surgeons, and other medical personnel during the course of a lung segmentectomy procedure, beginning with setting up the operating theater and ending with transferring the patient to a post-operative recovery room.

**[0335]** The situationally aware surgical hub 106, 206 receives data from the data sources throughout the course of the surgical procedure, including data generated each time medical personnel utilize a modular device that is paired with the surgical hub 106, 206. The surgical hub 106, 206 can receive this data from the paired modular devices and other data sources and continually derive inferences (i.e., contextual information) about the ongoing procedure as new data is received, such as which step of the procedure is being performed at any given time. The situational awareness system of the surgical hub 106, 206 is able to, for example, record data

pertaining to the procedure for generating reports, verify the steps being taken by the medical personnel, provide data or prompts (e.g., via a display screen) that may be pertinent for the particular procedural step, adjust modular devices based on the context (e.g., activate monitors, adjust the field of view (FOV) of the medical imaging device, or change the energy level of an ultrasonic surgical instrument or RF electrosurgical instrument), and take any other such action described above.

**[0336]** As the first step 5202 in this illustrative procedure, the hospital staff members retrieve the patient's EMR from the hospital's EMR database. Based on select patient data in the EMR, the surgical hub 106, 206 determines that the procedure to be performed is a thoracic procedure.

**[0337]** Second step 5204, the staff members scan the incoming medical supplies for the procedure. The surgical hub 106, 206 cross-references the scanned supplies with a list of supplies that are utilized in various types of procedures and confirms that the mix of supplies corresponds to a thoracic procedure. Further, the surgical hub 106, 206 is also able to determine that the procedure is not a wedge procedure (because the incoming supplies either lack certain supplies that are necessary for a thoracic wedge procedure or do not otherwise correspond to a thoracic wedge procedure).

**[0338]** Third step 5206, the medical personnel scan the patient band via a scanner that is communicably connected to the surgical hub 106, 206. The surgical hub 106, 206 can then confirm the patient's identity based on the scanned data.

**[0339]** Fourth step 5208, the medical staff turns on the auxiliary equipment. The auxiliary equipment being utilized can vary according to the type of surgical procedure and the techniques to be used by the surgeon, but in this illustrative case they include a smoke evacuator, insufflator, and medical imaging device. When activated, the auxiliary equipment that are modular devices can automatically pair with the surgical hub 106, 206 that is located within a particular vicinity of the modular devices as part of their initialization process. The surgical hub 106, 206 can then derive contextual information about the surgical procedure by detecting the types of modular devices that pair with it during this pre-operative or initialization phase. In this particular example, the surgical hub 106, 206 determines that the surgical procedure is a VATS procedure based on this particular combination of paired modular devices. Based on the combination of the data from the patient's EMR, the list of medical supplies to be used in the procedure, and the type of modular devices that connect to the hub, the surgical hub 106, 206 can generally infer the specific procedure that the surgical team will be performing. Once the surgical hub 106, 206 knows what specific procedure is being performed, the surgical hub 106, 206 can then retrieve the steps of that procedure from a memory or from the cloud and then cross-reference the data it subsequently receives from the connected data sources (e.g., modular devices and patient monitoring devices) to infer what step of the surgical procedure the surgical team is performing.

**[0340]** Fifth step 5210, the staff members attach the EKG electrodes and other patient monitoring devices to the patient. The EKG electrodes and other patient monitoring devices are able to pair

with the surgical hub 106, 206. As the surgical hub 106, 206 begins receiving data from the patient monitoring devices, the surgical hub 106, 206 thus confirms that the patient is in the operating theater.

**[0341]** Sixth step 5212, the medical personnel induce anesthesia in the patient. The surgical hub 106, 206 can infer that the patient is under anesthesia based on data from the modular devices and/or patient monitoring devices, including EKG data, blood pressure data, ventilator data, or combinations thereof, for example. Upon completion of the sixth step 5212, the pre-operative portion of the lung segmentectomy procedure is completed and the operative portion begins.

**[0342]** Seventh step 5214, the patient's lung that is being operated on is collapsed (while ventilation is switched to the contralateral lung). The surgical hub 106, 206 can infer from the ventilator data that the patient's lung has been collapsed, for example. The surgical hub 106, 206 can infer that the operative portion of the procedure has commenced as it can compare the detection of the patient's lung collapsing to the expected steps of the procedure (which can be accessed or retrieved previously) and thereby determine that collapsing the lung is the first operative step in this particular procedure.

**[0343]** Eighth step 5216, the medical imaging device (e.g., a scope) is inserted and video from the medical imaging device is initiated. The surgical hub 106, 206 receives the medical imaging device data (i.e., video or image data) through its connection to the medical imaging device. Upon receipt of the medical imaging device data, the surgical hub 106, 206 can determine that the laparoscopic portion of the surgical procedure has commenced. Further, the surgical hub 106, 206 can determine that the particular procedure being performed is a segmentectomy, as opposed to a lobectomy (note that a wedge procedure has already been discounted by the surgical hub 106, 206 based on data received at the second step 5204 of the procedure). The data from the medical imaging device 124 (FIG. 2) can be utilized to determine contextual information regarding the type of procedure being performed in a number of different ways, including by determining the angle at which the medical imaging device is oriented with respect to the visualization of the patient's anatomy, monitoring the number or medical imaging devices being utilized (i.e., that are activated and paired with the surgical hub 106, 206), and monitoring the types of visualization devices utilized. For example, one technique for performing a VATS lobectomy places the camera in the lower anterior corner of the patient's chest cavity above the diaphragm, whereas one technique for performing a VATS segmentectomy places the camera in an anterior intercostal position relative to the segmental fissure. Using pattern recognition or machine learning techniques, for example, the situational awareness system can be trained to recognize the positioning of the medical imaging device according to the visualization of the patient's anatomy. As another example, one technique for performing a VATS lobectomy utilizes a single medical imaging device, whereas another technique for performing a VATS segmentectomy utilizes multiple cameras. As yet another example, one technique for performing a VATS segmentectomy utilizes an infrared light source (which can be communicably coupled to the surgical hub as part of the visualization system) to visualize the

segmental fissure, which is not utilized in a VATS lobectomy. By tracking any or all of this data from the medical imaging device, the surgical hub 106, 206 can thereby determine the specific type of surgical procedure being performed and/or the technique being used for a particular type of surgical procedure.

**[0344]** Ninth step 5218, the surgical team begins the dissection step of the procedure. The surgical hub 106, 206 can infer that the surgeon is in the process of dissecting to mobilize the patient's lung because it receives data from the RF or ultrasonic generator indicating that an energy instrument is being fired. The surgical hub 106, 206 can cross-reference the received data with the retrieved steps of the surgical procedure to determine that an energy instrument being fired at this point in the process (i.e., after the completion of the previously discussed steps of the procedure) corresponds to the dissection step. In certain instances, the energy instrument can be an energy tool mounted to a robotic arm of a robotic surgical system.

**[0345]** Tenth step 5220, the surgical team proceeds to the ligation step of the procedure. The surgical hub 106, 206 can infer that the surgeon is ligating arteries and veins because it receives data from the surgical stapling and cutting instrument indicating that the instrument is being fired. Similarly to the prior step, the surgical hub 106, 206 can derive this inference by cross-referencing the receipt of data from the surgical stapling and cutting instrument with the retrieved steps in the process. In certain instances, the surgical instrument can be a surgical tool mounted to a robotic arm of a robotic surgical system.

**[0346]** Eleventh step 5222, the segmentectomy portion of the procedure is performed. The surgical hub 106, 206 can infer that the surgeon is transecting the parenchyma based on data from the surgical stapling and cutting instrument, including data from its cartridge. The cartridge data can correspond to the size or type of staple being fired by the instrument, for example. As different types of staples are utilized for different types of tissues, the cartridge data can thus indicate the type of tissue being stapled and/or transected. In this case, the type of staple being fired is utilized for parenchyma (or other similar tissue types), which allows the surgical hub 106, 206 to infer that the segmentectomy portion of the procedure is being performed.

**[0347]** Twelfth step 5224, the node dissection step is then performed. The surgical hub 106, 206 can infer that the surgical team is dissecting the node and performing a leak test based on data received from the generator indicating that an RF or ultrasonic instrument is being fired. For this particular procedure, an RF or ultrasonic instrument being utilized after parenchyma was transected corresponds to the node dissection step, which allows the surgical hub 106, 206 to make this inference. It should be noted that surgeons regularly switch back and forth between surgical stapling/cutting instruments and surgical energy (i.e., RF or ultrasonic) instruments depending upon the particular step in the procedure because different instruments are better adapted for particular tasks. Therefore, the particular sequence in which the stapling/cutting instruments and surgical energy instruments are used can indicate what step of the procedure the surgeon is performing. Moreover, in certain instances, robotic tools can be utilized for one or more steps in a surgical

procedure and/or handheld surgical instruments can be utilized for one or more steps in the surgical procedure. The surgeon(s) can alternate between robotic tools and handheld surgical instruments and/or can use the devices concurrently, for example. Upon completion of the twelfth step 5224, the incisions are closed up and the post-operative portion of the procedure begins.

**[0348]** Thirteenth step 5226, the patient's anesthesia is reversed. The surgical hub 106, 206 can infer that the patient is emerging from the anesthesia based on the ventilator data (i.e., the patient's breathing rate begins increasing), for example.

**[0349]** Lastly, the fourteenth step 5228 is that the medical personnel remove the various patient monitoring devices from the patient. The surgical hub 106, 206 can thus infer that the patient is being transferred to a recovery room when the hub loses EKG, BP, and other data from the patient monitoring devices. As can be seen from the description of this illustrative procedure, the surgical hub 106, 206 can determine or infer when each step of a given surgical procedure is taking place according to data received from the various data sources that are communicably coupled to the surgical hub 106, 206.

**[0350]** Situational awareness is further described in U.S. Provisional Patent Application Serial No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed December 28, 2017, which is herein incorporated by reference in its entirety. In certain instances, operation of a robotic surgical system, including the various robotic surgical systems disclosed herein, for example, can be controlled by the hub 106, 206 based on its situational awareness and/or feedback from the components thereof and/or based on information from the cloud 102.

**[0351]** While several forms have been illustrated and described, it is not the intention of the applicant to restrict or limit the scope of the appended claims to such detail. Numerous modifications, variations, changes, substitutions, combinations, and equivalents to those forms may be implemented and will occur to those skilled in the art without departing from the scope of the present disclosure. Moreover, the structure of each element associated with the described forms can be alternatively described as a means for providing the function performed by the element. 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, combinations, and variations as falling within the scope of the disclosed forms. The appended claims are intended to cover all such modifications, variations, changes, substitutions, modifications, and equivalents.

**[0352]** 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, and/or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. 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 one or more program products 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.

**[0353]** Instructions used to program logic to perform various disclosed aspects can be stored within a memory in the system, such as dynamic random access memory (DRAM), cache, flash memory, or other storage. Furthermore, the instructions can be distributed via a network or by way of other computer readable media. Thus a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer), but is not limited to, floppy diskettes, optical disks, compact disc, read-only memory (CD-ROMs), and magneto-optical disks, read-only memory (ROMs), random access memory (RAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic or optical cards, flash memory, or a tangible, machine-readable storage used in the transmission of information over the Internet via electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.). Accordingly, the non-transitory computer-readable medium includes any type of tangible machine-readable medium suitable for storing or transmitting electronic instructions or information in a form readable by a machine (e.g., a computer).

**[0354]** As used in any aspect herein, the term “control circuit” may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor comprising one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, digital signal processor (DSP), programmable logic device (PLD), programmable logic array (PLA), or field programmable gate array (FPGA)), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof. The control circuit may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit (IC), an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, as used herein “control circuit” 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.

**[0355]** As used in any aspect herein, the term "logic" may refer to an app, software, firmware and/or circuitry configured to perform any of the aforementioned operations. Software may be embodied as a software package, code, instructions, instruction sets and/or data recorded on non-transitory computer readable storage medium. Firmware may be embodied as code, instructions or instruction sets and/or data that are hard-coded (e.g., nonvolatile) in memory devices.

**[0356]** As used in any aspect herein, the terms "component," "system," "module" and the like can refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution.

**[0357]** As used in any aspect herein, an "algorithm" refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities and/or logic states 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 and/or states.

**[0358]** A network may include a packet switched network. The communication devices may be capable of communicating with each other using a selected packet switched network communications protocol. One example communications protocol may include an Ethernet communications protocol which may be capable permitting communication using a Transmission Control Protocol/Internet Protocol (TCP/IP). The Ethernet protocol may comply or be compatible with the Ethernet standard published by the Institute of Electrical and Electronics Engineers (IEEE) titled "IEEE 802.3 Standard", published in December, 2008 and/or later versions of this standard. Alternatively or additionally, the communication devices may be capable of communicating with each other using an X.25 communications protocol. The X.25 communications protocol may comply or be compatible with a standard promulgated by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). Alternatively or additionally, the communication devices may be capable of communicating with each other using a frame relay communications protocol. The frame relay communications protocol may comply or be compatible with a standard promulgated by Consultative Committee for International Telegraph and Telephone (CCITT) and/or the American National Standards Institute (ANSI). Alternatively or additionally, the transceivers may be capable of communicating with each other using an Asynchronous Transfer Mode (ATM) communications protocol. The ATM communications protocol may comply or be compatible with an

ATM standard published by the ATM Forum titled "ATM-MPLS Network Interworking 2.0" published August 2001, and/or later versions of this standard. Of course, different and/or after-developed connection-oriented network communication protocols are equally contemplated herein.

**[0359]** Unless specifically stated otherwise as apparent from the foregoing disclosure, it is appreciated that, throughout the foregoing disclosure, discussions using terms such as "processing," "computing," "calculating," "determining," "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.

**[0360]** 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.

**[0361]** The terms "proximal" and "distal" are used herein with reference to a clinician manipulating the handle portion of the surgical instrument. The term "proximal" refers to the portion closest to the clinician and the term "distal" refers to the portion located away from the clinician. It will be further appreciated that, for convenience and clarity, spatial terms such as "vertical", "horizontal", "up", and "down" may be used herein with respect to the drawings. However, surgical instruments are used in many orientations and positions, and these terms are not intended to be limiting and/or absolute.

**[0362]** Those skilled in the art will recognize 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.

**[0363]** 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."

**[0364]** 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 flow diagrams 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.

**[0365]** It is worthy to note that any reference to "one aspect," "an aspect," "an exemplification," "one exemplification," and the like 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 an exemplification," and "in one exemplification" 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.

**[0366]** Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials is 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.

**[0367]** 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.

**[0368]** Various aspects of the subject matter described herein are set out in the following numbered examples.

**[0369]** Example 1. An electrosurgical device, comprising: a controller comprising an electrical generator; a surgical probe comprising a distal active electrode, wherein the active electrode is in electrical communication with an electrical source terminal of the electrical generator; and a return pad in electrical communication with an electrical return terminal of the electrical generator, wherein the electrical generator is configured to source an electrical current from the electrical source terminal, and wherein the electrical current sourced by the electrical generator combines characteristics of a therapeutic electrical signal and characteristics of an excitable tissue stimulating signal.

**[0370]** Example 2. The electrosurgical device of Example 1, wherein the therapeutic electrical signal is a radiofrequency signal having a frequency greater than 200kHz and less than 5MHz.

**[0371]** Example 3.The electrosurgical device of any one or more of Examples 1 through 2, wherein the excitable tissue stimulating signal is an AC signal having a frequency less than 200 kHz.

**[0372]** Example 4. The electrosurgical device of any one or more of Examples 1 through 3, wherein the electrical current sourced by the electrical generator comprises at least one alternating therapeutic electrical signal and at least one alternating excitable tissue stimulating signal.

**[0373]** Example 5. The electrosurgical device of any one or more of Examples 1 through 4, wherein the electrical current sourced by the electrical generator comprises a therapeutic electrical signal amplitude modulated by the excitable tissue stimulating signal.

**[0374]** Example 6. The electrosurgical device of any one or more of Examples 1 through 5, wherein the electrical current sourced by the electrical generator comprises a therapeutic electrical signal DC offset by the excitable tissue stimulating signal.

**[0375]** Example 7. The electrosurgical device of any one or more of Examples 1 through 6, wherein the return pad further comprises at least one sensing device having a sensing device

output, and the sensing device is configured to determine a stimulation of an excitable tissue by the excitable tissue stimulating signal.

**[0376]** Example 8. The electrosurgical device of Example 7, wherein the controller is configured to receive the sensing device output.

**[0377]** Example 9. The electrosurgical device of Example 8, wherein the controller comprises a processor and at least one memory component in data communication with the processor, and wherein the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to determine a distance of the active electrode from an excitable tissue based at least in part on the sensor output received by the controller.

**[0378]** Example 10. The electrosurgical device of Example 9, wherein the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to alter a value of at least one characteristic of the therapeutic electrical signal when the distance of the active electrode from an excitable tissue is less than a predetermined value.

**[0379]** Example 11. An electrosurgical system comprising: a processor; and a memory coupled to the processor, the memory configured to store instructions executable by the processor to: cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal; cause the electrical generator to transmit the combination signal into a tissue of a patient through an active electrode in physical contact with the patient; and receive a sensing device output signal from a sensing device disposed within a return pad in physical contact with the patient.

**[0380]** Example 12. The electrosurgical system of Example 11, wherein the memory is configured to further store instructions executable by the processor to: determine, based at least in part on the sensing device output signal, a distance from the active electrode to an excitable tissue.

**[0381]** Example 13. The electrosurgical system of Example 12, wherein the memory is configured to further store instructions executable by the processor to: cause the controller to alter one or more characteristics of the therapeutic signal when the distance from the active electrode to the excitable tissue is less than a predetermined value.

**[0382]** Example 14. The electrosurgical system of any one or more of Examples 11-13, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor to cause the electrical generator to alternate the therapeutic signal and the excitable tissue stimulating signal.

**[0383]** Example 15. The electrosurgical system of any one or more of Examples 11-14, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor

to cause the electrical generator to modulate an amplitude of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

**[0384]** Example 16. The electrosurgical system of any one or more of Examples 11-15, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor to cause the electrical generator to offset a DC value of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

**[0385]** Example 17. An electrosurgical system comprising: a control circuit configured to: control an electrical output of an electrical generator, in which the electrical output comprises one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal; receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient; determine a distance between a location of an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device; and alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

**[0386]** Example 18. The electrosurgical system of Example 17, wherein the control circuit configured to alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value comprises a control circuit configured to minimize the at least one characteristic of the therapeutic signal.

**[0387]** Example 19. A non-transitory computer readable medium storing computer readable instructions which, when executed, causes a machine to: control an electrical output of an electrical generator, in which the electrical output comprises one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal; receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient; determine a distance between a location of an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device; and alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

CLAIMS

1. An electrosurgical device, comprising:

a controller comprising an electrical generator;

a surgical probe comprising a distal active electrode, wherein the active electrode is in electrical communication with an electrical source terminal of the electrical generator; and

a return pad in electrical communication with an electrical return terminal of the electrical generator,

wherein the electrical generator is configured to source an electrical current from the electrical source terminal, and

wherein the electrical current sourced by the electrical generator combines characteristics of a therapeutic electrical signal and characteristics of an excitable tissue stimulating signal.

2. The electrosurgical device of claim 1, wherein the therapeutic electrical signal is a radiofrequency signal having a frequency greater than 200kHz and less than 5MHz.

3. The electrosurgical device of claim 1, wherein the excitable tissue stimulating signal is an AC signal having a frequency less than 200 kHz.

4. The electrosurgical device of claim 1, wherein the electrical current sourced by the electrical generator comprises at least one alternating therapeutic electrical signal and at least one alternating excitable tissue stimulating signal.

5. The electrosurgical device of claim 1, wherein the electrical current sourced by the electrical generator comprises a therapeutic electrical signal amplitude modulated by the excitable tissue stimulating signal.

6. The electrosurgical device of claim 1, wherein the electrical current sourced by the electrical generator comprises a therapeutic electrical signal DC offset by the excitable tissue stimulating signal.

7. The electrosurgical device of claim 1, wherein the return pad further comprises at least one sensing device having a sensing device output, and the sensing device is configured to determine a stimulation of an excitable tissue by the excitable tissue stimulating signal.

8. The electrosurgical device of claim 7, wherein the controller is configured to receive the sensing device output.

9. The electrosurgical device of claim 8, wherein the controller comprises a processor and at least one memory component in data communication with the processor, and wherein the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to determine a distance of the active electrode from an excitable tissue based at least in part on the sensor output received by the controller.

10. The electrosurgical device of claim 9, wherein the at least one memory component stores one or more instructions that, when executed by the processor, cause the processor to alter a value of at least one characteristic of the therapeutic electrical signal when the distance of the active electrode from an excitable tissue is less than a predetermined value.

11. An electrosurgical system comprising:

a processor; and

a memory coupled to the processor, the memory configured to store instructions executable by the processor to:

cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal;

cause the electrical generator to transmit the combination signal into a tissue of a patient through an active electrode in physical contact with the patient; and

receive a sensing device output signal from a sensing device disposed within a return pad in physical contact with the patient.

12. The electrosurgical system of claim 11, wherein the memory is configured to further store instructions executable by the processor to:

determine, based at least in part on the sensing device output signal, a distance from the active electrode to an excitable tissue.

13. The electrosurgical system of claim 12, wherein the memory is configured to further store instructions executable by the processor to:

cause the controller to alter one or more characteristics of the therapeutic signal when the distance from the active electrode to the excitable tissue is less than a predetermined value.

14. The electrosurgical system of claim 11, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor to cause the electrical generator to alternate the therapeutic signal and the excitable tissue stimulating signal.

15. The electrosurgical system of claim 11, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor to cause the electrical generator to modulate an amplitude of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

16. The electrosurgical system of claim 11, wherein the instructions executable by the processor to cause an electrical generator to combine one or more characteristics of a therapeutic signal with one or more characteristics of an excitable tissue stimulating signal to form a combination signal comprises instructions executable by the processor to cause the electrical generator to offset a DC value of the therapeutic signal by an amplitude of the excitable tissue stimulating signal.

17. An electrosurgical system comprising:

a control circuit configured to:

control an electrical output of an electrical generator, in which the electrical output comprises one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal;

receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient;

determine a distance between a location of an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device; and

alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

18. The electrosurgical system of claim 17, wherein the control circuit configured to alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value comprises a control circuit configured to minimize the at least one characteristic of the therapeutic signal.

19. A non-transitory computer readable medium storing computer readable instructions which, when executed, causes a machine to:

control an electrical output of an electrical generator, in which the electrical output comprises one or more characteristics of a therapeutic signal and one or more characteristics of an excitable tissue stimulating signal;

receive a sensing device signal from at least one sensing device configured to measure an activity of an excitable tissue of a patient;

determine a distance between a location of an active electrode configured to transmit the electrical output of the electrical generator into a patient tissue and a location of the at least one sensing device; and

alter the electrical output of the electrical generator in at least one characteristic of the therapeutic signal when the distance between the location of the active electrode configured to transmit the electrical output of the electrical generator into the patient tissue and the location of the at least one sensing device is less than a pre-determined value.

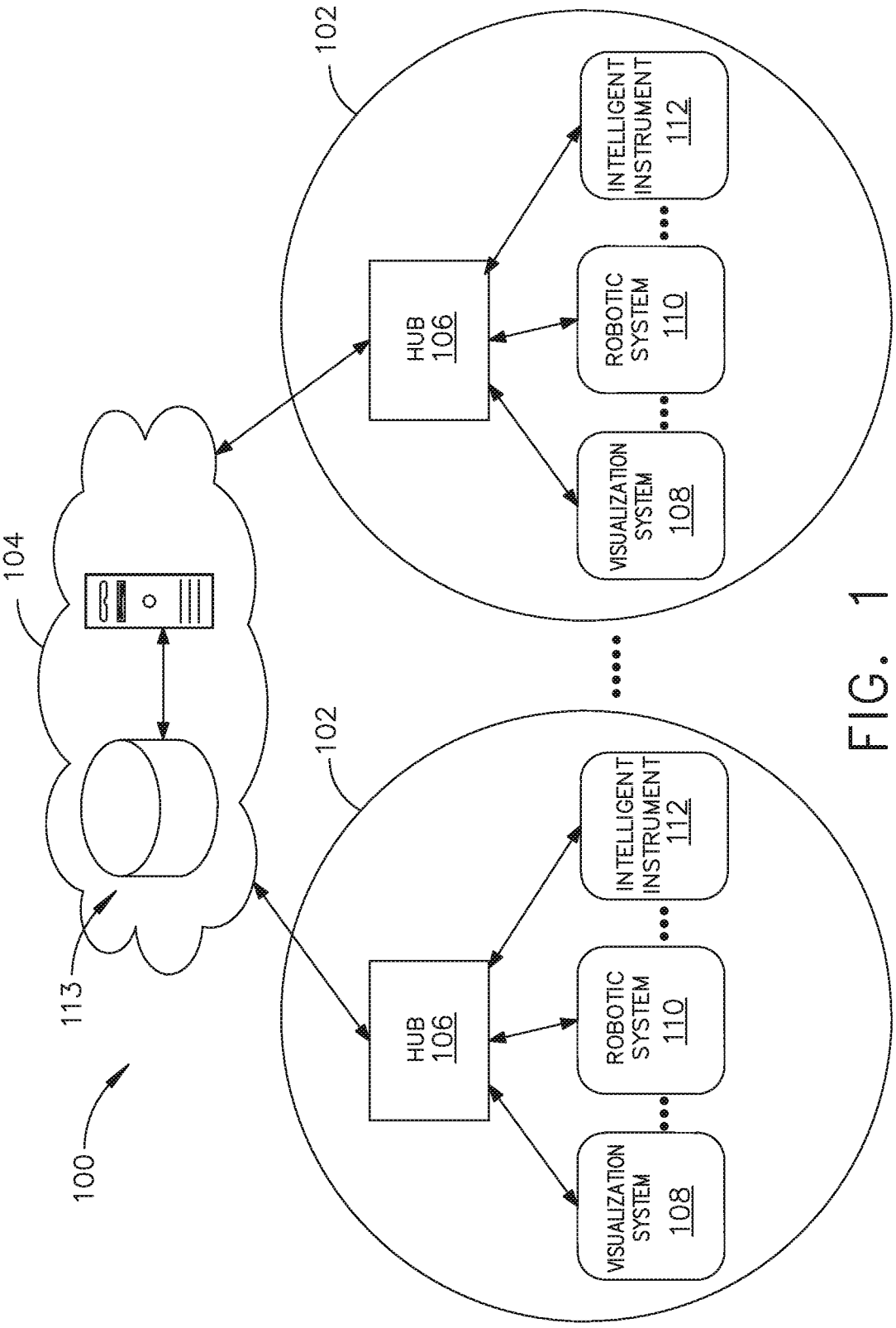
100
113
104
102
HUB 106
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
VISUALIZATION SYSTEM 108
102
HUB 106
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
VISUALIZATION SYSTEM 108

FIG. 1

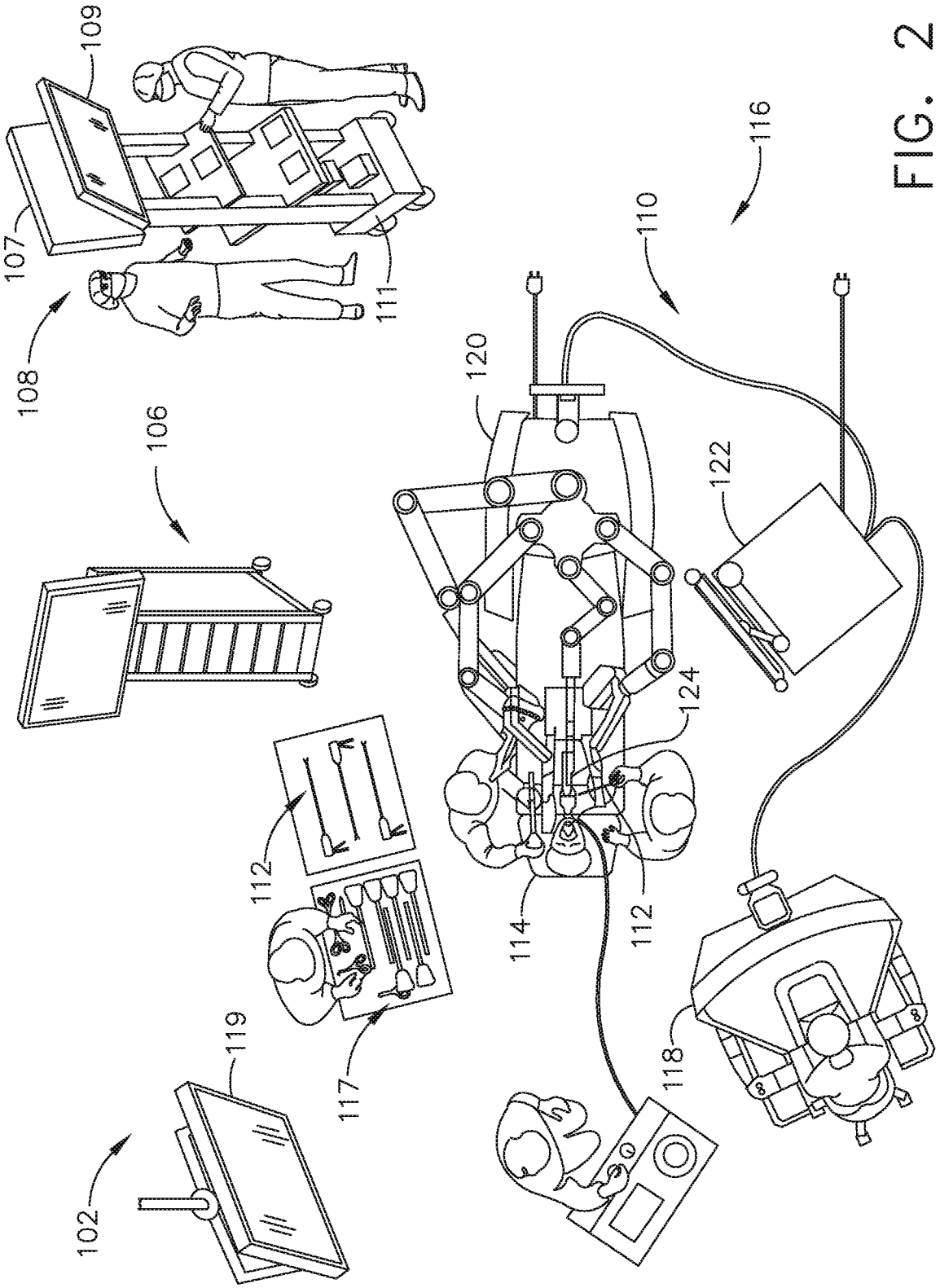
109
107
108
111
106
116
110
120
122
124
112
114
112
119
117
118
102

FIG. 2

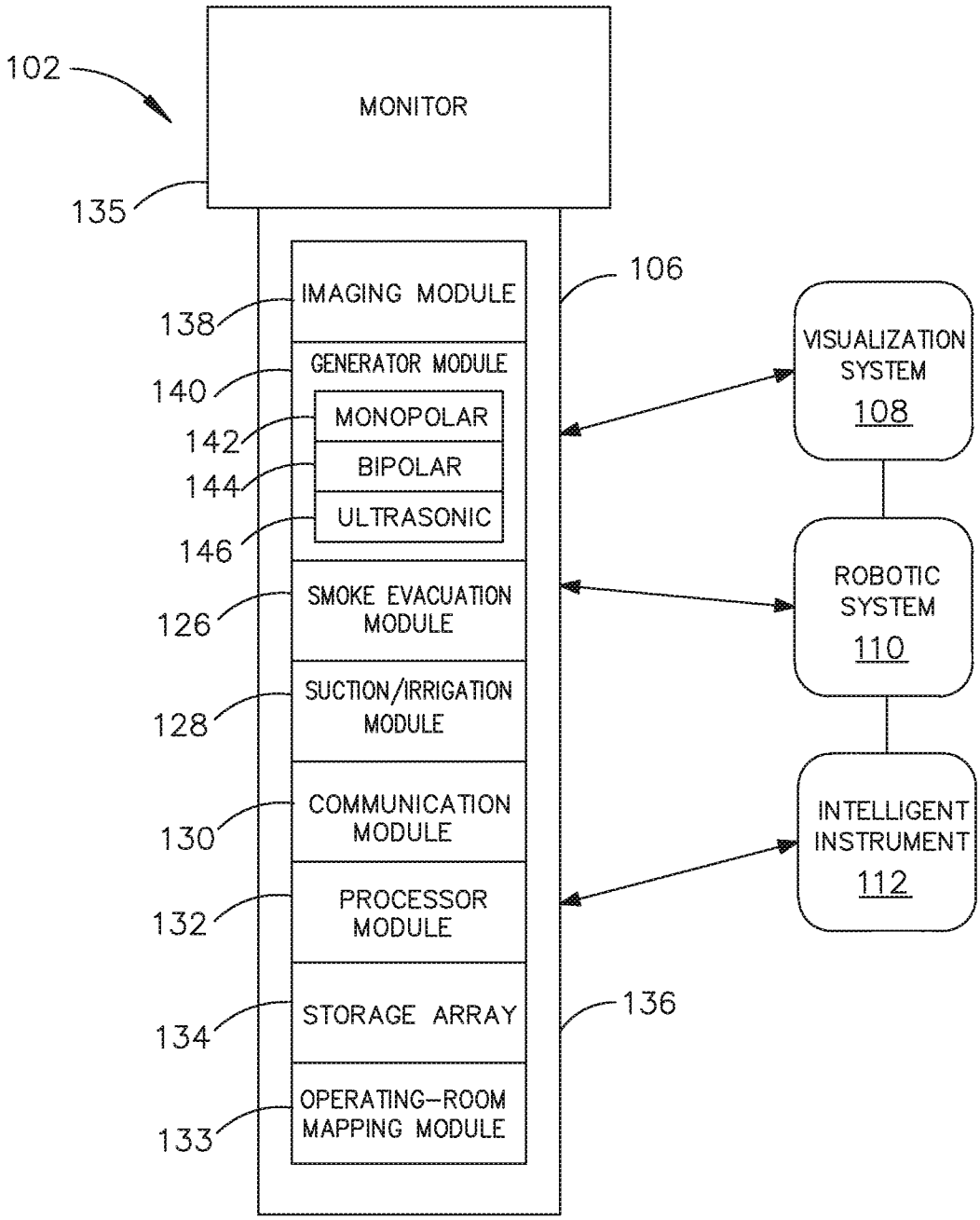
102
MONITOR
135
IMAGING MODULE
138
GENERATOR MODULE
140
MONOPOLAR
142
BIPOLAR
144
ULTRASONIC
146
SMOKE EVACUATION MODULE
126
SUCTION/IRRIGATION MODULE
128
COMMUNICATION MODULE
130
PROCESSOR MODULE
132
STORAGE ARRAY
134
OPERATING-ROOM MAPPING MODULE
133
106
136
VISUALIZATION SYSTEM
108
ROBOTIC SYSTEM
110
INTELLIGENT INSTRUMENT
112

FIG. 3

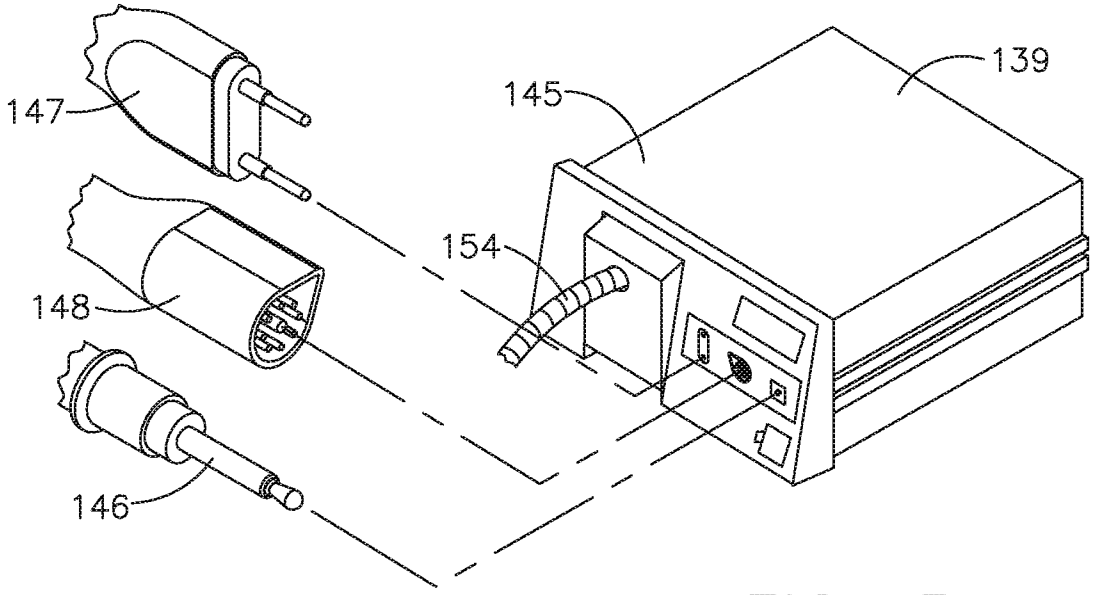
147
148
146
145
154
139

FIG. 5

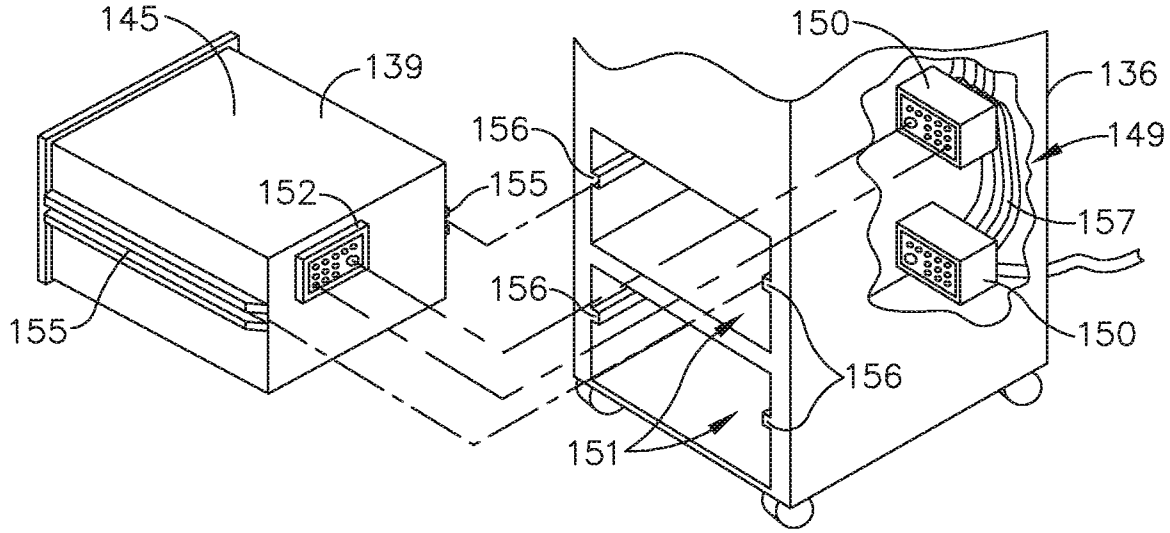
145
139
152
155
155
156
156
156
151
150
136
149
157
150

FIG. 4

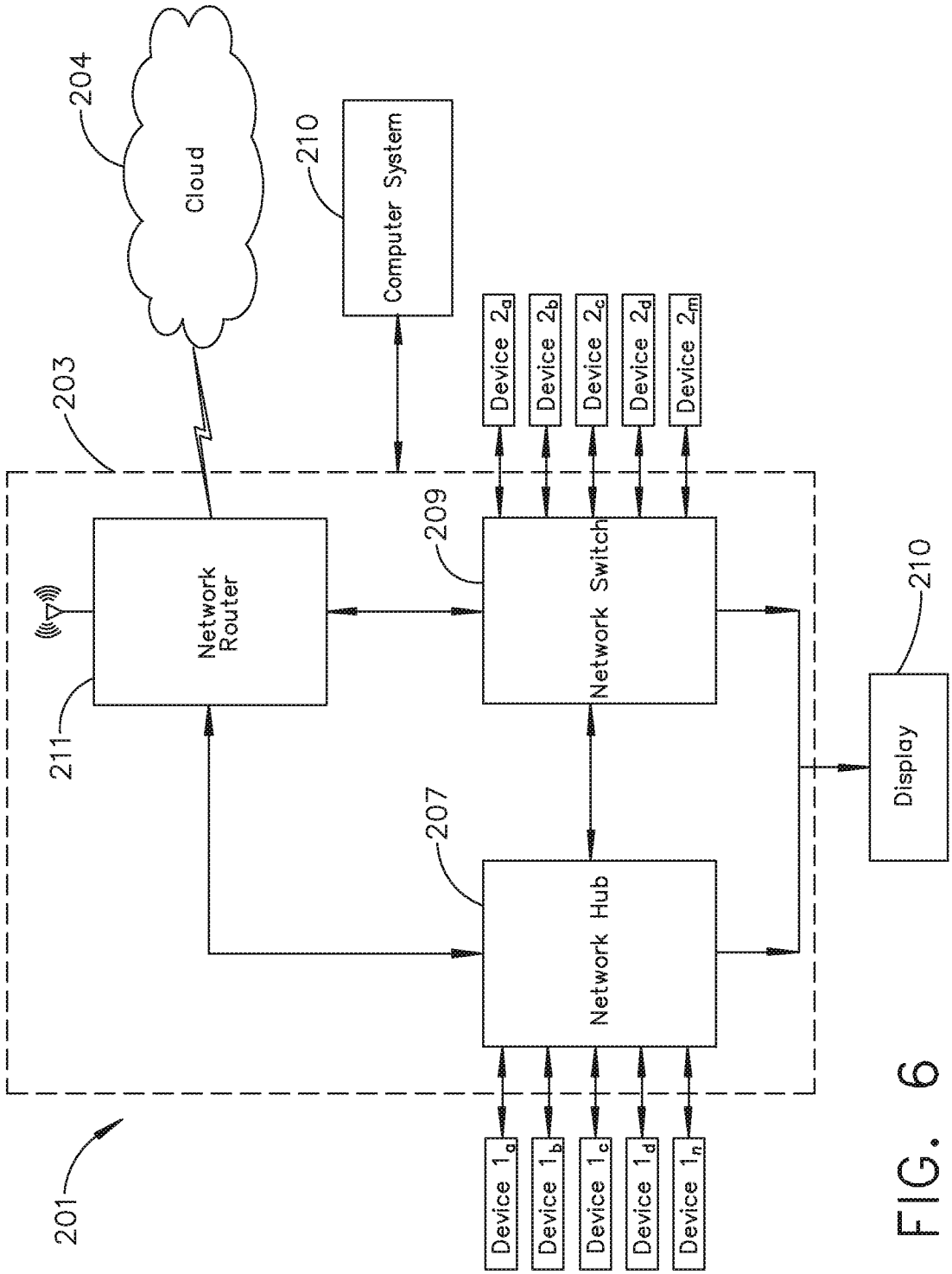
204
Cloud
210
Computer System
Device 2a
Device 2b
Device 2c
Device 2d
Device 2m
203
209
Network Router
Network Switch
211
210
Display
207
Network Hub
201
Device 1a
Device 1b
Device 1c
Device 1d
Device 1n

FIG. 6

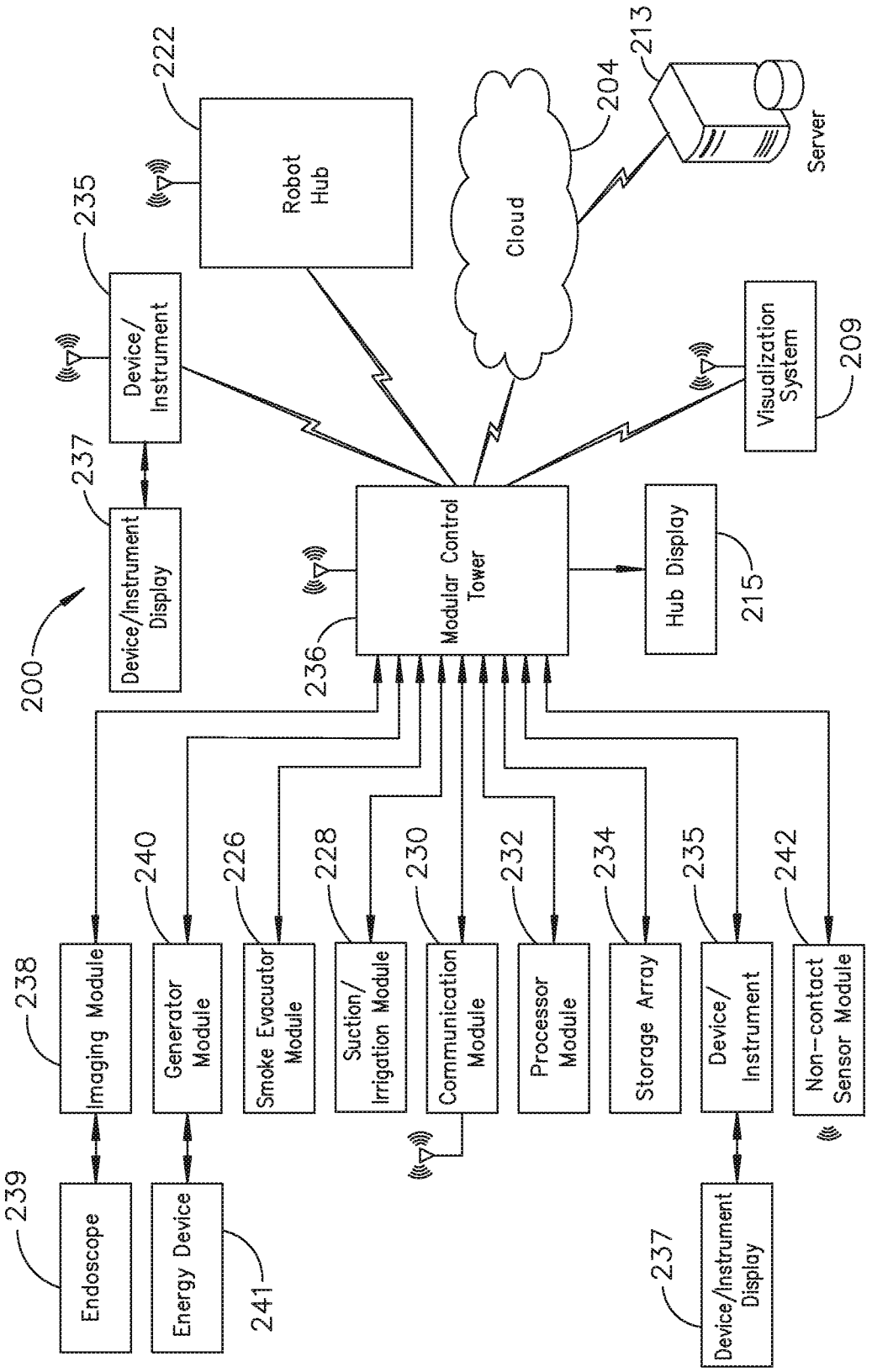
200
Device/Instrument Display
237
Device/ Instrument
235
Robot Hub
222
Cloud
204
Server
213
Visualization System
209
Modular Control Tower
236
Hub Display
215
Imaging Module
238
Generator Module
240
Smoke Evacuator Module
226
Suction/ Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/ Instrument
235
Non-contact Sensor Module
242
Endoscope
239
Energy Device
241
Device/Instrument Display
237

FIG. 7

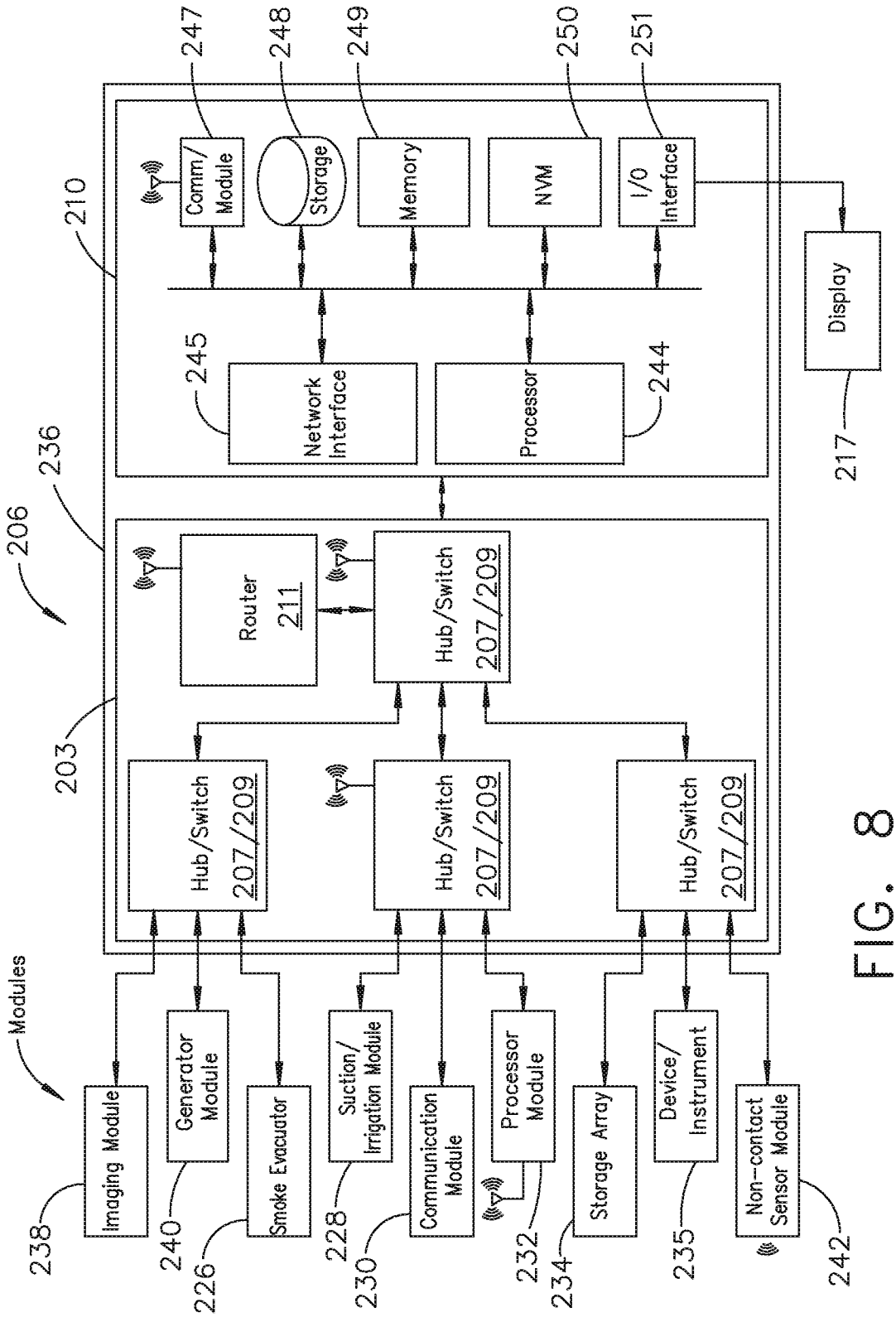
247
248
249
250
251
210
Comm/ Module
Storage
Memory
NVM
I/O Interface
Display
217
245
Network Interface
Processor
244
236
206
Router 211
Hub/Switch 207/209
203
Hub/Switch 207/209
Hub/Switch 207/209
Hub/Switch 207/209
Modules
Imaging Module
Generator Module
Smoke Evacuator
Suction/ Irrigation Module
Communication Module
Processor Module
Storage Array
Device/ Instrument
Non-contact Sensor Module
238
240
226
228
230
232
234
235
242

FIG. 8

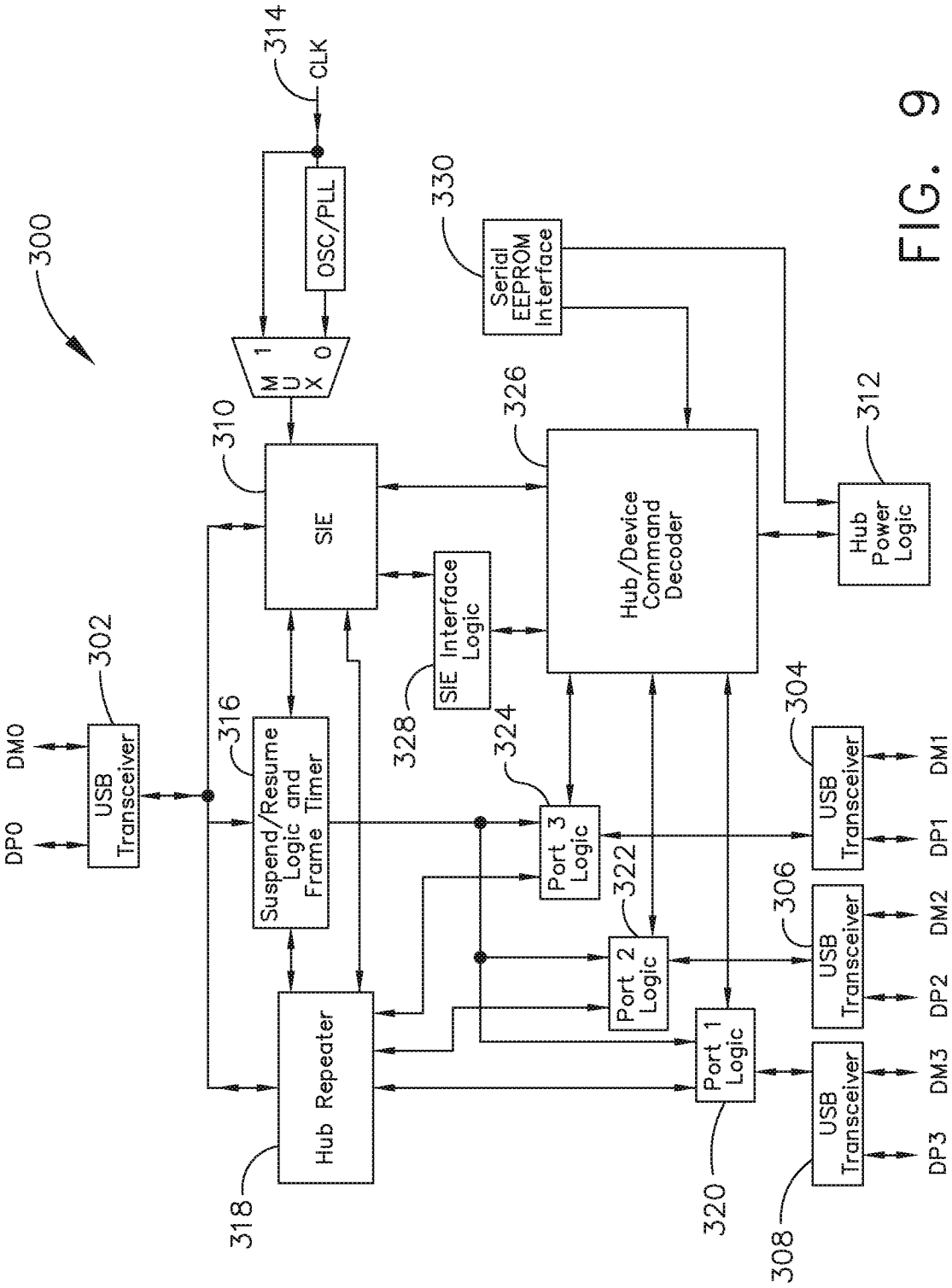
300
314
CLK
OSC/PLL
330
Serial EEPROM Interface
M U X
1
0
310
SIE
326
Hub/Device Command Decoder
312
Hub Power Logic
SIE Interface Logic
328
302
USB Transceiver
DP0
DM0
316
Suspend/Resume Logic and Frame Timer
324
Port 3 Logic
304
USB Transceiver
DP1
DM1
322
Port 2 Logic
306
USB Transceiver
DP2
DM2
Port 1 Logic
320
USB Transceiver
DP3
DM3
308
Hub Repeater
318

FIG. 9

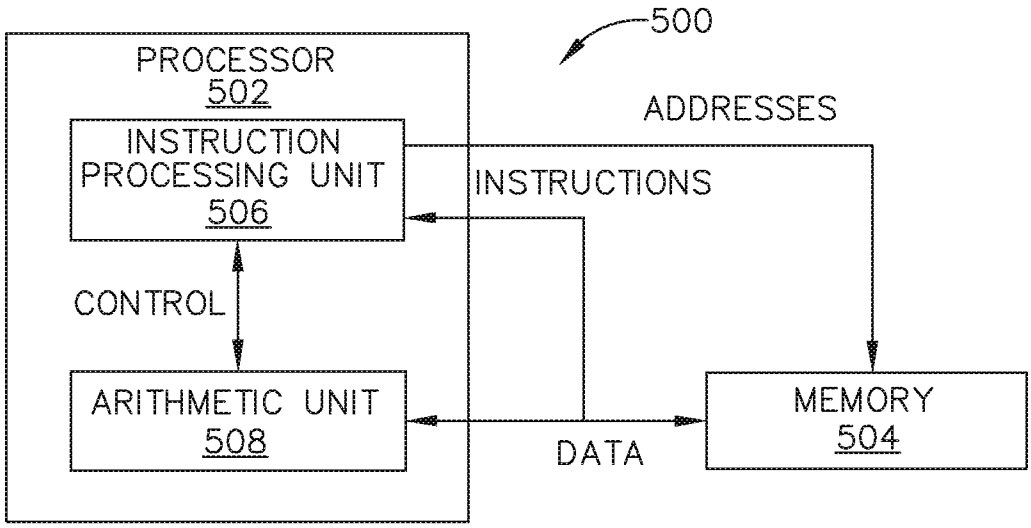


FIG. 10

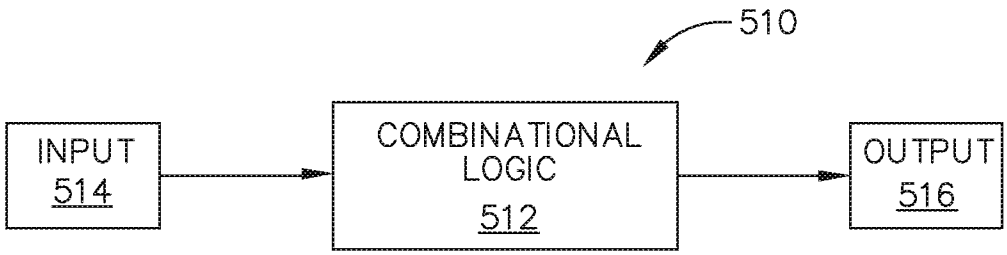


FIG. 11

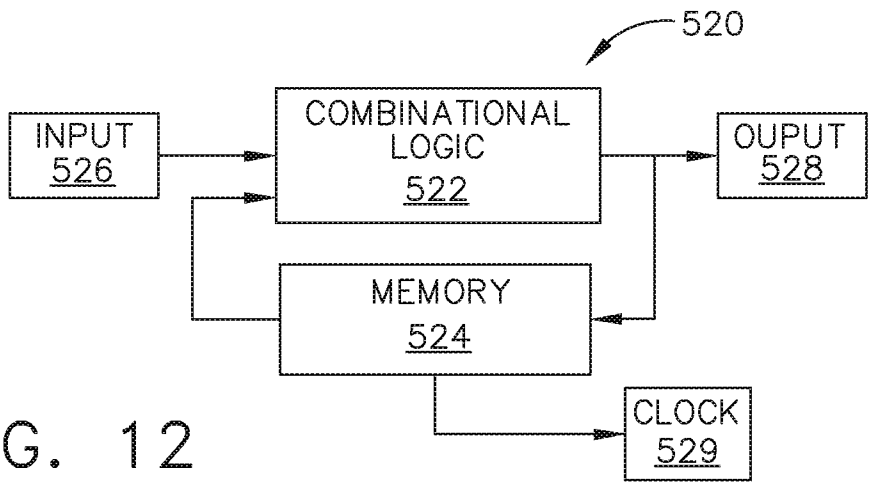


FIG. 12

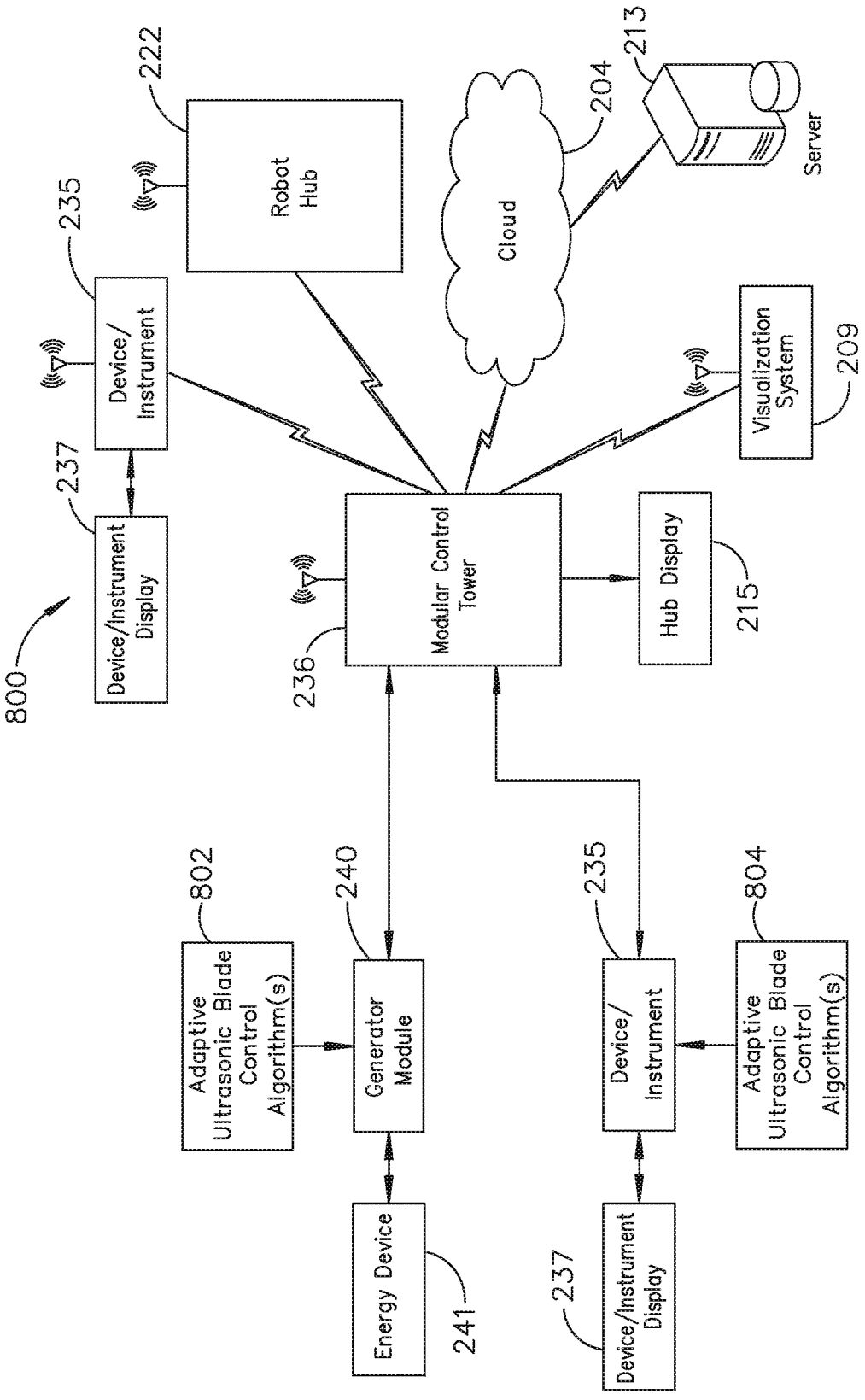
800
Device/Instrument Display
237
Device/ Instrument
235
Robot Hub
222
Cloud
204
Server
213
Visualization System
209
Modular Control Tower
236
Hub Display
215
Adaptive Ultrasonic Blade Control Algorithm(s)
802
Generator Module
240
Energy Device
241
Device/ Instrument
235
Adaptive Ultrasonic Blade Control Algorithm(s)
804
Device/Instrument Display
237

FIG. 13

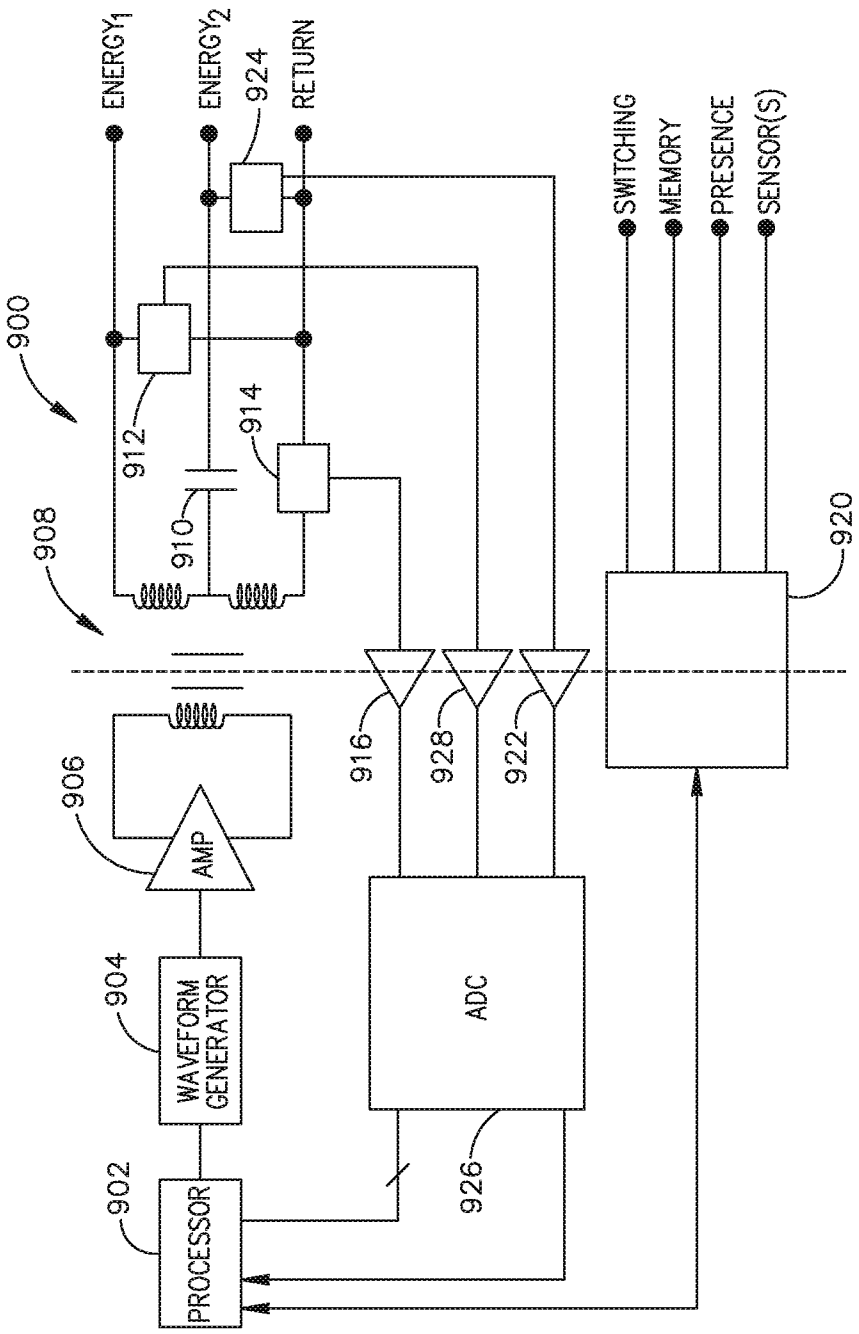
ENERGY1
ENERGY2
924
RETURN
SWITCHING
MEMORY
PRESENCE
SENSOR(S)
900
912
914
910
908
920
916
928
922
906
AMP
904
WAVEFORM GENERATOR
ADC
902
PROCESSOR
926

FIG. 14

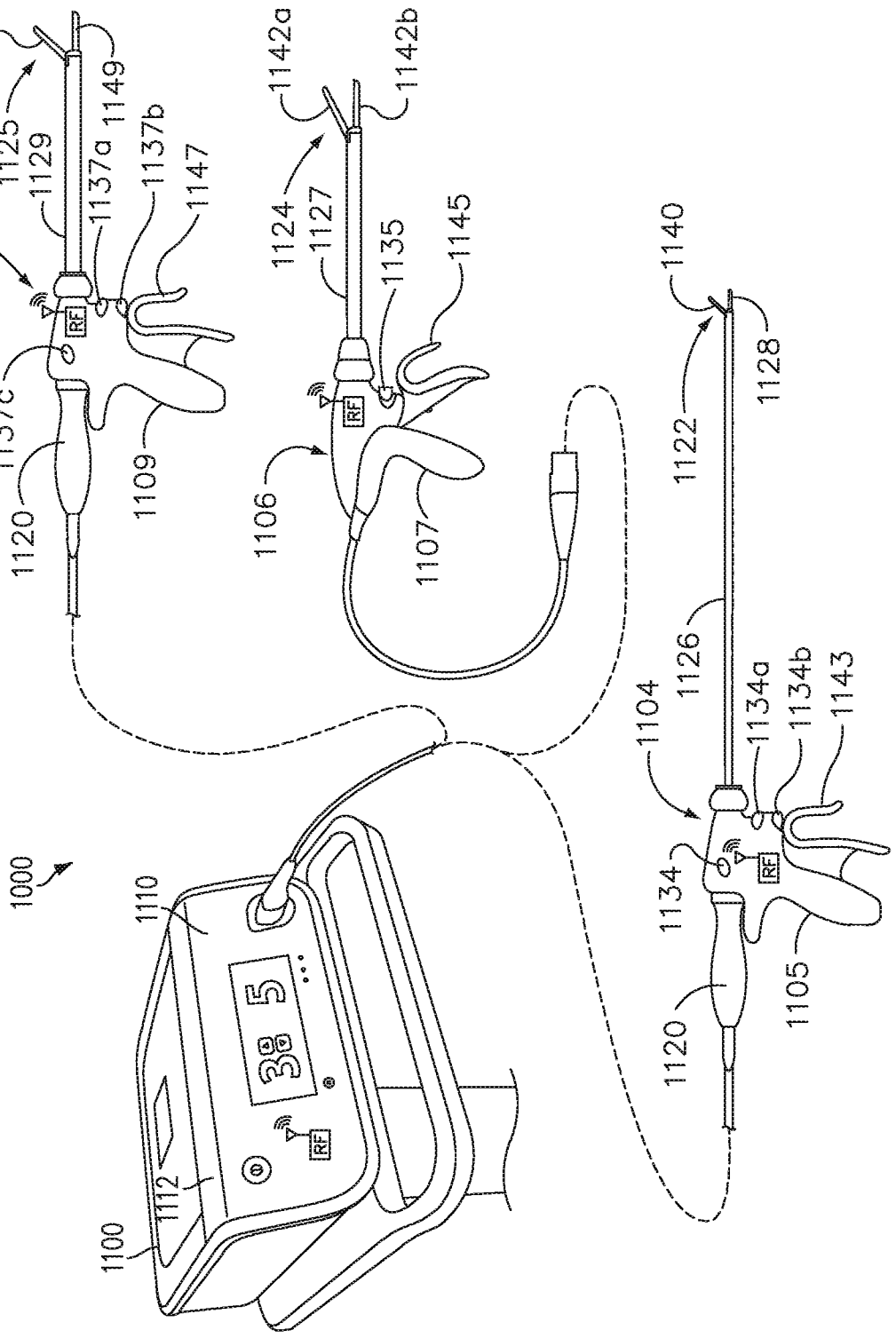
1000
1100
1110
1112
1104
1105
1106
1107
1108
1109
1120
1122
1124
1125
1126
1127
1128
1129
1134
1134a
1134b
1135
1137a
1137b
1137c
1140
1142a
1142b
1143
1145
1146
1147
1149
RF

FIG. 15

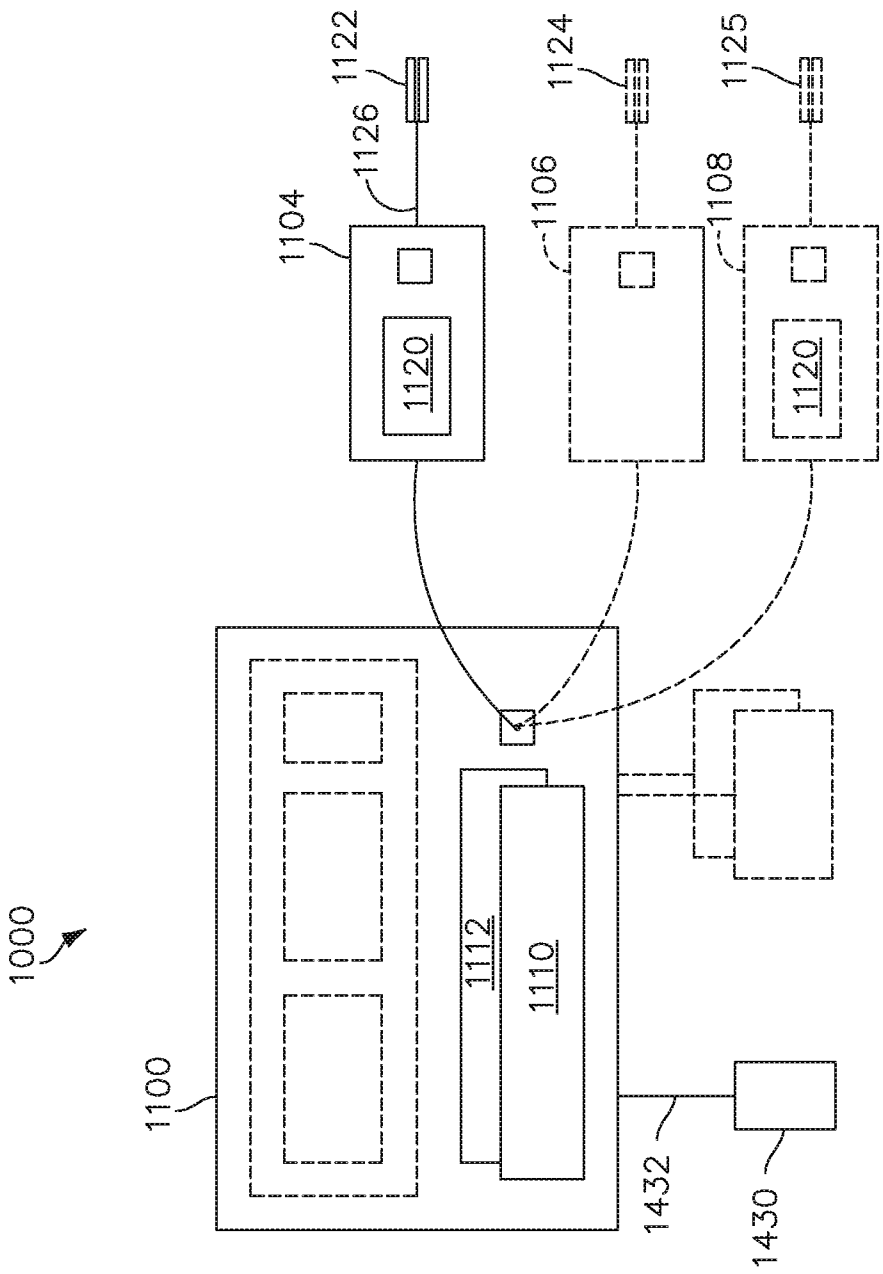
1000
1100
1110
1112
1120
1120
1122
1124
1125
1126
1104
1106
1108
1432
1430

FIG. 16

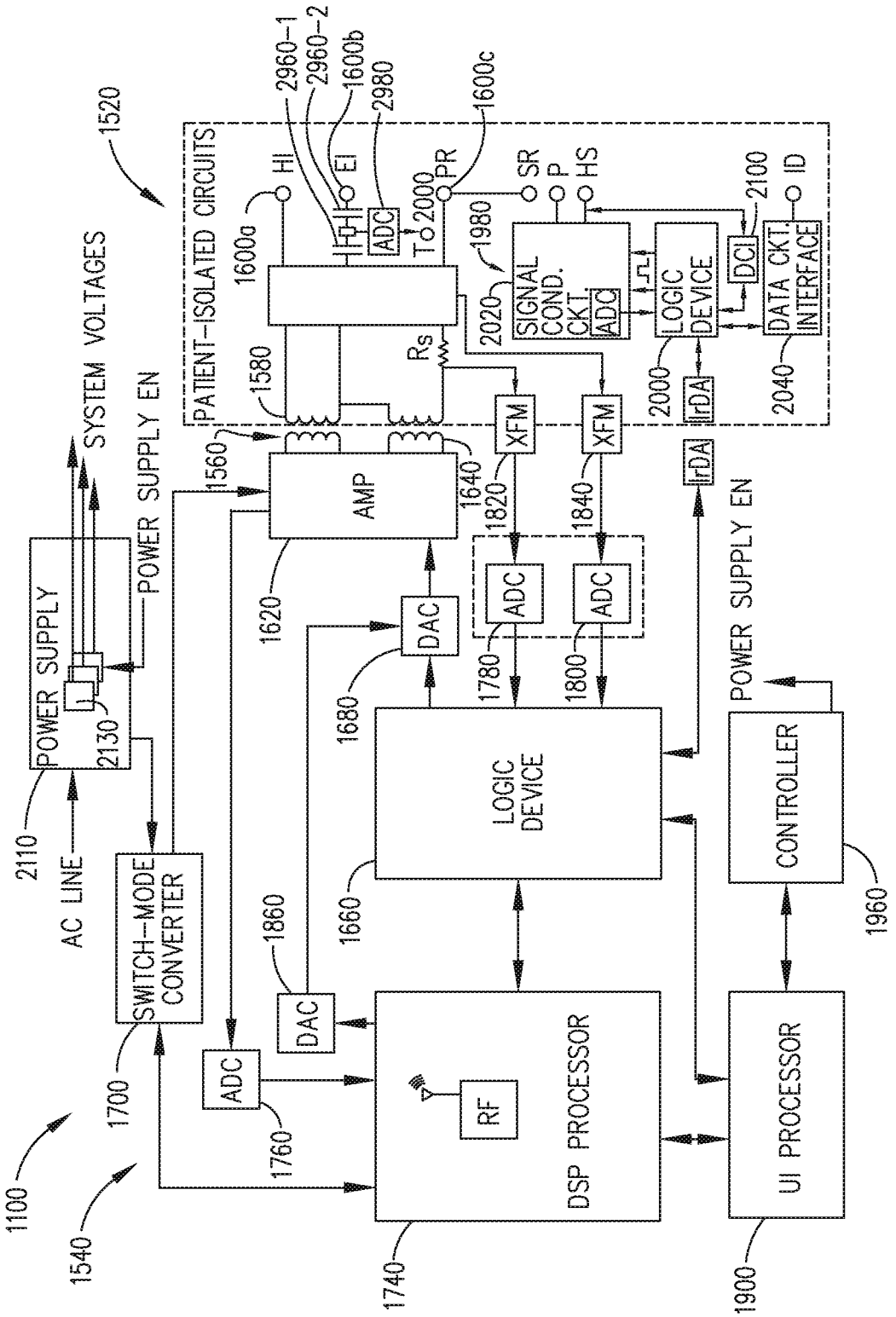
1100
1540
1700
2110
AC LINE
2130
POWER SUPPLY
SYSTEM VOLTAGES
1520
POWER SUPPLY EN
SWITCH-MODE CONVERTER
1560
PATIENT-ISOLATED CIRCUITS
1600a
2960-1
2960-2
1600b
2980
1600c
HI
EI
ADC
T
2000
PR
SR
P
HS
1980
2020
SIGNAL COND. CKT.
ADC
LOGIC DEVICE
DCI
2100
DATA CKT. INTERFACE
ID
1580
Rs
2000
IrDA
2040
XFM
XFM
AMP
1640
1820
1840
1620
DAC
ADC
ADC
1780
1800
1680
LOGIC DEVICE
IrDA
POWER SUPPLY EN
CONTROLLER
1660
1960
1860
DAC
ADC
1760
RF
DSP PROCESSOR
UI PROCESSOR
1740
1900

FIG. 17

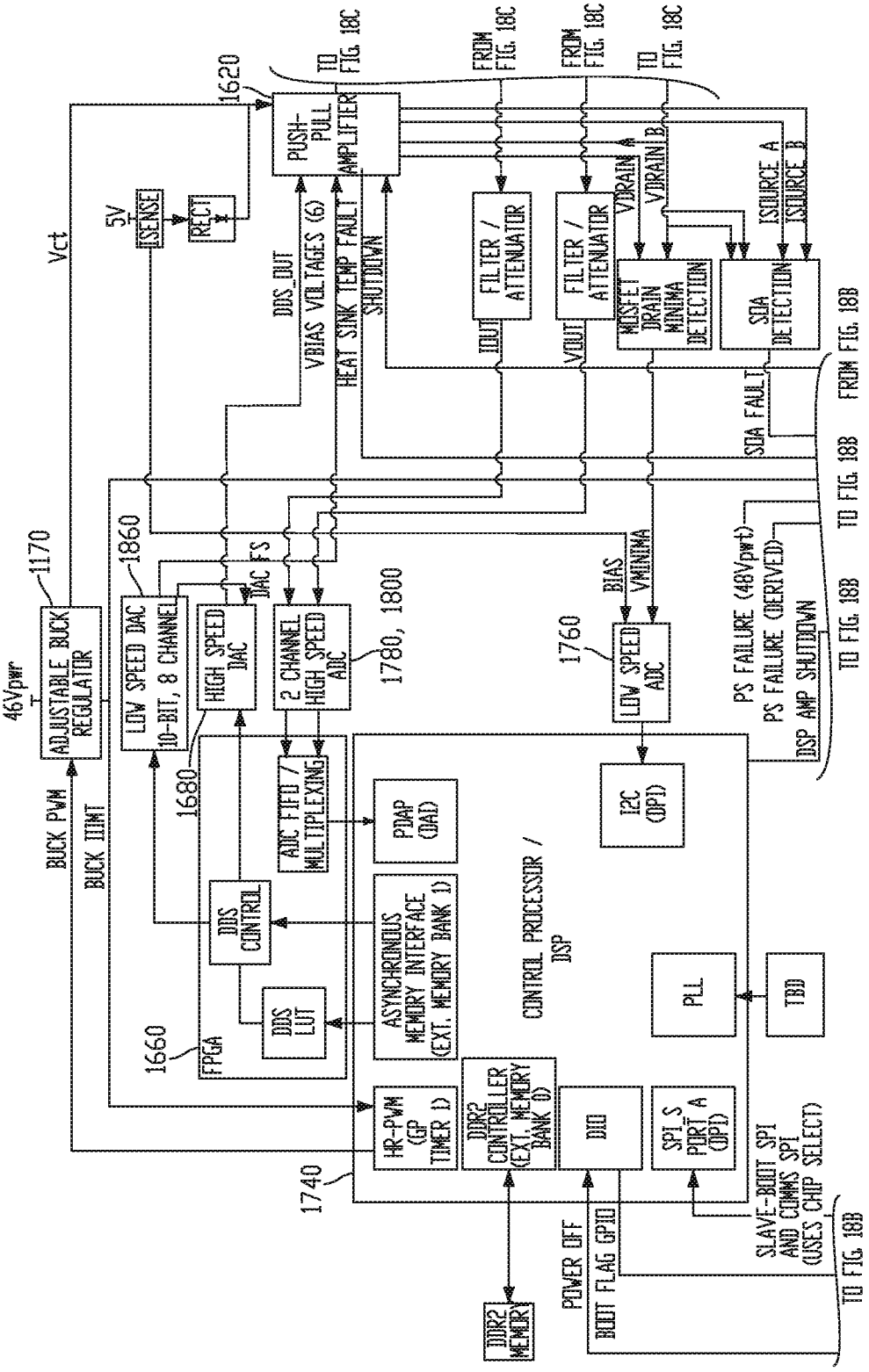
46Vpwr
1170
ADJUSTABLE BUCK REGULATOR
BUCK PWM
BUCK IIMT
Vct
5V
ISENSE
RECT
1620
PUSH-PULL AMPLIFIER
TO FIG. 18C
FROM FIG. 18C
FROM FIG. 18C
TO FIG. 18C
VBIAS VOLTAGES (6)
HEAT SINK TEMP FAULT
SHUTDOWN
FILTER / ATTENUATOR
IOUT
FILTER / ATTENUATOR
VOUT
VDRAIN A
VDRAIN B
MOSFET DRAIN MINIMA DETECTION
ISOURCE A
ISOURCE B
SOA DETECTION
SOA FAULT
FROM FIG. 18B
1860
LOW SPEED DAC
10-BIT, 8 CHANNEL
1680
HIGH SPEED DAC
2 CHANNEL HIGH SPEED ADC
1780, 1800
DAC FS
BIAS
VMINIMA
1760
LOW SPEED ADC
PS FAILURE (48Vpwr)
PS FAILURE (DERIVED)
DSP AMP SHUTDOWN
TO FIG. 18B
TO FIG. 18B
ADC FIFO / MULTIPLEXING
PDAP (DAC)
I2C (OPI)
DDS CONTROL
ASYNCHRONOUS MEMORY INTERFACE (EXT. MEMORY BANK 1)
CONTROL PROCESSOR / DSP
DDS LUT
1660
FPGA
PLL
TBD
HR-PWM (GP TIMER 1)
DDR2 CONTROLLER (EXT. MEMORY BANK 0)
DIO
SPI_S PORT A (OPI)
1740
DDR2 MEMORY
POWER OFF
BOOT FLAG GPIO
SLAVE-BOOT SPI AND COMMS SPI (USES CHIP SELECT)
TO FIG. 18B

FIG. 18A

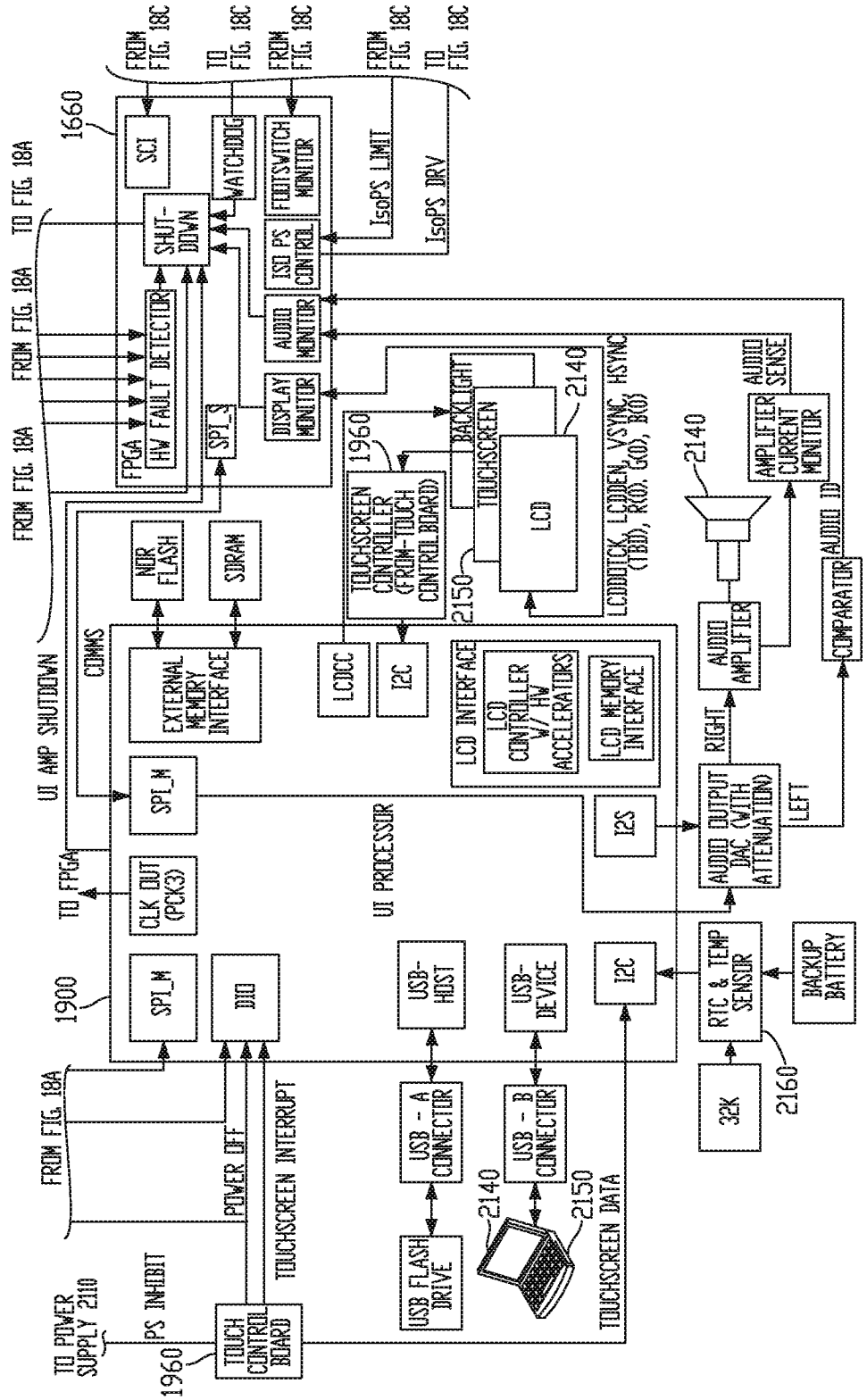
FROM FIG. 18C
TO FIG. 18C
FROM FIG. 18C
TO FIG. 18C
FROM FIG. 18C
TO FIG. 18C
1660
SCI
WATCHDOG
FOOTSWITCH MONITOR
SHUT-DOWN
ISO PS CONTROL
ISOPS LIMIT
ISOPS DRV
FROM FIG. 18A
TO FIG. 18A
FROM FIG. 18A
FPGA
HW FAULT DETECTOR
SPI_S
AUDIO MONITOR
DISPLAY MONITOR
1960
TOUCHSCREEN CONTROLLER (FROM-TOUCH CONTROL BOARD)
BACKLIGHT
TOUCHSCREEN
LCD
2140
2150
LCDBUTTCK, LCDDEN, VSYNC, HSYNC (TBD), R(0:7), G(0:7), B(0:7)
AUDIO SENSE
AMPLIFIER CURRENT MONITOR
AUDIO ID
COMPARATOR
NOR FLASH
SDRAM
COMMS
EXTERNAL MEMORY INTERFACE
LCDCC
I2C
LCD INTERFACE
LCD CONTROLLER W/ HW ACCELERATORS
LCD MEMORY INTERFACE
AUDIO AMPLIFIER
UI AMP SHUTDOWN
SPI_M
UI PROCESSOR
I2S
AUDIO OUTPUT DAC (WITH ATTENUATION)
RIGHT
LEFT
TO FPGA
CLK OUT (PCK3)
1900
SPI_M
DIO
USB-HOST
USB-DEVICE
I2C
RTC & TEMP SENSOR
BACKUP BATTERY
FROM FIG. 18A
POWER OFF
TOUCHSCREEN INTERRUPT
USB - A CONNECTOR
USB - B CONNECTOR
32K
2160
2140
2150
TO POWER SUPPLY 2110
PS INHIBIT
1960
TOUCH CONTROL BOARD
USB FLASH DRIVE
TOUCHSCREEN DATA

FIG. 18B

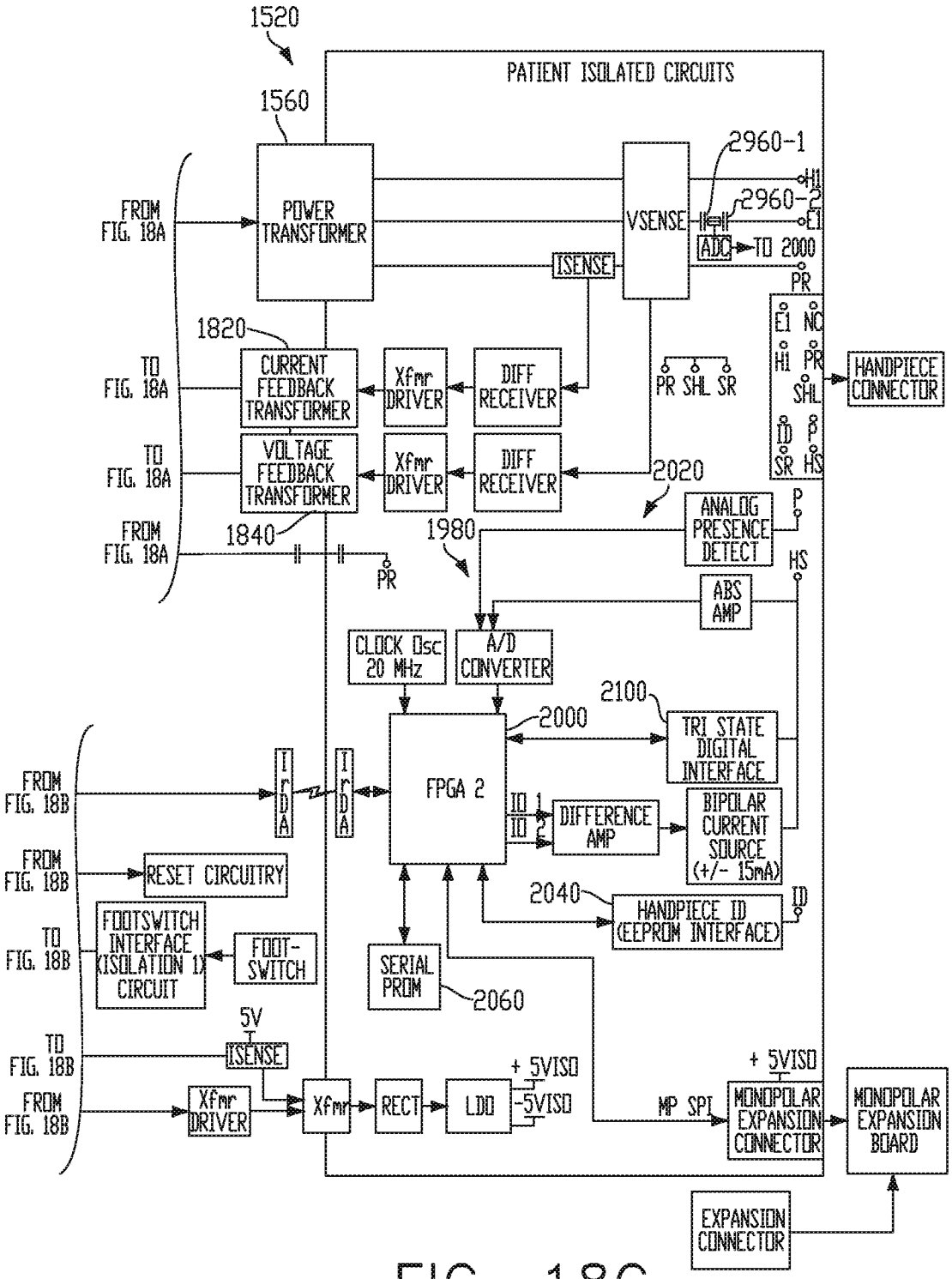
1520
PATIENT ISOLATED CIRCUITS
1560
POWER TRANSFORMER
VSENSE
ISENSE
2960-1
2960-2
ADC
TO 2000
PR
E1 NC
HI PR
SHL
ID
SR HS
HANDPIECE CONNECTOR
FROM FIG. 18A
1820
CURRENT FEEDBACK TRANSFORMER
Xfmr DRIVER
DIFF RECEIVER
PR SHL SR
TO FIG. 18A
VOLTAGE FEEDBACK TRANSFORMER
2020
ANALOG PRESENCE DETECT
1840
1980
ABS AMP
CLOCK Osc 20 MHz
A/D CONVERTER
2100
2000
TRI STATE DIGITAL INTERFACE
FPGA 2
IrDA
ID 1
ID 2
DIFFERENCE AMP
BIPOLAR CURRENT SOURCE (+/- 15mA)
FROM FIG. 18B
RESET CIRCUITRY
2040
HANDPIECE ID (EEPROM INTERFACE)
FOOTSWITCH INTERFACE (ISOLATION 1X CIRCUIT
FOOT-SWITCH
SERIAL PROM
2060
5V
+ 5VISO
-5VISO
LDO
RECT
MP SPI
MONOPOLAR EXPANSION CONNECTOR
MONOPOLAR EXPANSION BOARD
EXPANSION CONNECTOR

FIG. 18C

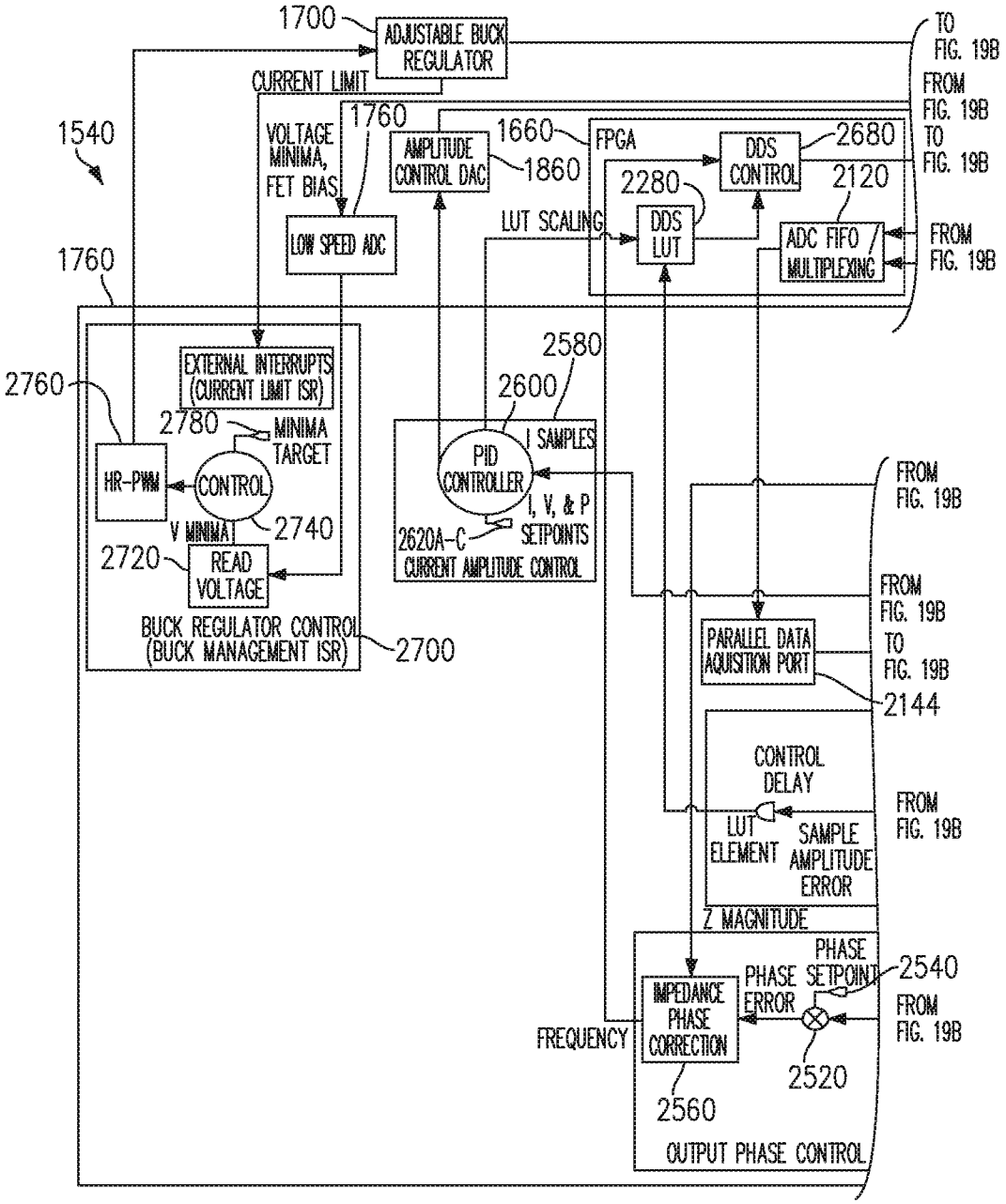
1700
ADJUSTABLE BUCK REGULATOR
CURRENT LIMIT
1540
1760
VOLTAGE MINIMA, FET BIAS
LOW SPEED ADC
AMPLITUDE CONTROL DAC
1660
1860
FPGA
DDS CONTROL
2680
2280
2120
LUT SCALING
DDS LUT
ADC FIFO / MULTIPLEXING
TO FIG. 19B
FROM FIG. 19B
TO FIG. 19B
FROM FIG. 19B
1760
2580
2600
2760
EXTERNAL INTERRUPTS (CURRENT LIMIT ISR)
2780
MINIMA TARGET
HR-PWM
CONTROL
2740
V MINIMA
2720
READ VOLTAGE
BUCK REGULATOR CONTROL (BUCK MANAGEMENT ISR)
2700
PID CONTROLLER
I SAMPLES
I, V, & P SETPOINTS
2620A-C
CURRENT AMPLITUDE CONTROL
FROM FIG. 19B
FROM FIG. 19B
PARALLEL DATA AQUISITION PORT
TO FIG. 19B
2144
CONTROL DELAY
LUT ELEMENT
SAMPLE AMPLITUDE ERROR
FROM FIG. 19B
Z MAGNITUDE
PHASE SETPOINT
2540
PHASE ERROR
FROM FIG. 19B
FREQUENCY
IMPEDANCE PHASE CORRECTION
2520
2560
OUTPUT PHASE CONTROL

FIG. 19A

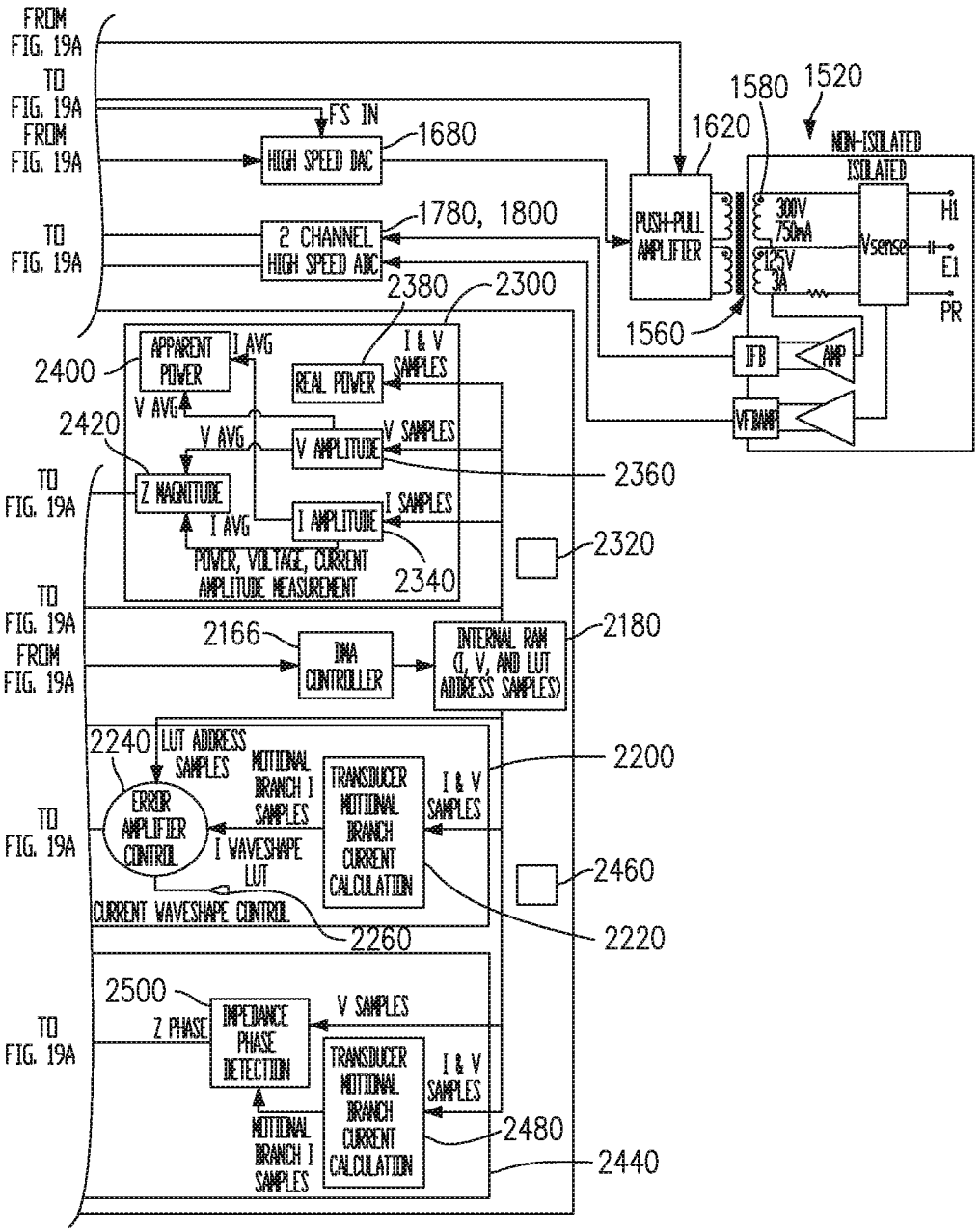
FROM FIG. 19A
TO FIG. 19A
FROM FIG. 19A
TO FIG. 19A
FS IN
HIGH SPEED DAC
1680
2 CHANNEL HIGH SPEED ADC
1780, 1800
1580
1520
1620
NON-ISOLATED
ISOLATED
PUSH-PULL AMPLIFIER
300V 75mA
125V 3A
Vsense
HI
E1
PR
1560
IFB
AMP
VF BIAS
2380
2300
2400
APPARENT POWER
I AVG
REAL POWER
I & V SAMPLES
V AVG
2420
V AVG
V AMPLITUDE
V SAMPLES
2360
TO FIG. 19A
Z MAGNITUDE
I AMPLITUDE
I SAMPLES
I AVG
POWER, VOLTAGE, CURRENT AMPLITUDE MEASUREMENT
2340
2320
TO FIG. 19A
2166
DMA CONTROLLER
INTERNAL RAM (I, V, AND LUT ADDRESS SAMPLES)
2180
FROM FIG. 19A
2240
LUT ADDRESS SAMPLES
2200
ERROR AMPLIFIER CONTROL
MOTIONAL BRANCH I SAMPLES
TRANSDUCER MOTIONAL BRANCH CURRENT CALCULATION
I & V SAMPLES
TO FIG. 19A
I WAVESHAPE LUT
2460
CURRENT WAVESHAPE CONTROL
2260
2220
2500
Z PHASE
IMPEDANCE PHASE DETECTION
V SAMPLES
TO FIG. 19A
TRANSDUCER MOTIONAL BRANCH CURRENT CALCULATION
I & V SAMPLES
MOTIONAL BRANCH I SAMPLES
2480
2440

FIG. 19B

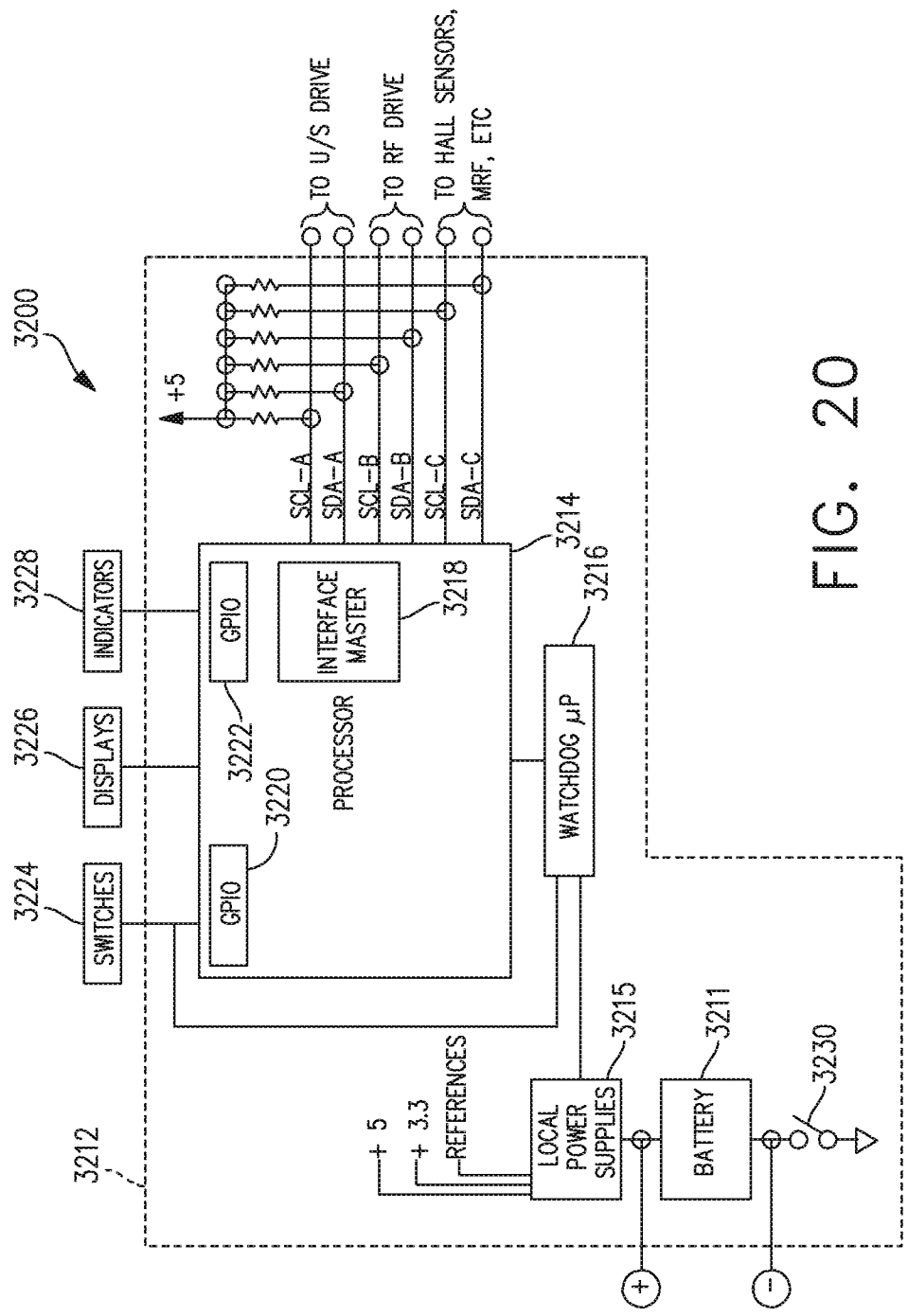
3200
+5
TO U/S DRIVE
TO RF DRIVE
TO HALL SENSORS, MRF, ETC
SCL-A
SDA-A
SCL-B
SDA-B
SCL-C
SDA-C
3214
3228
INDICATORS
3226
DISPLAYS
3224
SWITCHES
GPIO
3222
GPIO
3220
INTERFACE MASTER
3218
PROCESSOR
3216
WATCHDOG μP
3212
+ 5
+ 3.3
REFERENCES
LOCAL POWER SUPPLIES
3215
BATTERY
3211
3230
+
-

FIG. 20

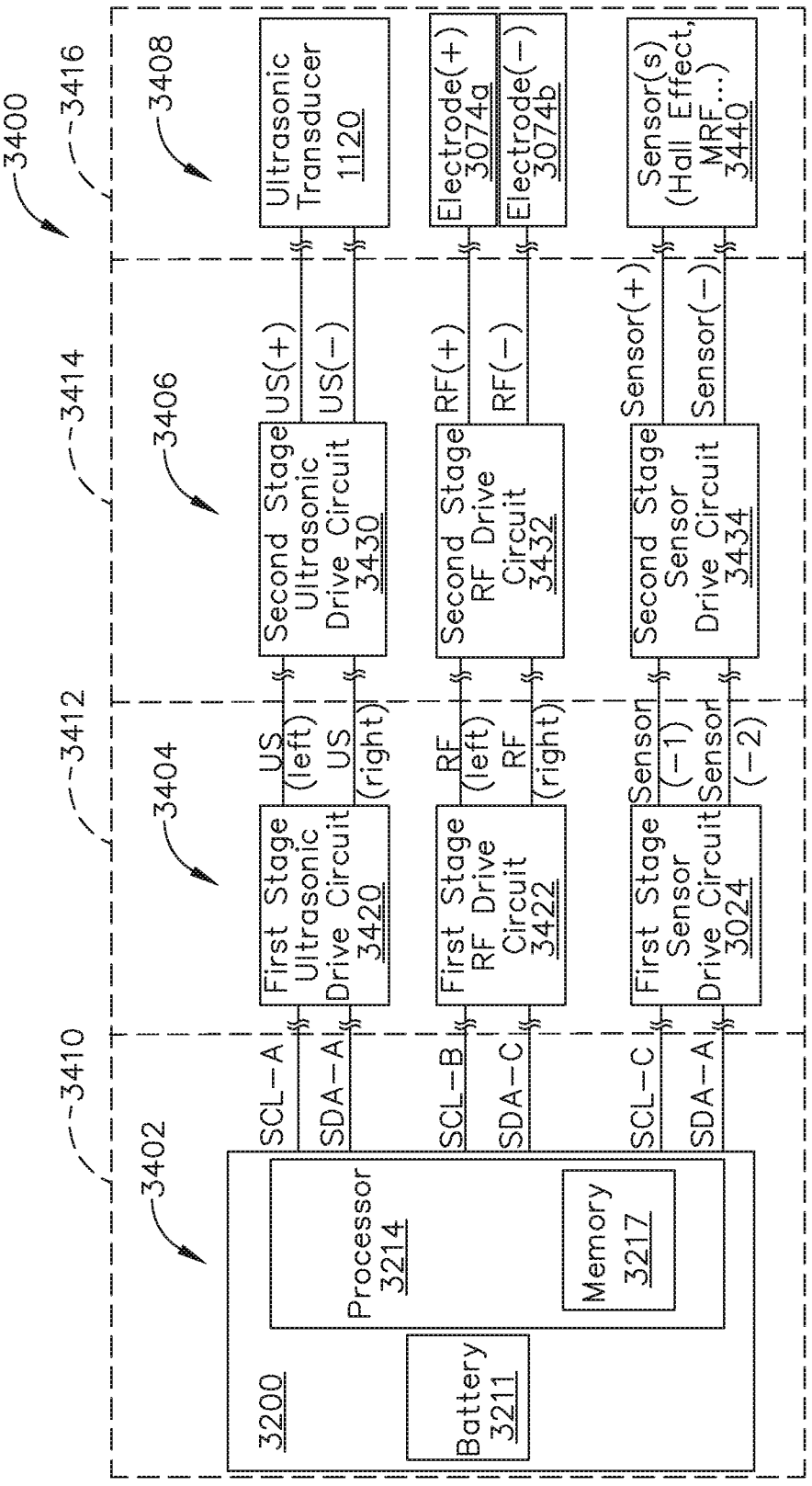
3400
3416
3408
3414
3406
3412
3404
3410
3402
Ultrasonic Transducer 1120
Electrode(+) 3074a
Electrode(−) 3074b
Sensor(s) (Hall Effect, MRF...) 3440
Second Stage Ultrasonic Drive Circuit 3430
Second Stage RF Drive Circuit 3432
Second Stage Sensor Drive Circuit 3434
US(+)
US(−)
RF(+)
RF(−)
Sensor(+)
Sensor(−)
First Stage Ultrasonic Drive Circuit 3420
First Stage RF Drive Circuit 3422
First Stage Sensor Drive Circuit 3024
US (left)
US (right)
RF (left)
RF (right)
Sensor (−1)
Sensor (−2)
SCL−A
SDA−A
SCL−B
SDA−C
SCL−C
SDA−A
3200
Processor 3214
Memory 3217
Battery 3211

FIG. 21

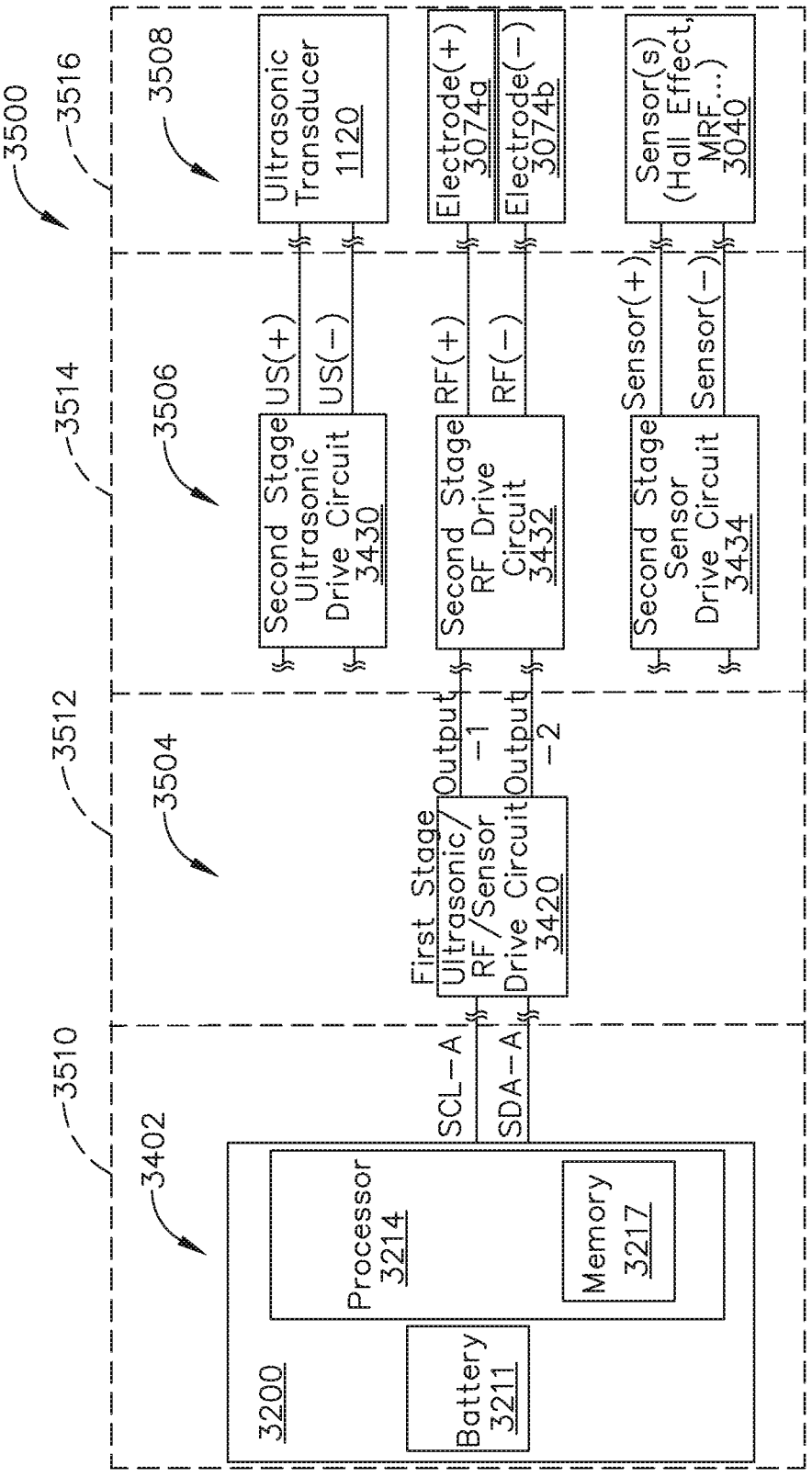
3500
3516
3508
3514
3506
3512
3504
3510
3402
3200
Battery 3211
Processor 3214
Memory 3217
SCL-A
SDA-A
First Stage Ultrasonic/ RF/Sensor Drive Circuit 3420
Output -1
Output -2
Second Stage Ultrasonic Drive Circuit 3430
Second Stage RF Drive Circuit 3432
Second Stage Sensor Drive Circuit 3434
US(+)
US(−)
RF(+)
RF(−)
Sensor(+)
Sensor(−)
Ultrasonic Transducer 1120
Electrode(+) 3074a
Electrode(−) 3074b
Sensor(s) (Hall Effect, MRF...) 3040

FIG. 22

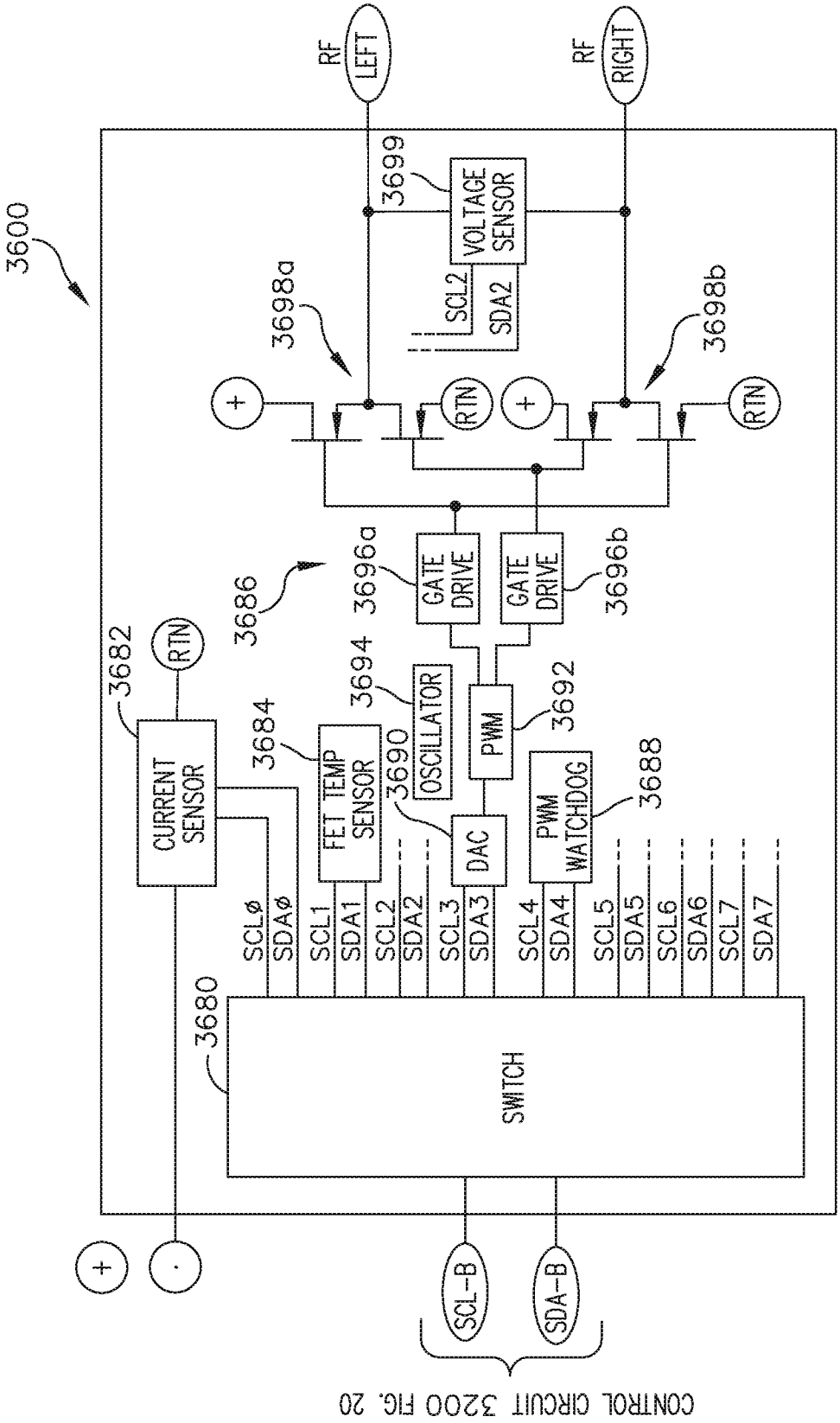
3600
RF LEFT
RF RIGHT
3699
VOLTAGE SENSOR
SCL2
SDA2
3698a
3698b
+
RTN
+
RTN
3686
3696a
GATE DRIVE
GATE DRIVE
3696b
3682
RTN
3694
OSCILLATOR
PWM
3692
3684
FET TEMP SENSOR
3690
DAC
PWM WATCHDOG
3688
CURRENT SENSOR
SCLø
SDAø
SCL1
SDA1
SCL2
SDA2
SCL3
SDA3
SCL4
SDA4
SCL5
SDA5
SCL6
SDA6
SCL7
SDA7
3680
SWITCH
+
-
SCL-B
SDA-B
CONTROL CIRCUIT 3200 FIG. 20

FIG. 23

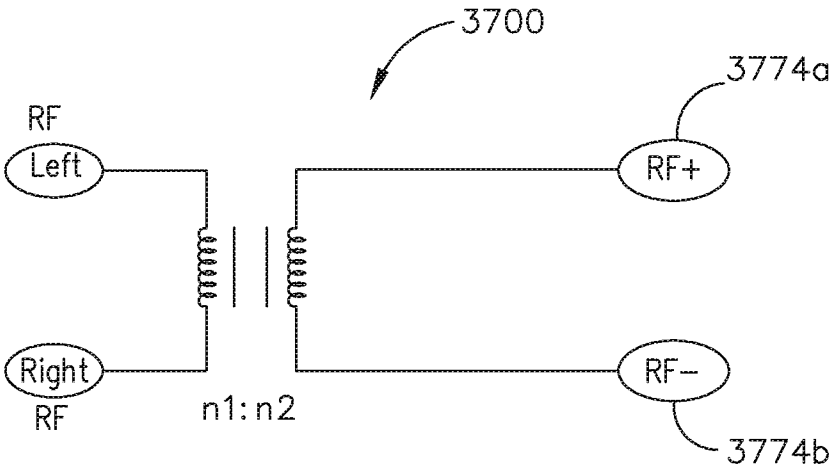
3700
3774a
RF
Left
RF+
Right
RF
n1:n2
RF−
3774b

FIG. 24

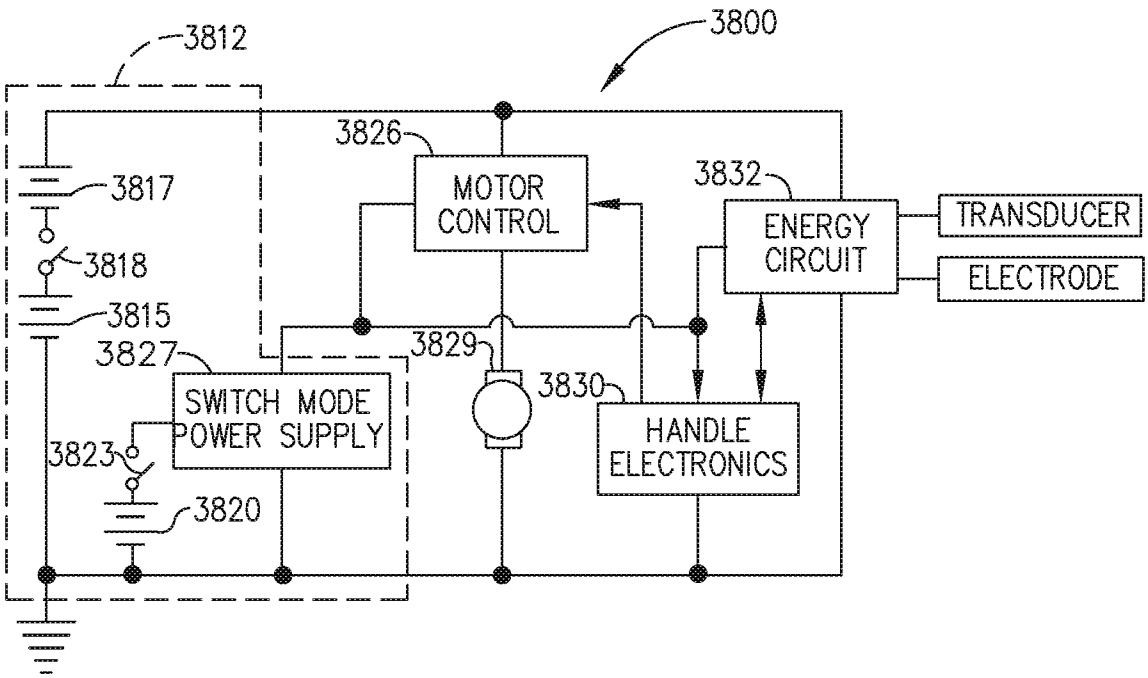
3812
3800
3826
MOTOR CONTROL
3832
ENERGY CIRCUIT
TRANSDUCER
ELECTRODE
3817
3818
3815
3827
3829
3830
SWITCH MODE POWER SUPPLY
HANDLE ELECTRONICS
3823
3820

FIG. 25

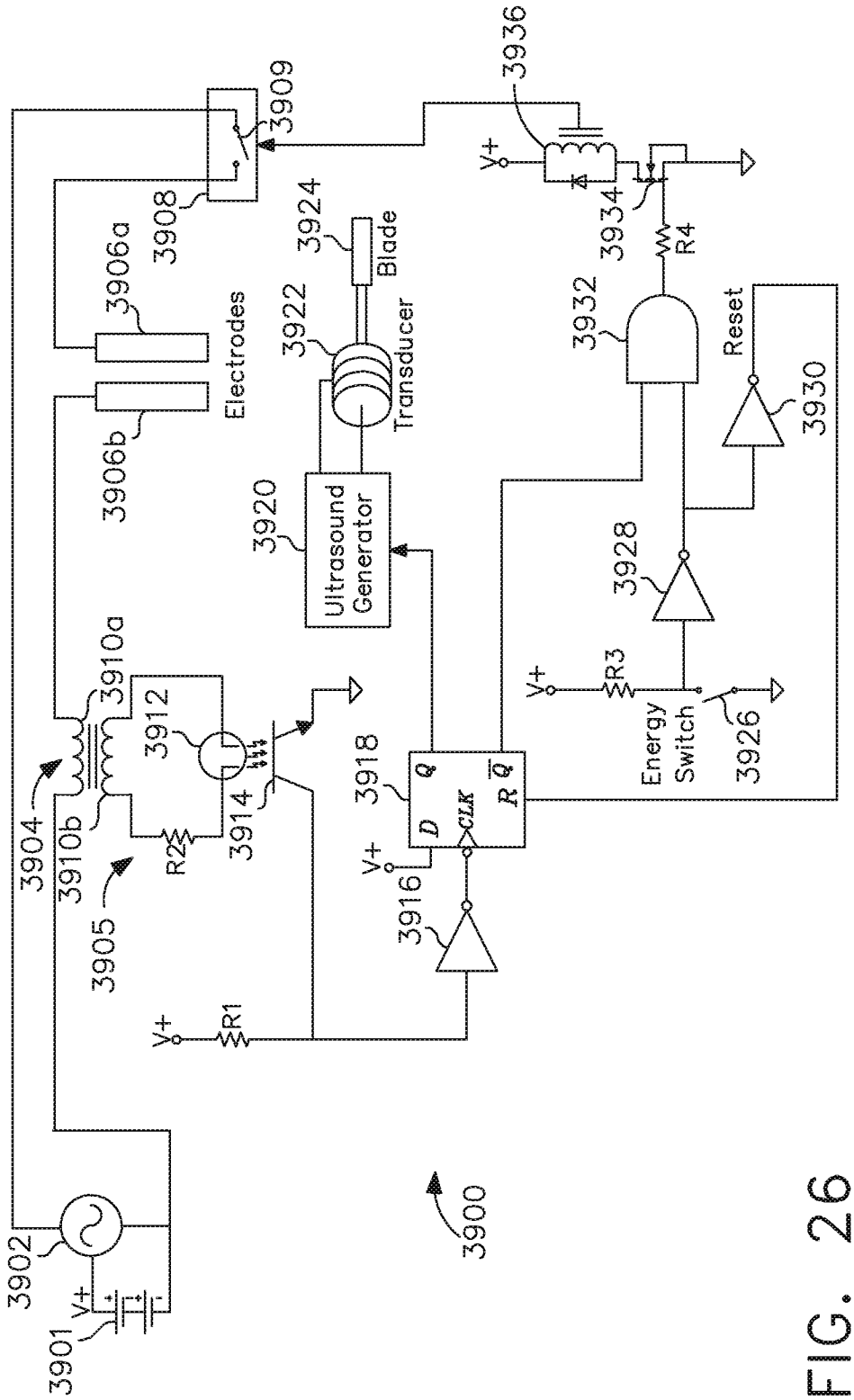
3900
3901
3902
V+
3904
3905
3906a
3906b
Electrodes
3908
3909
3910a
3910b
3912
3914
R2
3916
3918
D
Q
CLK
R
3920
Ultrasound Generator
3922
Transducer
3924
Blade
3926
Energy Switch
3928
3930
Reset
3932
3934
R4
3936
R1
R3

FIG. 26

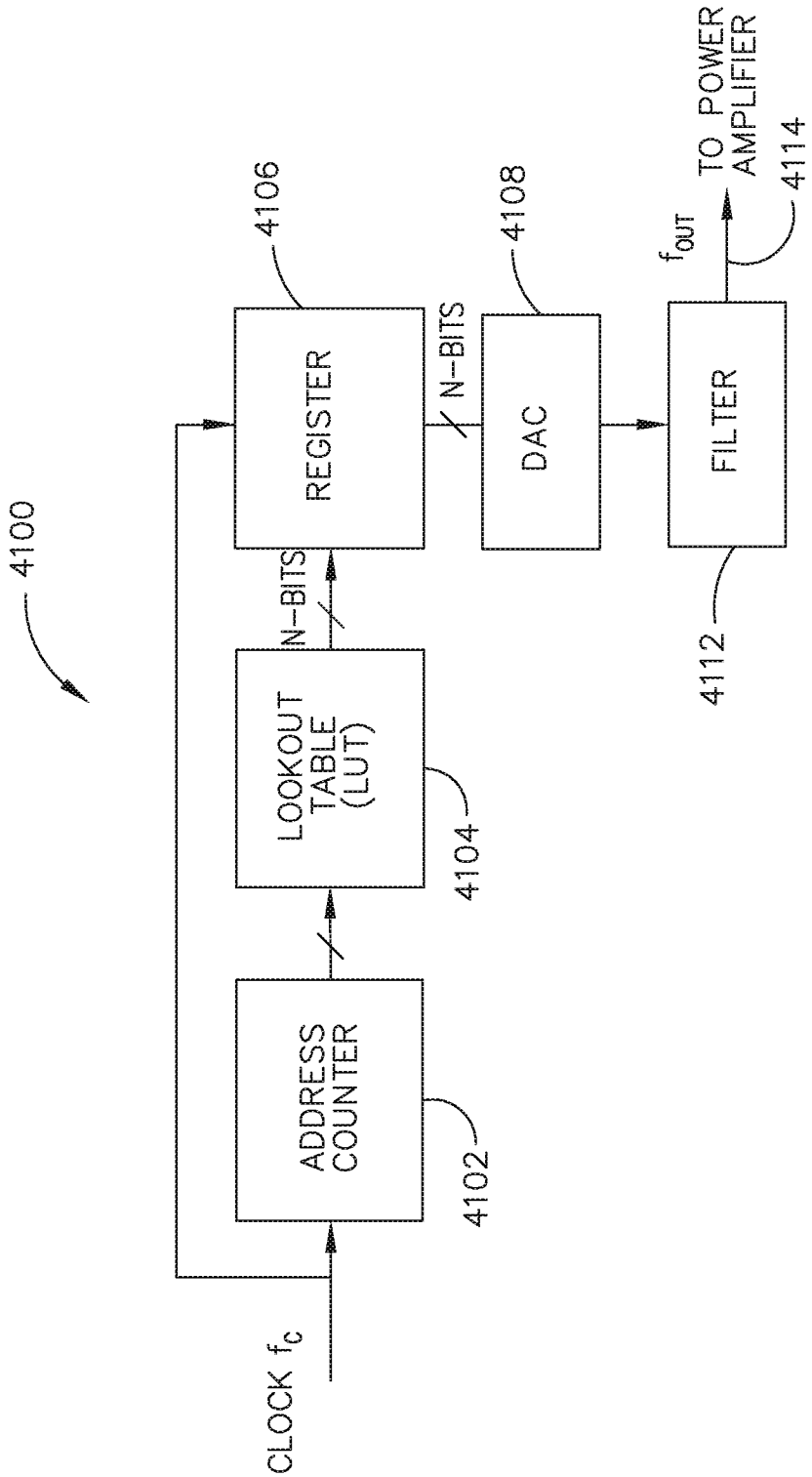
4100
CLOCK $f_c$
ADDRESS COUNTER
4102
LOOKOUT TABLE (LUT)
4104
N-BITS
REGISTER
4106
N-BITS
DAC
4108
FILTER
4112
$f_{OUT}$
TO POWER AMPLIFIER
4114

FIG. 27

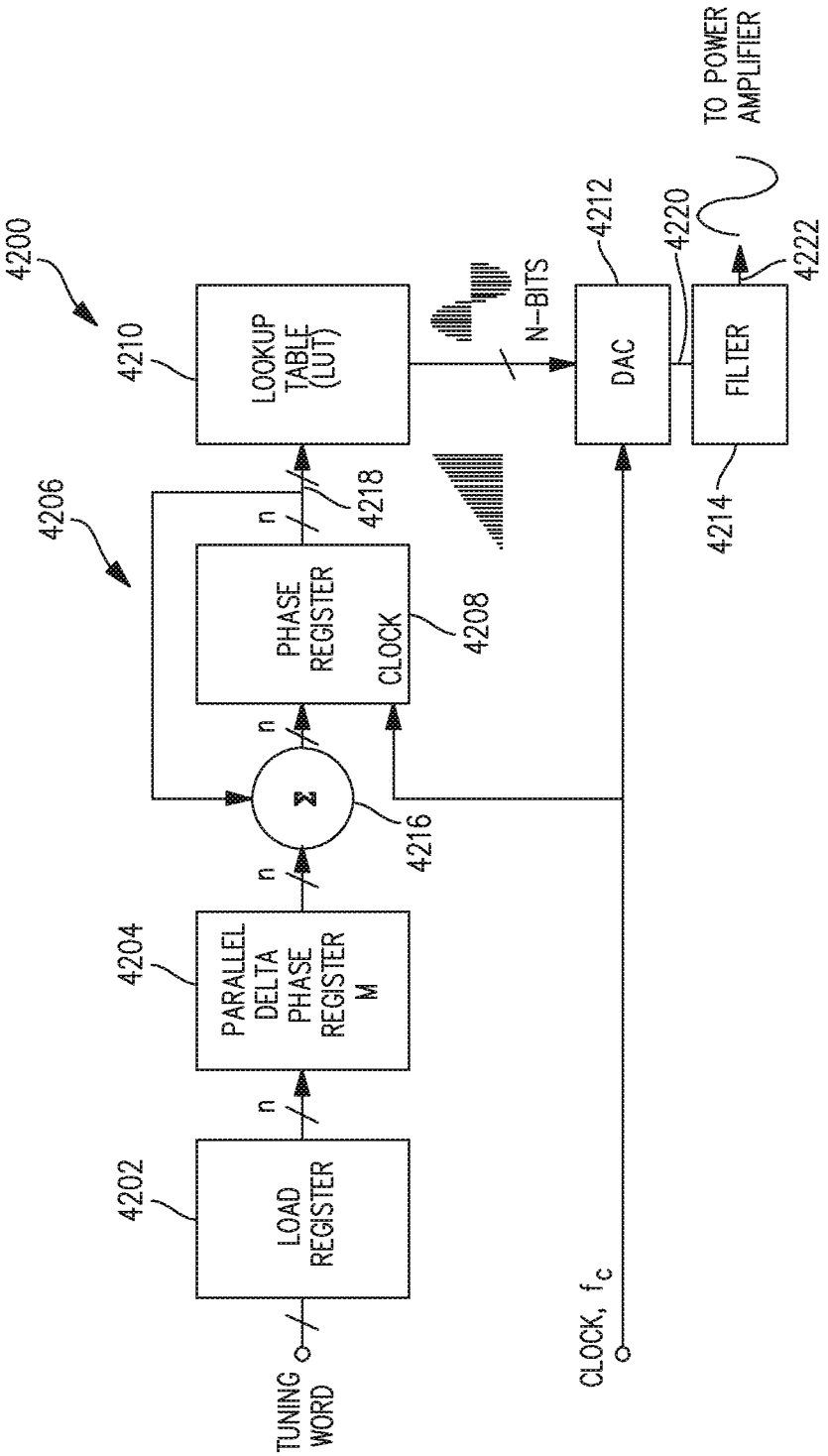
4200
4210
LOOKUP TABLE (LUT)
N-BITS
4212
DAC
4220
TO POWER AMPLIFIER
4222
FILTER
4214
4206
4218
n
PHASE REGISTER
CLOCK
4208
n
Σ
4216
n
4204
PARALLEL DELTA PHASE REGISTER M
n
4202
LOAD REGISTER
TUNING WORD
CLOCK, $f_c$

FIG. 28

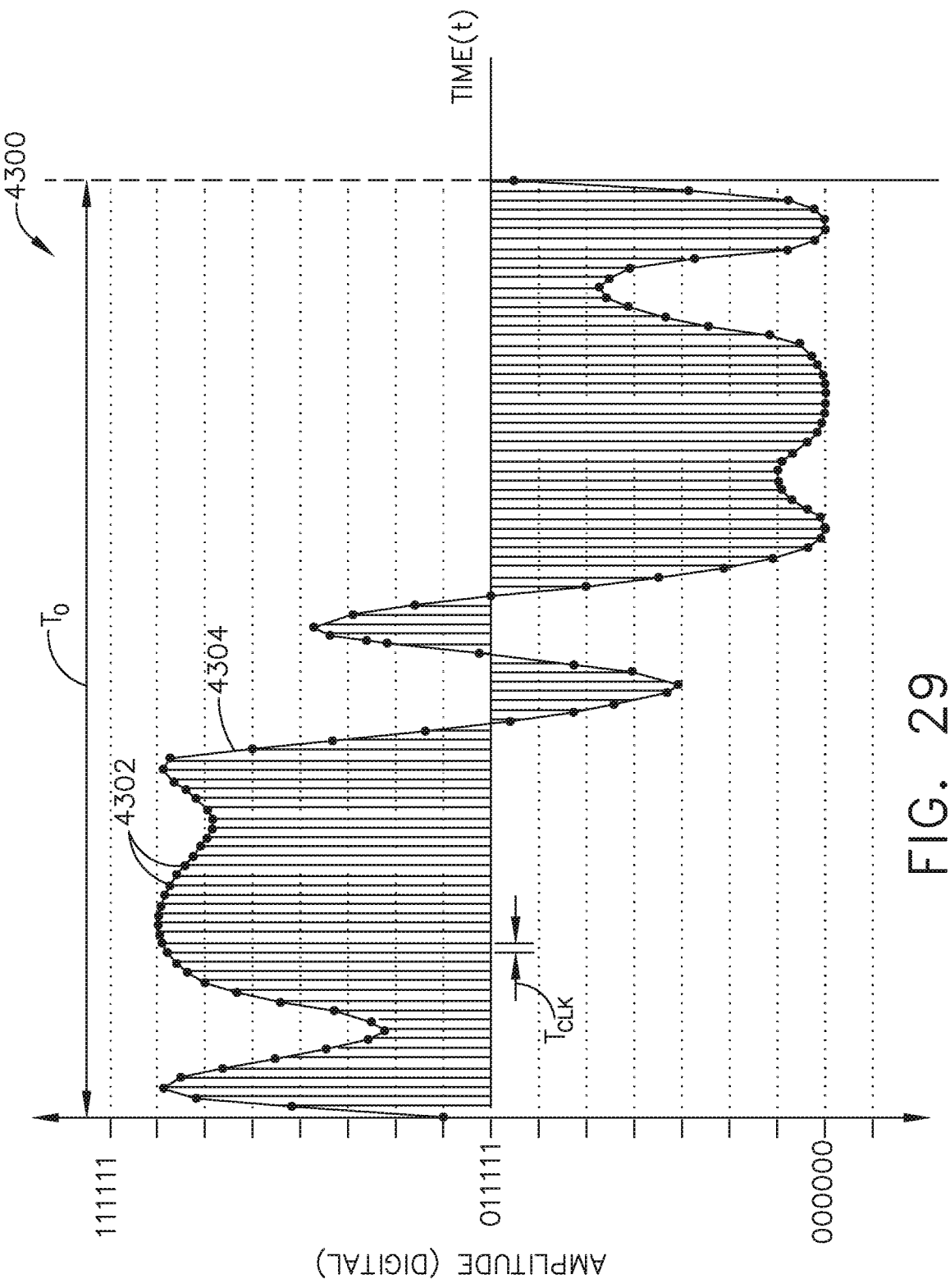
4300
TIME(t)
$T_0$
4304
4302
$T_{CLK}$
111111
011111
000000
AMPLITUDE (DIGITAL)

FIG. 29

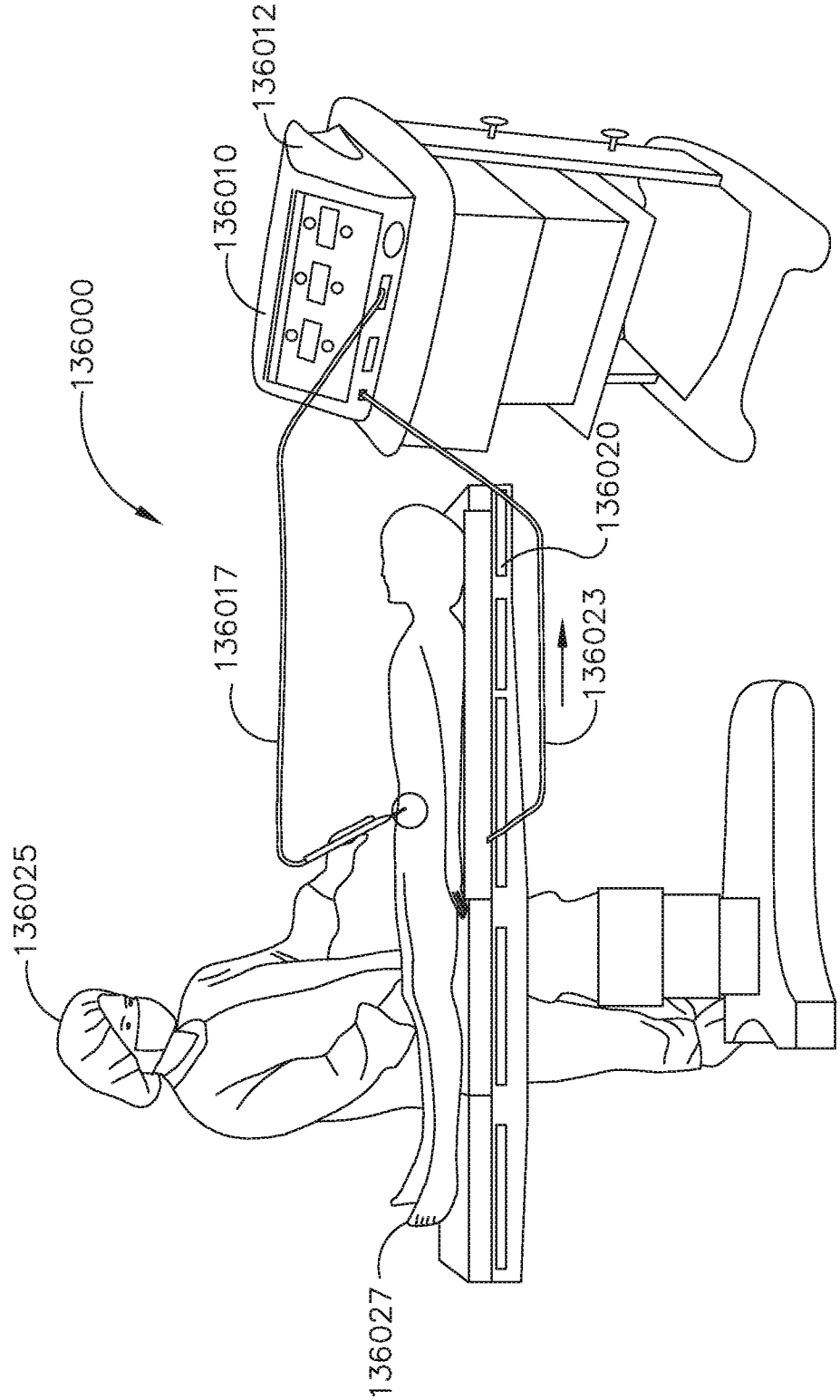


FIG. 30

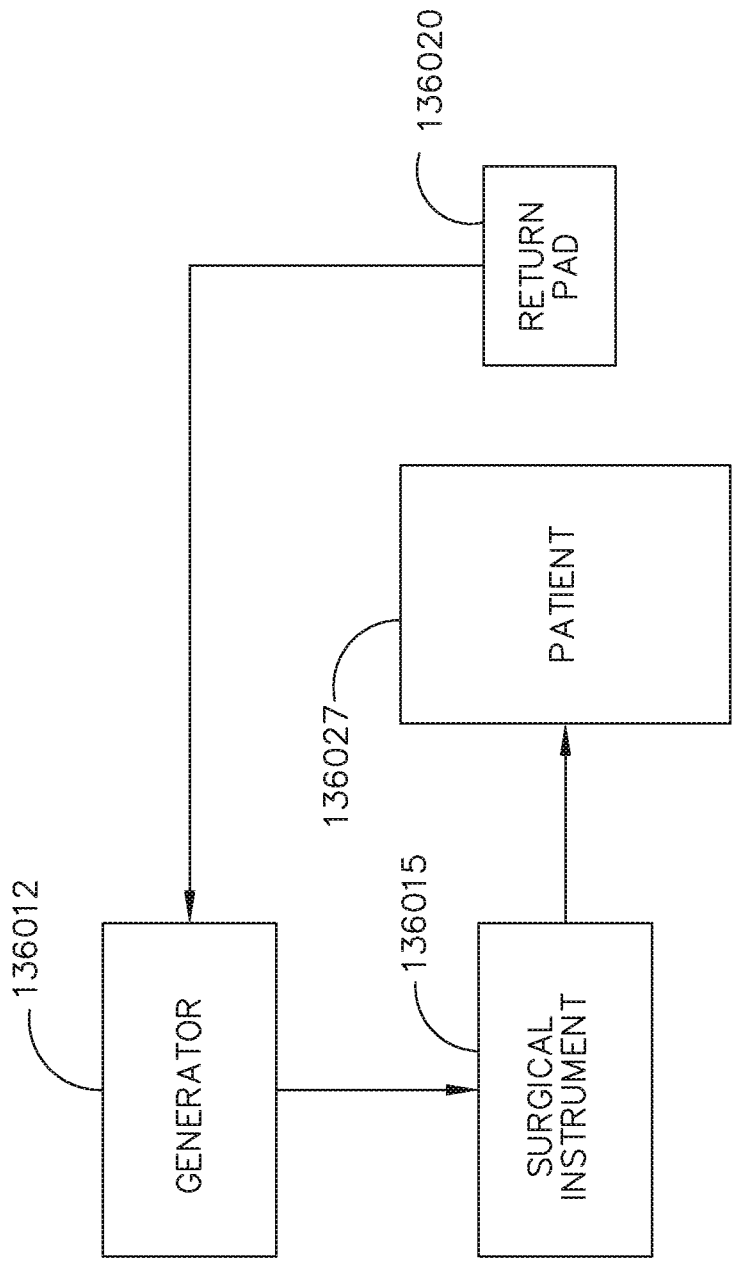
136020
RETURN PAD
PATIENT
136027
136012
GENERATOR
136015
SURGICAL INSTRUMENT

FIG. 31

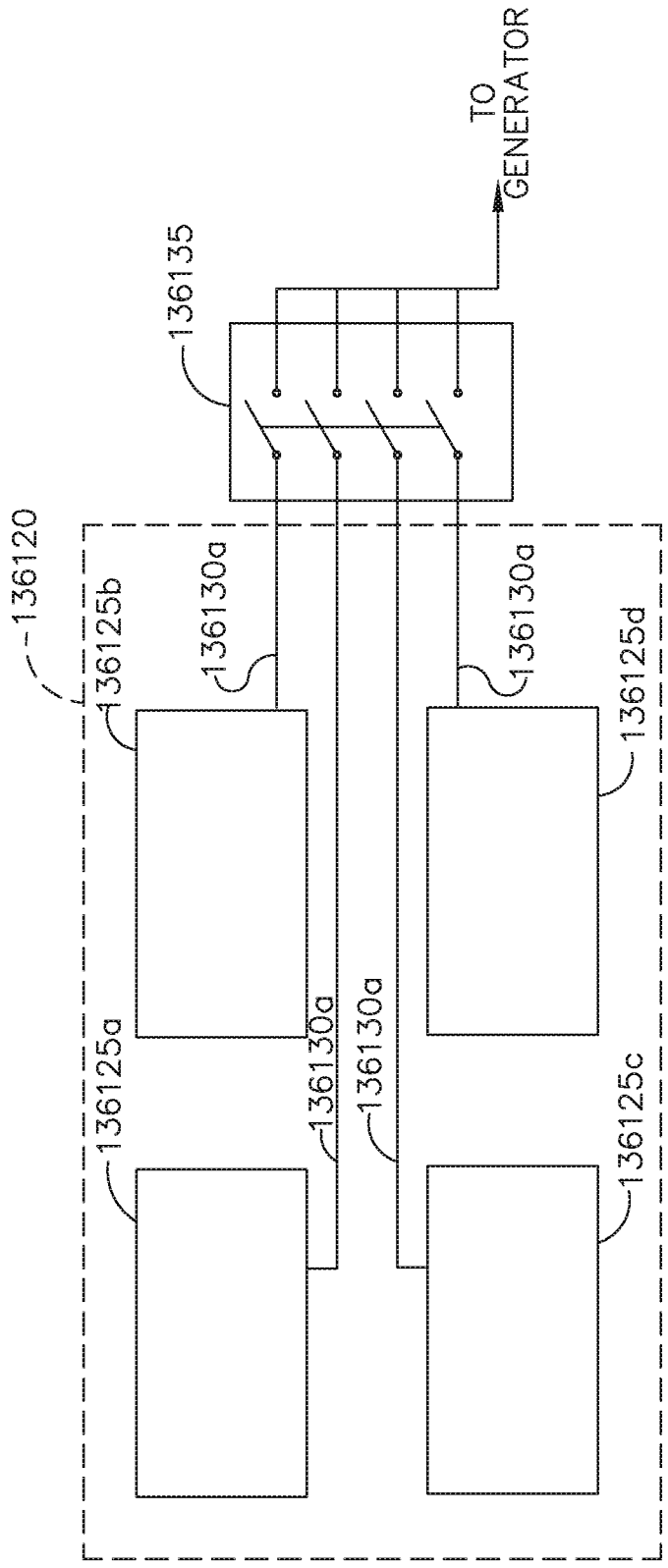
TO GENERATOR
136135
136120
136125b
136130a
136130a
136125d
136125a
136130a
136130a
136125c

FIG. 32

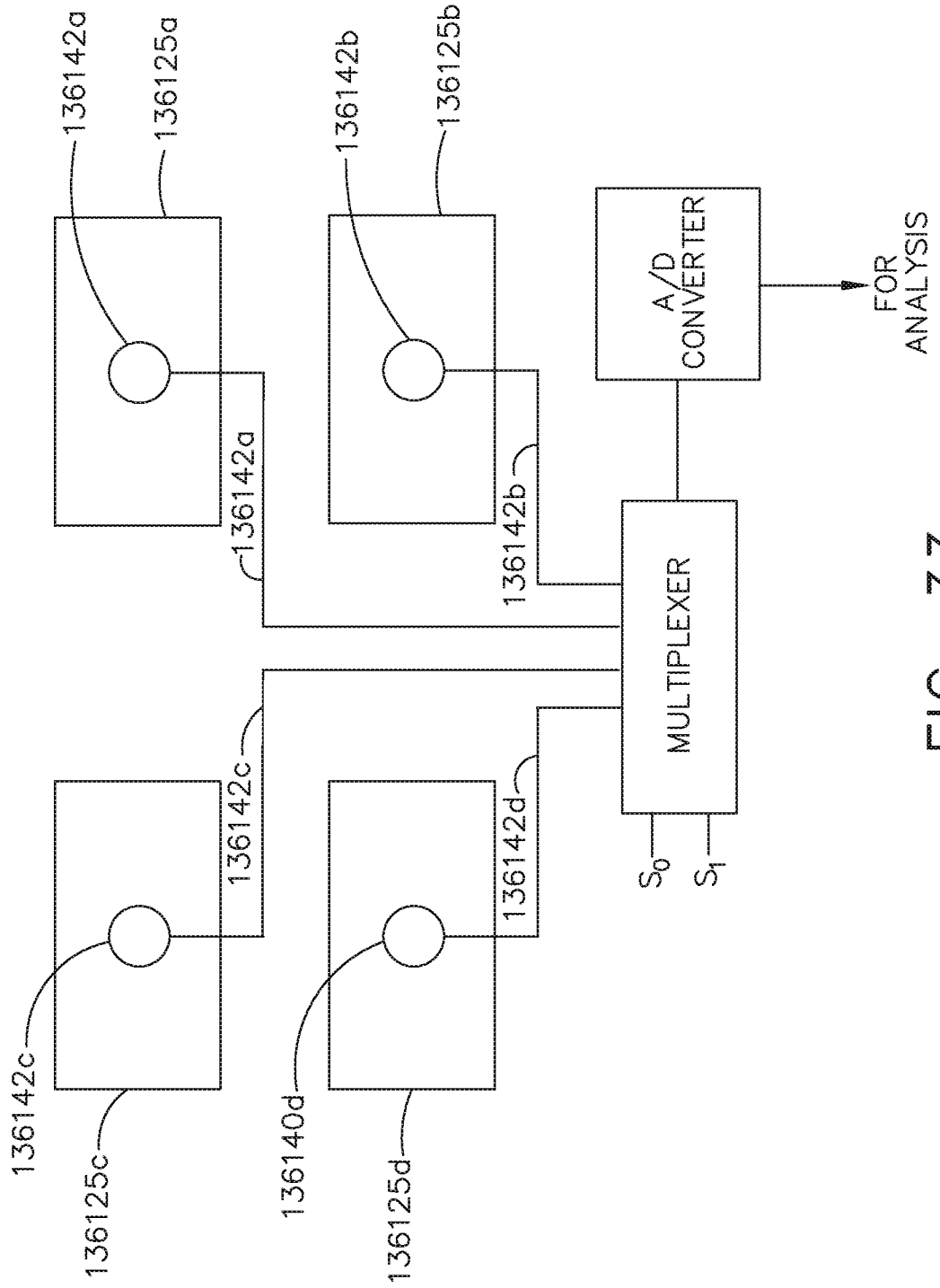
136142a
136125a
136142b
136125b
136142a
136142b
A/D CONVERTER
FOR ANALYSIS
MULTIPLEXER
136142c
136142d
$S_0$
$S_1$
136142c
136125c
136140d
136125d

FIG. 33

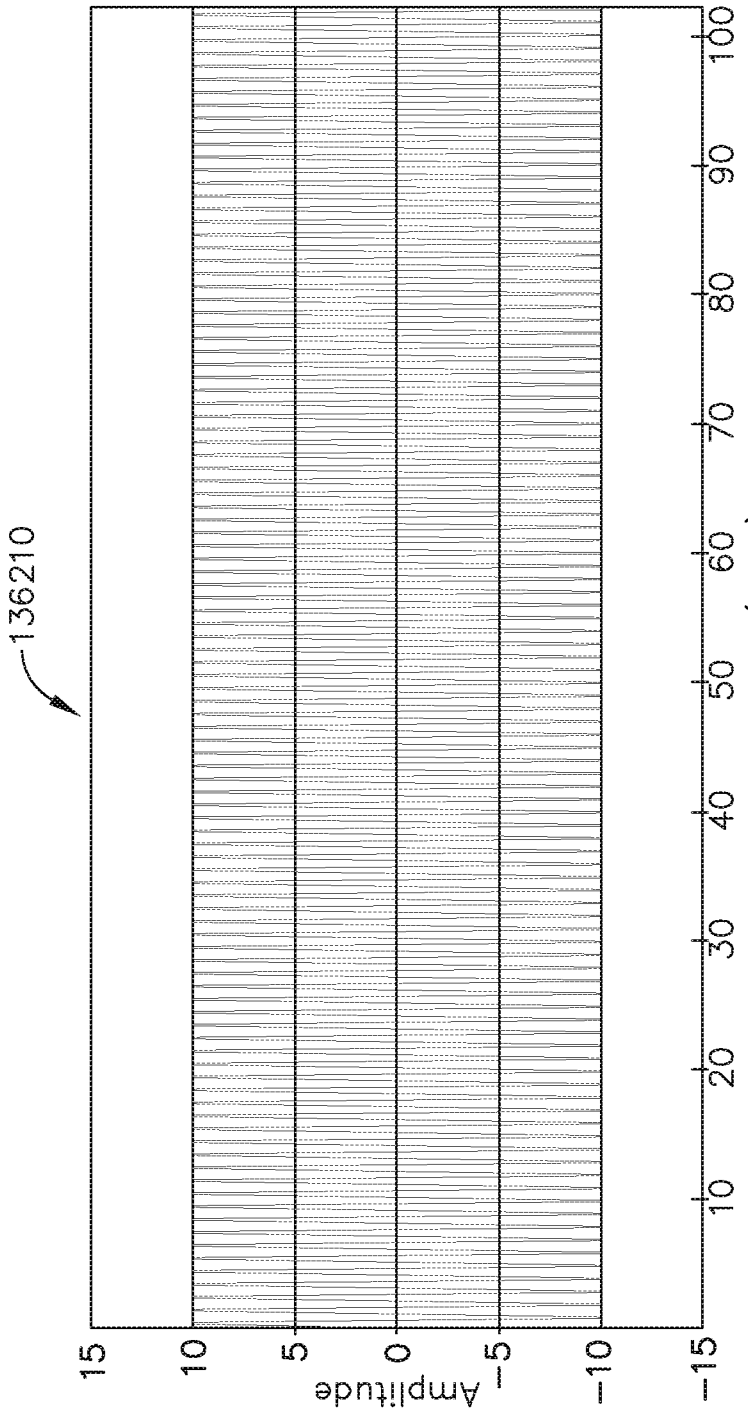
136210
Amplitude
15
10
5
0
−5
−10
−15
10
20
30
40
50
60
70
80
90
100
Time (μsec)

FIG. 34

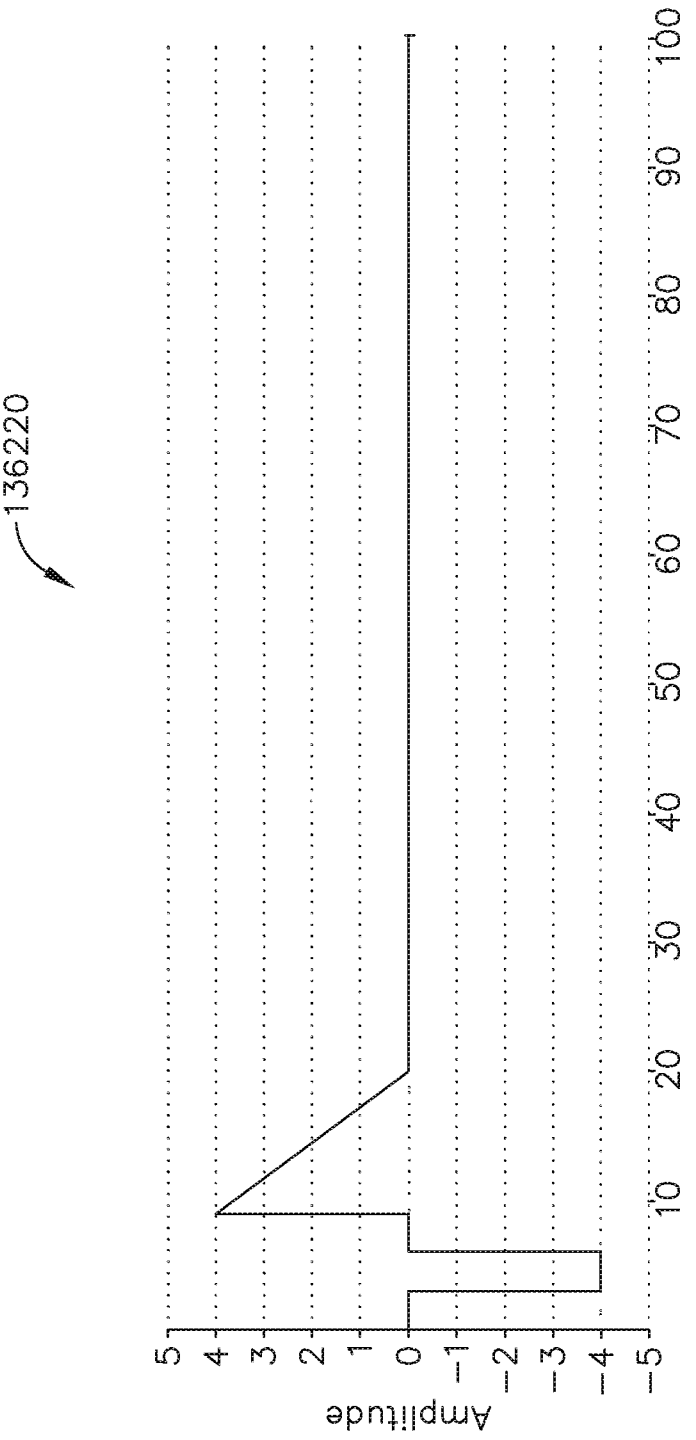
136220
Amplitude
5
4
3
2
1
0
−1
−2
−3
−4
−5
10
20
30
40
50
60
70
80
90
100
Time (μsec)

FIG. 35

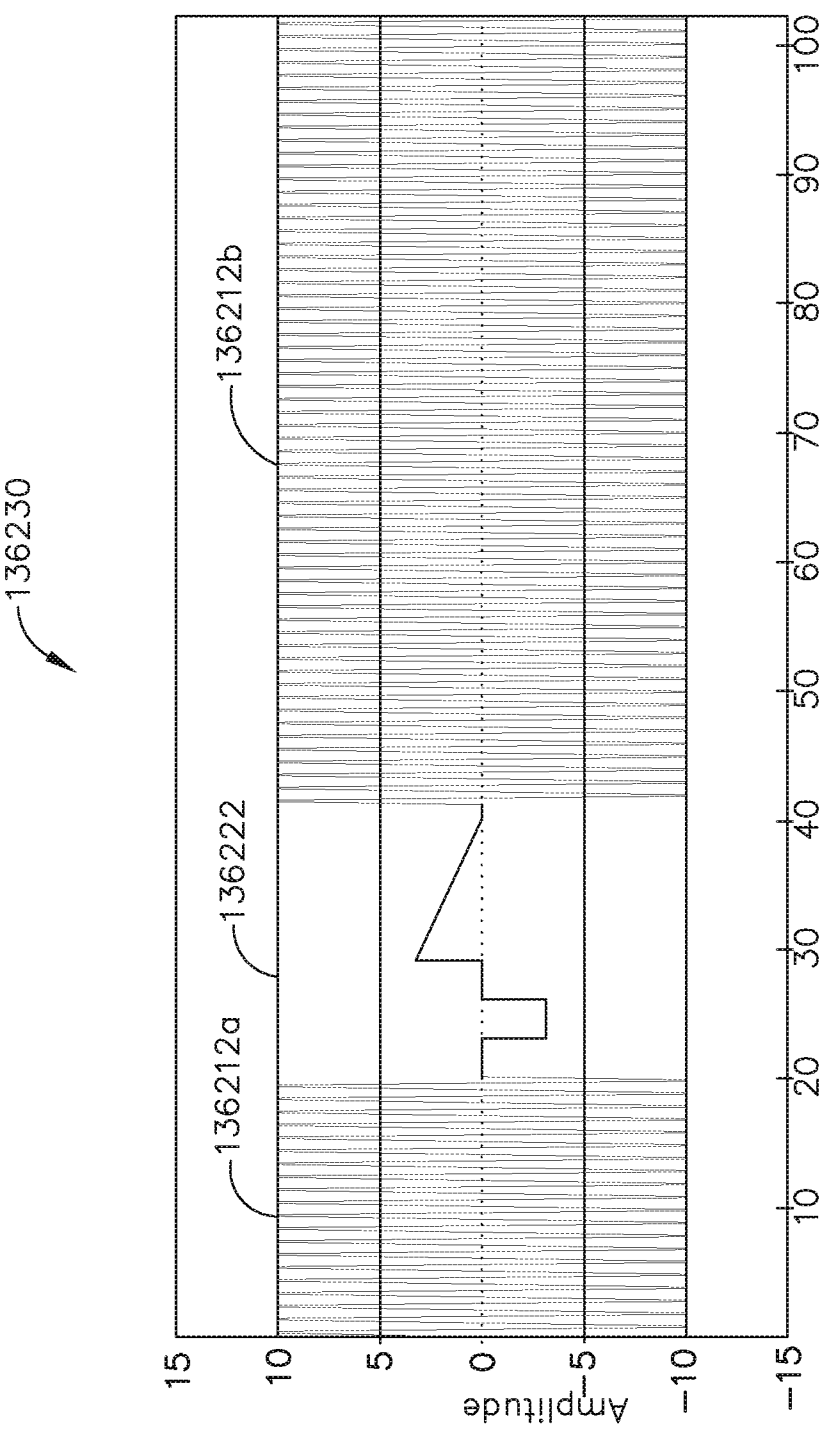
136230
136212b
136222
136212a
15
10
5
0
5
10
15
Amplitude
10
20
30
40
50
60
70
80
90
100
Time (μsec)

FIG. 36A

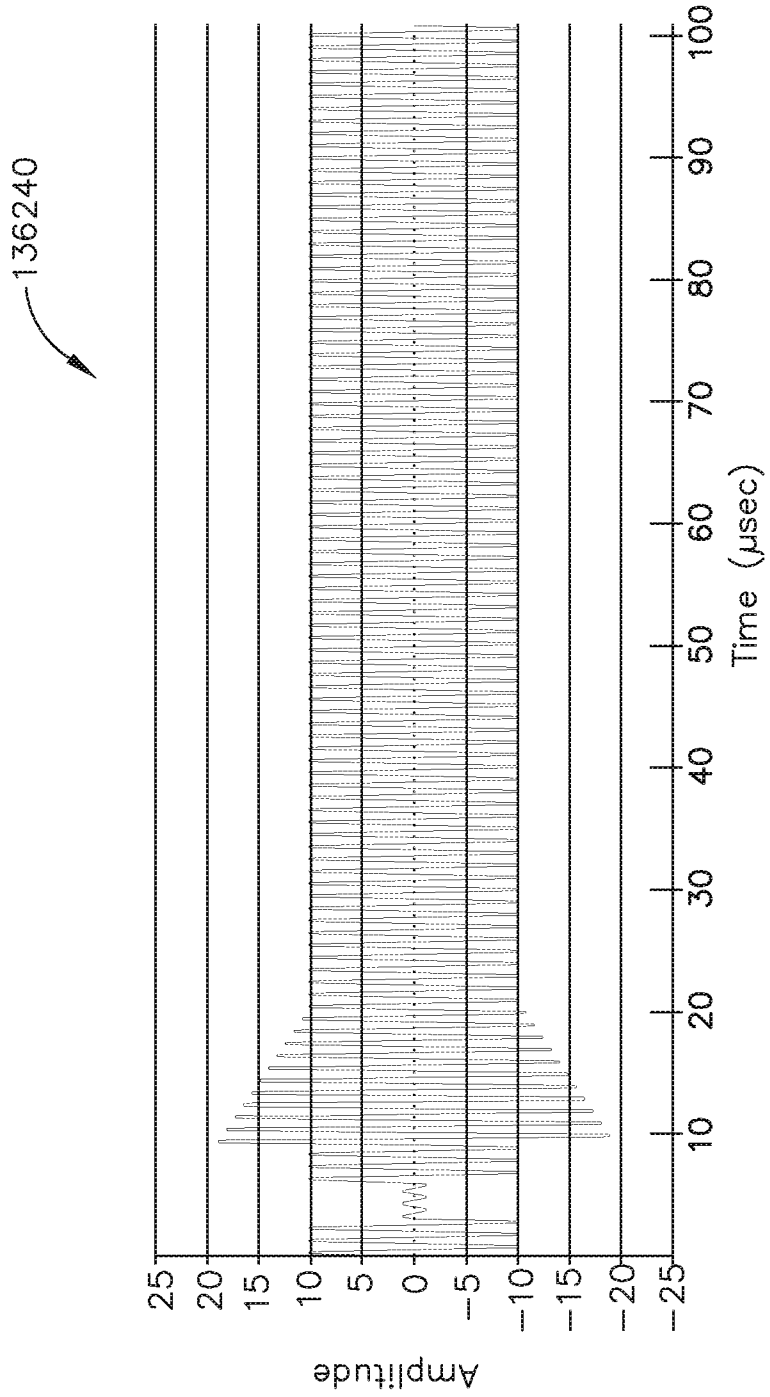
136240
Amplitude
25
20
15
10
5
0
−5
−10
−15
−20
−25
10
20
30
40
50
60
70
80
90
100
Time (μsec)

FIG. 36B

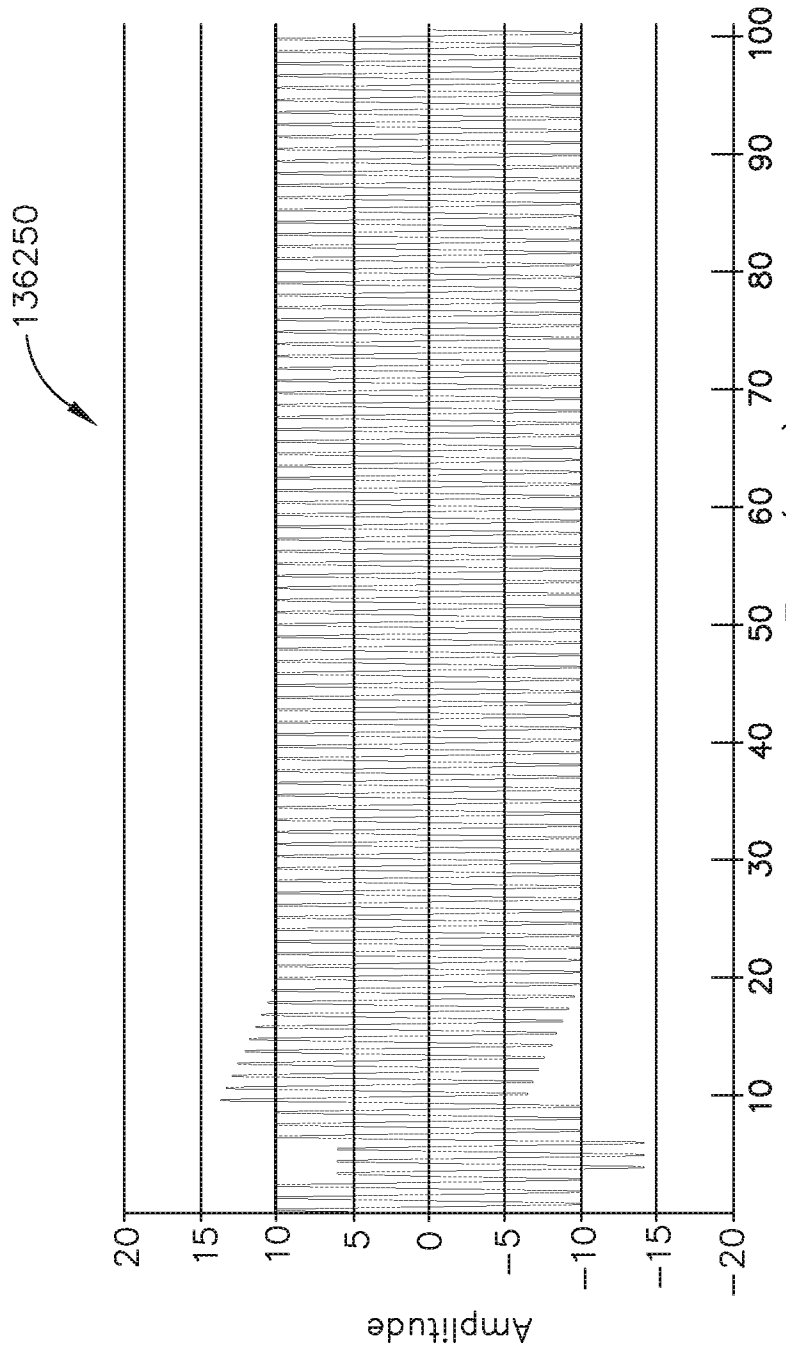
136250
Amplitude
20
15
10
5
0
−5
−10
−15
−20
10
20
30
40
50
60
70
80
90
100
Time (μsec)

FIG. 36C

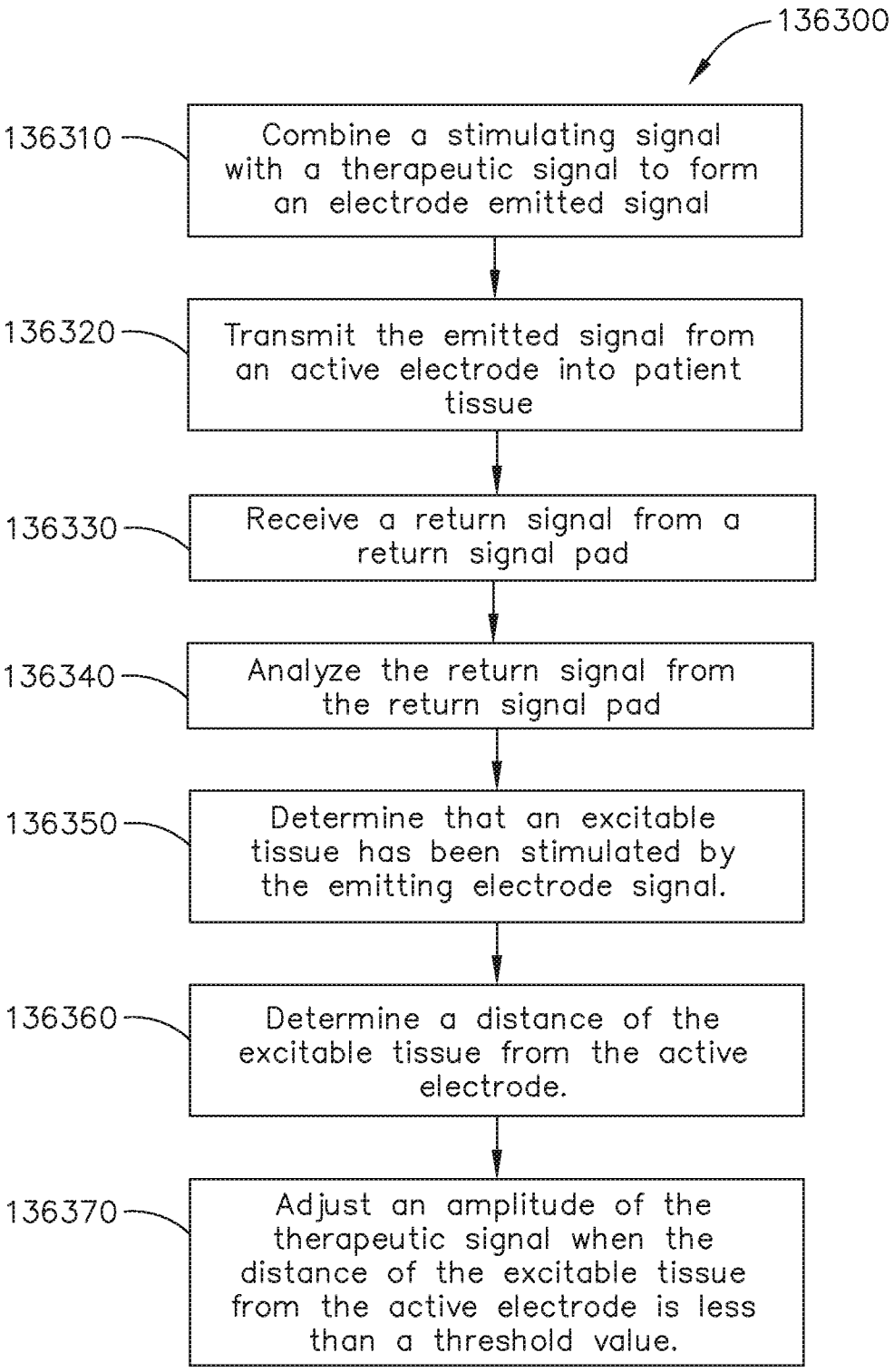
136300
136310
Combine a stimulating signal with a therapeutic signal to form an electrode emitted signal
136320
Transmit the emitted signal from an active electrode into patient tissue
136330
Receive a return signal from a return signal pad
136340
Analyze the return signal from the return signal pad
136350
Determine that an excitable tissue has been stimulated by the emitting electrode signal.
136360
Determine a distance of the excitable tissue from the active electrode.
136370
Adjust an amplitude of the therapeutic signal when the distance of the excitable tissue from the active electrode is less than a threshold value.

FIG. 37

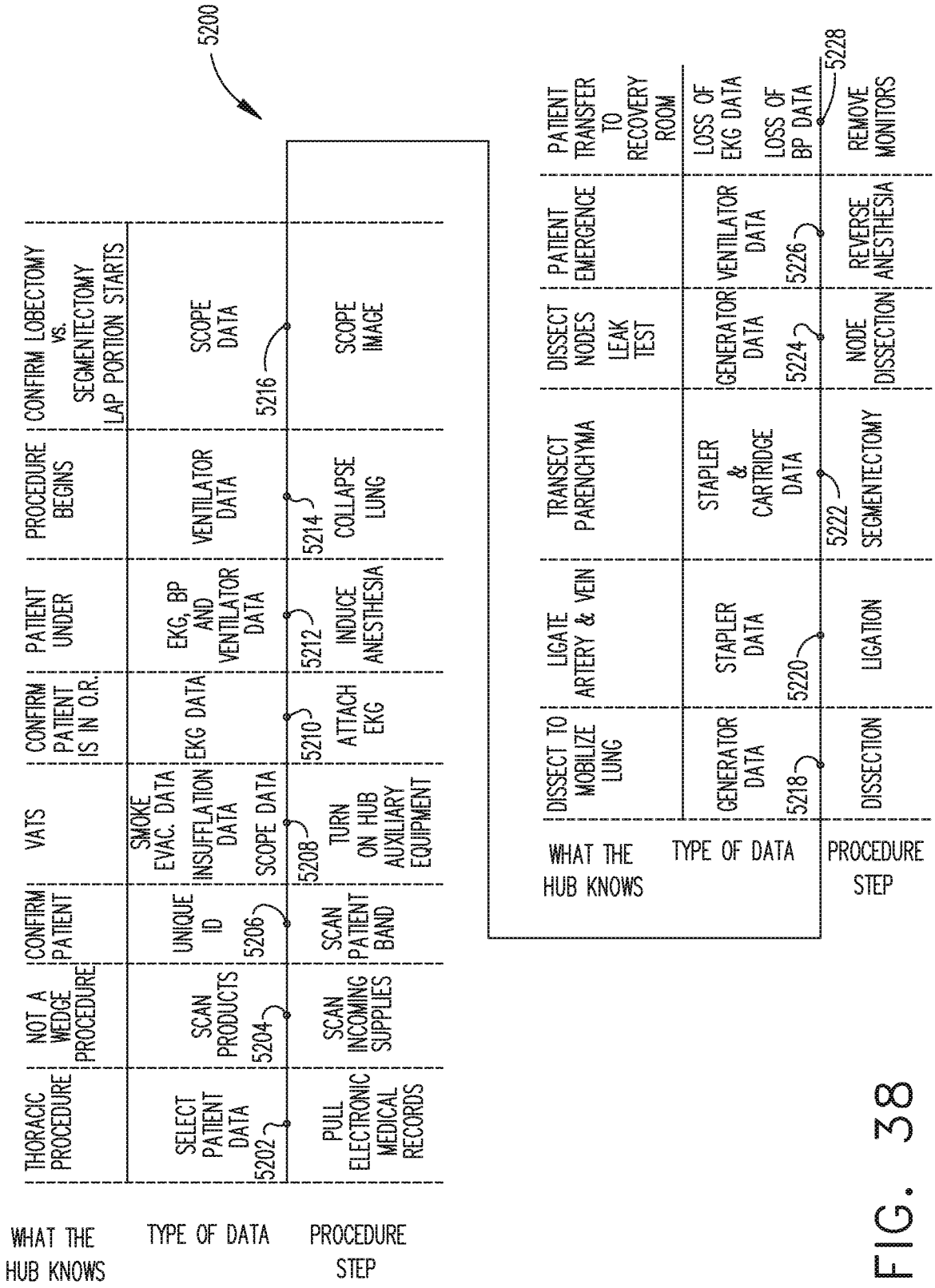
5200
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
THORACIC PROCEDURE
NOT A WEDGE PROCEDURE
CONFIRM PATIENT
VATS
CONFIRM PATIENT IS IN O.R.
PATIENT UNDER
PROCEDURE BEGINS
CONFIRM LOBECTOMY vs. SEGMENTECTOMY
SELECT PATIENT DATA
5202
SCAN PRODUCTS
5204
UNIQUE ID
5206
SMOKE EVAC. DATA
INSUFFLATION DATA
SCOPE DATA
5208
EKG DATA
EKG, BP AND VENTILATOR DATA
VENTILATOR DATA
SCOPE DATA
5216
PULL ELECTRONIC MEDICAL RECORDS
SCAN INCOMING SUPPLIES
SCAN PATIENT BAND
TURN ON HUB AUXILIARY EQUIPMENT
5210
ATTACH EKG
5212
INDUCE ANESTHESIA
5214
COLLAPSE LUNG
SCOPE IMAGE
DISSECT TO MOBILIZE LUNG
LIGATE ARTERY & VEIN
TRANSECT PARENCHYMA
DISSECT NODES
LEAK TEST
PATIENT EMERGENCE
PATIENT TRANSFER TO RECOVERY ROOM
GENERATOR DATA
5218
STAPLER DATA
5220
STAPLER & CARTRIDGE DATA
5222
GENERATOR DATA
5224
VENTILATOR DATA
5226
LOSS OF EKG DATA
LOSS OF BP DATA
5228
DISSECTION
LIGATION
SEGMENTECTOMY
NODE DISSECTION
REVERSE ANESTHESIA
REMOVE MONITORS

FIG. 38