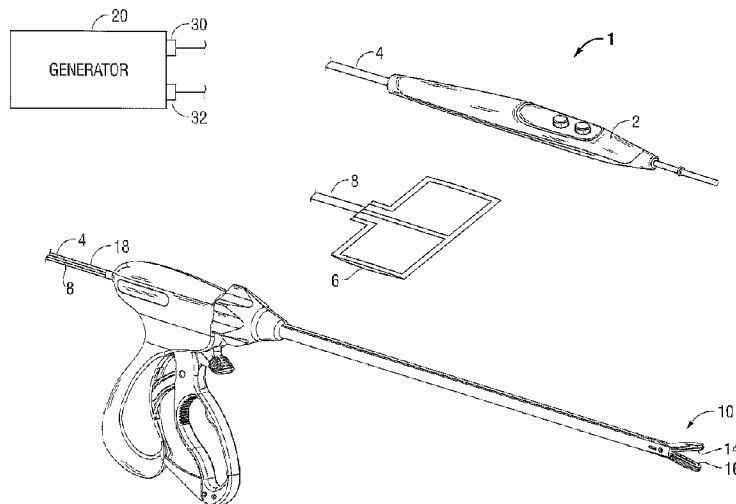




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 (72) **Inventeur/Inventor:**
ORSZULAK, JAMES H., US
 (73) **Propriétaire/Owner:**
COVIDIEN LP, US
 (74) **Agent:** OSLER, HOSKIN & HARCOURT LLP

(54) **Titre : APPAREIL ELECTROCHIRURGICAL DOTE D'UN DISPOSITIF DE COMMANDE EN TEMPS REEL DE L'ENERGIE RF DELIVREE AUX TISSUS**
 (54) **Title: ELECTROSURGICAL APPARATUS WITH REAL-TIME RF TISSUE ENERGY CONTROL**



(57) **Abrégé/Abstract:**

A radio-frequency (RF) amplifier having a direct response to an arbitrary signal source to output one or more electro-surgical waveforms within an energy activation request, is disclosed. The RF amplifier includes a phase compensator coupled to an RF arbitrary source, the phase compensator configured to generate a reference signal as a function of an arbitrary RF signal from the RF arbitrary source and a phase control signal; at least one error correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal; and at least one power component coupled to the at least one error correction amplifier and to a high voltage power source configured to supply high voltage direct current thereto, the at least one power component configured to operate in response to the control signal to generate at least one component of the at least one electro-surgical waveform.

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(71) Applicant (for all designated States except US): **COVIDI-EN LP** [US/US]; 15 Hampshire Street, Mansfield, Massachusetts 02048 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **ORSZULAK, James H.** [US/US]; 2200 Country Road 103, Nederland, Colorado 80466 (US).(74) Agent: **PERKINS, Stephen B.**; ATTN: IP LEGAL, 5920 Longbow Drive, Boulder, Colorado 80301 (US).

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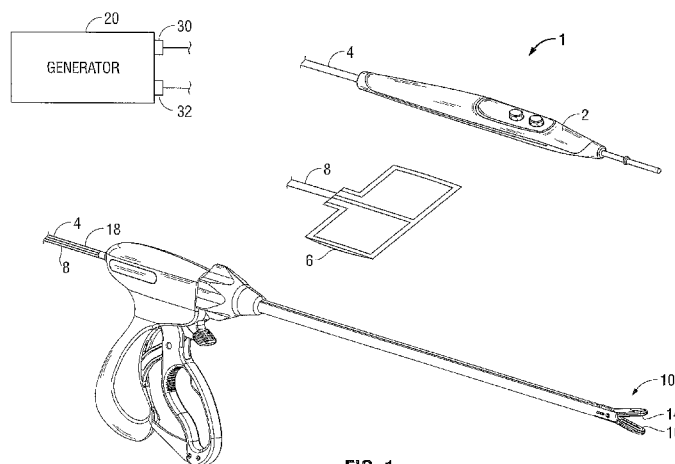


FIG. 1

(57) Abstract: A radio-frequency (RF) amplifier having a direct response to an arbitrary signal source to output one or more electrosurgical waveforms within an energy activation request, is disclosed. The RF amplifier includes a phase compensator coupled to an RF arbitrary source, the phase compensator configured to generate a reference signal as a function of an arbitrary RF signal from the RF arbitrary source and a phase control signal; at least one error correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal; and at least one power component coupled to the at least one error correction amplifier and to a high voltage power source configured to supply high voltage direct current thereto, the at least one power component configured to operate in response to the control signal to generate at least one component of the at least one electrosurgical waveform.



WO 2013/019702 A1

ELECTROSURGICAL APPARATUS WITH REAL-TIME RF TISSUE ENERGY CONTROL

10 BACKGROUND

Technical Field

The present disclosure relates to electrosurgical apparatuses, systems and methods. More particularly, the present disclosure is directed to an electrosurgical generator adapted for real-time adjustment of its output.

15 *Background of Related Art*

Energy-based tissue treatment is well known in the art. Various types of energy (e.g., electrical, ultrasonic, microwave, cryogenic, heat, laser, etc.) are applied to tissue to achieve a desired result. Electrosurgery involves application of high radio frequency electrical current, microwave energy or resistive heating to a surgical site to cut, ablate, coagulate or seal tissue.

20 In bipolar electrosurgery, one of the electrodes of the hand-held instrument functions as the active electrode and the other as the return electrode. The return electrode is placed in close proximity to the active electrode such that an electrical circuit is formed between the two electrodes (e.g., electrosurgical forceps). In this manner, the applied electrical current is limited to the body tissue positioned between the electrodes.

25 Bipolar electrosurgical techniques and instruments can be used to coagulate blood vessels or tissue, e.g., soft tissue structures, such as lung, brain and intestine. A surgeon can

5 either cauterize, coagulate/desiccate and/or simply reduce or slow bleeding, by controlling the intensity, frequency and duration of the electrosurgical energy applied between the electrodes and through the tissue. In order to achieve one of these desired surgical effects without causing unwanted charring of tissue at the surgical site or causing collateral damage to adjacent tissue, e.g., thermal spread, it is necessary to control the output from the
10 electrosurgical generator, e.g., power, waveform, voltage, current, pulse rate, etc.

In monopolar electrosurgery, the active electrode is typically a part of the surgical instrument held by the surgeon that is applied to the tissue to be treated. A patient return electrode is placed remotely from the active electrode to carry the current back to the generator and safely disperse current applied by the active electrode. The return
15 electrodes usually have a large patient contact surface area to minimize heating at that site. Heating is caused by high current densities which directly depend on the surface area. A larger surface contact area results in lower localized heat intensity. Return electrodes are typically sized based on assumptions of the maximum current utilized during a particular surgical procedure and the duty cycle (i.e., the percentage of time the generator is on).

20 Conventional electrosurgical generators operate in one operational mode (e.g., cutting, coagulation, spray, etc.) which is set prior to commencement of the procedure during a given activation period. If during treatment a need arises to switch from one mode to another, such as during a cutting procedure when a vessel is cut and begins to bleed, the first mode (e.g., cutting) is terminated manually and the second mode (e.g., coagulation) is switched on.
25 There is a need for an electrosurgical generator which can switch between a plurality of modes automatically in response to sensed tissue and/or energy feedback signals.

5 **SUMMARY**

A radio-frequency (RF) amplifier for outputting at least one electrosurgical waveform is disclosed. The RF amplifier includes a phase compensator coupled to an RF arbitrary source, the phase compensator configured to generate a reference signal as a function of an arbitrary RF signal from the RF arbitrary source and a phase control signal; at least one error
10 correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal; and at least one power component coupled to the at least one error correction amplifier and to a high voltage power source configured to supply high voltage direct current thereto, the at least one power component configured to operate in response to the control signal to generate
15 at least one component of the at least one electrosurgical waveform.

In another embodiment, an RF amplifier configured to output at least one electrosurgical waveform in response to an arbitrary RF signal is disclosed. The RF amplifier includes a phase compensator coupled to an RF arbitrary source, the phase compensator configured to generate a reference signal as a function of an arbitrary RF signal from the RF
20 arbitrary source and a phase control signal; at least one error correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal; at least one power component coupled to the at least one error correction amplifier, the at least one power component configured to operate in response to the control signal to generate at least one component of
25 the at least one electrosurgical waveform; at least one current sensor configured to measure current of the at least one electrosurgical waveform and to operate with the at least one power

5 component to output a current control signal as a function of the measured current; a patient
isolation transformer coupled to the RF amplifier, the patient isolation transformer including
a primary winding coupled to the at least one power component, wherein the patient isolation
is the only isolation coupling component for delivering the at least one electrosurgical
10 waveform to a patient and is configured to operate in a phase-correlated manner with the at
least one electrosurgical waveform of the RF amplifier; and a high voltage power source
configured to supply high voltage direct current to the RF amplifier.

In embodiments, an electrosurgical generator is disclosed. The generator includes a
high voltage power source configured to supply high voltage direct current; an RF arbitrary
source configured to generate an arbitrary RF signal; and a radio-frequency (RF) amplifier
15 configured to output at least one electrosurgical waveform. The RF amplifier includes: a
phase compensator coupled to the RF arbitrary source, the phase compensator configured to
generate a reference signal as a function of the arbitrary RF signal from the RF arbitrary
source and a phase control signal; at least one error correction amplifier coupled to the phase
compensator, the at least one error correction amplifier configured to output a control signal
20 at least as a function of the reference signal; and at least one power component coupled to the
at least one error correction amplifier and to the high voltage power source, the at least one
power component configured to operate in response to the control signal to generate at least
one component of the at least one electrosurgical waveform. The generator also includes a
controller configured to adjust at least one of the arbitrary RF signal and the phase control
25 signal in response to at least one selected electrosurgical operational mode.

5 According to another embodiment of the present disclosure, an electrosurgical generator is disclosed. The generator includes a high voltage power source configured to supply high voltage direct current; an RF arbitrary source configured to generate an arbitrary RF signal; and one or more radio-frequency (RF) amplifiers configured to output at least one electrosurgical waveform. The radio-frequency (RF) amplifiers include: a phase compensator
10 coupled to the RF arbitrary source, the phase compensator configured to generate a reference signal as a function of the arbitrary RF signal from the RF arbitrary source and a phase control signal; a first control loop and a second control loop. The first control loop includes a first error correction amplifier coupled to the phase compensator, the first error correction amplifier configured to output a first control signal at least as a function of the reference
15 signal and a first power component coupled to the first error correction amplifier and to the high voltage power source, the first power component configured to operate in response to the first control signal to generate a first component of the at least one electrosurgical waveform. The second control loop includes a second error correction amplifier coupled to the phase compensator, the second error correction amplifier configured to output a second control
20 signal at least as a function of the reference signal; and a second power component coupled to the second error correction amplifier and to the high voltage power source, the second power component configured to operate in response to the second control signal to generate a second component of the at least one electrosurgical waveform. The generator also includes a controller configured to adjust at least one of the arbitrary RF signal and the phase control
25 signal in response to at least one selected electrosurgical operational mode.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

Various embodiments of the present disclosure are described herein with reference to the drawings wherein:

Fig. 1 is a schematic block diagram of an electrosurgical system according to one embodiment of the present disclosure;

10 Fig. 2 is a front view of an electrosurgical generator according to an embodiment of the present disclosure;

Fig. 3 is a schematic block diagram of the electrosurgical generator of Fig. 2 according to an embodiment of the present disclosure; and

15 Fig. 4 is a schematic block diagram of a radio frequency amplifier of the electrosurgical generator of Fig. 3 according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

Particular embodiments of the present disclosure are described hereinbelow with reference to the accompanying drawings. In the following description, well-known functions or constructions are not described in detail to avoid obscuring the present disclosure in
20 unnecessary detail.

The generator according to the present disclosure can perform monopolar and/or bipolar electrosurgical procedures, including vessel sealing procedures. The generator may include a plurality of outputs for interfacing with various electrosurgical instruments (e.g., a monopolar active electrode, return electrode, bipolar electrosurgical forceps, footswitch,

5 etc.). Further, the generator includes electronic circuitry configured for generating radio frequency power specifically suited for various electrosurgical modes (e.g., ablation, coagulation, cutting, blending, division, etc.) and procedures (e.g., monopolar, bipolar, vessel sealing).

Fig. 1 is a schematic illustration of a bipolar and monopolar electrosurgical system 1
10 according to one embodiment of the present disclosure. The system 1 includes one or more monopolar electrosurgical instruments 2 having one or more electrodes (e.g., electrosurgical cutting probe, ablation electrode(s), etc.) for treating tissue of a patient. Electrosurgical energy is supplied to the instrument 2 by a generator 20 via a supply line 4 that is connected to an active terminal 30 of the generator 20, allowing the instrument 2 to coagulate, ablate
15 and/or otherwise treat tissue. The energy is returned to the generator 20 through a return electrode 6 via a return line 8 at a return terminal 32 of the generator 20. The system 1 may include a plurality of return electrodes 6 that are arranged to minimize the chances of tissue damage by maximizing the overall contact area with the patient. In addition, the generator 20 and the return electrode 6 may be configured for monitoring so-called "tissue-to-patient"
20 contact to insure that sufficient contact exists therebetween to further minimize chances of tissue damage.

The system 1 may also include a bipolar electrosurgical forceps 10 having one or more electrodes for treating tissue of a patient. The electrosurgical forceps 10 includes opposing jaw members having one or more active electrodes 14 and a return electrode 16
25 disposed therein. The active electrode 14 and the return electrode 16 are connected to the generator 20 through cable 18 that includes the supply and return lines 4, 8 coupled to the

5 active and return terminals 30, 32, respectively. The electrosurgical forceps 10 is coupled to the generator 20 at a connector 60 or 62 (Fig. 2) having connections to the active and return terminals 30 and 32 (e.g., pins) via a plug (not shown) disposed at the end of the cable 18, wherein the plug includes contacts from the supply and return lines 4, 8.

With reference to Fig. 2, the generator 20 may be any suitable type (e.g.,
10 electrosurgical, microwave, etc.) and may include a plurality of connectors 50-62 to accommodate various types of electrosurgical instruments (e.g., multiple instruments 2, electrosurgical forceps 10, etc.). With reference to Fig. 2, front face 40 of the generator 20 is shown. The generator 20 includes one or more display screens 42, 44, 46 for providing the user with variety of output information (e.g., intensity settings, treatment complete indicators,
15 etc.). Each of the screens 42, 44, 46 is associated with a corresponding connector 50-62. The generator 20 includes suitable input controls (e.g., buttons, activators, switches, touch screen, etc.) for controlling the generator 20. The display screens 42, 44, 46 are also configured as touch screens that display a corresponding menu for the electrosurgical instruments (e.g., multiple instruments 2, electrosurgical forceps 10, etc.). The user then makes inputs by
20 simply touching corresponding menu options.

The generator 20 is configured to operate in a variety of modes. In one embodiment, the generator 20 may output the following modes, cut, blend, division with hemostasis, fulgurate and spray. Each of the modes operates based on a preprogrammed power curve that dictates how much power is output by the generator 20 at varying impedance ranges of the
25 load (e.g., tissue). Each of the power curves includes power, voltage and current control

5 range that are defined by the user-selected power setting and the measured minimum impedance of the load.

In the cut mode, the generator 20 may supply a continuous sine wave at a predetermined frequency (e.g., 472 kHz) having a crest factor of about 1.5 with an impedance of from about 100 Ω to about 2,000 Ω . The cut mode power curve may include three regions:
10 constant current into low impedance, constant power into medium impedance and constant voltage into high impedance. In the blend mode, the generator may supply bursts of a sine wave at the predetermined frequency, with the bursts reoccurring at a first predetermined rate (e.g., about 26.21 kHz). In one embodiment, the duty cycle of the bursts may be about 50%. The crest factor of one period of the sine wave may be about 1.5. The crest factor of the burst
15 may be about 2.7.

The division with hemostasis mode may include bursts of sine waves at a predetermined frequency (e.g., 472 kHz) reoccurring at a second predetermined rate (e.g., about 28.3 kHz). The duty cycle of the bursts may be about 25%. The crest factor of one burst may be about 4.3 across an impedance of from about 100 Ω to about 2,000 Ω . The fulgurate
20 mode may include bursts of sine waves at a predetermined frequency (e.g., 472 kHz) reoccurring at a third predetermined rate (e.g., about 30.66 kHz). The duty cycle of the bursts may be about 6.5% and the crest factor of one burst cycle may be about 5.55 across an impedance range of from about 100 Ω to about 2,000 Ω . The spray mode may include bursts of sine wave at a predetermined frequency (e.g., 472 kHz) reoccurring at a fourth
25 predetermined rate (e.g., about 21.7 kHz). The duty cycle of the bursts may be about 4.6%

5 and the crest factor of one burst cycle may be about 6.6 across the impedance range of from about 100 Ω to about 2,000 Ω .

The screen 46 of Fig. 2 controls bipolar sealing procedures performed by the forceps 10 that may be plugged into the connectors 60 and 62. The generator 20 outputs energy through the connectors 60 and 62 suitable for sealing tissue grasped by the forceps 10. The 10 screens 42 and 44 control monopolar output and the devices connected to the connectors 50 and 56. The connector 50 is configured to couple to the instrument 2 and the connector 52 is configured to couple to a foot switch (not shown). The foot switch provides for additional inputs (e.g., replicating inputs of the generator 20 and/or instrument 2). The screen 44 controls monopolar and bipolar output and the devices connected to the connectors 56 and 58, 15 respectively. Connector 56 is configured to couple to the instrument 2, allowing the generator 20 to power multiple instruments 2. Connector 58 is configured to couple to a bipolar instrument (not shown). When using the generator 20 in monopolar mode (e.g., with instruments 2), the return electrode 6 is coupled to the connector 54, which is associated with the screens 42 and 44. The generator 20 is configured to output the modes discussed above 20 through the connectors 50, 56, 58.

Fig. 3 shows a system block diagram of the generator 20 configured to output 25 electrosurgical energy. The generator 20, a controller 24, a high voltage DC power supply 27 (“HVPS”), a radio frequency amplifier 28, including an RF amplifier 28a and an RF amplifier 28b, includes a radio frequency (RF) arbitrary source 34, a sense processor 36, and a patient isolation transformer 38 including a primary winding 38a and a secondary winding 38b.

5 The HVPS 27 of Fig. 3 is configured to output high DC voltage from about 15 V DC to about 200 V DC and is connected to an AC source (e.g., electrical wall outlet) and provides high voltage DC power to the RF amplifier 28, which then converts high voltage DC power into radio frequency energy and delivers the energy to the terminals 30 and 32, which are, in turn, coupled to the connectors 50-62 for supplying energy to the instrument 2 and the return
10 pad 6 or the forceps 10. The HVPS 27 is coupled to the RF amplifiers 28a and 28b and provides DC energy thereto in a transparent manner to the operation of the RF amplifiers 28a and 28b. In particular, the controller 24 provides an HVPS control signal to drive the positive and negative potentials of the HVPS 27 for each of the RF amplifiers 28a and 28b with sufficient power to allow for uninhibited operation of the RF amplifiers 28a and 28b. In other
15 words, the controller 24 may control the RF amplifiers 28a and 28b via the RF arbitrary source 34 or directly without adjusting the HVPS 27.

The RF arbitrary source 34 may be any RF signal generator such as a voltage controlled oscillator, a direct digital synthesizer, or any suitable frequency generator configured to generate arbitrary waveforms from a fixed frequency reference clock. As
20 herein, the term “arbitrary” denotes an RF signal that may be any arbitrarily defined waveform, e.g., any frequency, amplitude, duty cycle, etc. The RF arbitrary source 34 supplies an RF signal to the RF amplifiers 28a and 28b. In embodiments, the RF signal may be a bipolar two-quadrant sinusoidal arbitrary RF signal. The RF amplifiers 28a and 28b process the RF arbitrary source signal and generate a differential RF drive signal to the patient
25 isolation transformer 38. RF output parameters, such as operating RF power, voltage and current amplitude, operating frequency, gain parameters, phase compensation, time dependent

5 configuration of the RF arbitrary source 34, are processed by the RF amplifiers 28a and 28b to deliver prescribed RF clinical treatment energy to achieve a desired tissue effect.

The RF amplifier 28a and RF amplifier 28b are coupled to the primary winding 38a of the patient isolation transformer 38. The RF amplifier 28a is configured to output a positive half-cycle having a phase angle from about 0° to about 180° and the RF amplifier 28b is
10 configured to output a negative half-cycle having a phase angle from about 0° to about -180° . Thus, while the RF amplifier 28a is providing sourcing RF current (e.g., outputs positive current), the RF amplifier 28b is providing sinking current (e.g., outputs negative current). Conversely, while the RF amplifier 28b is providing sourcing RF current (e.g., outputs positive current), the RF amplifier 28a is providing sinking current (e.g., outputs negative
15 current).

The patient isolation transformer 38 combines the differential RF drive output of the RF amplifiers 28a and 28b to deliver phase correlated RF energy (e.g., waveform) across to the secondary winding 38b to the terminals 30 and 32 with high signal-to-noise immunity to common-mode generated, spurious processing noise. In other words, the differential RF
20 drive output provides the common mode rejection and cancels spurious corruptive noise energy from altering the prescribed clinical treatment tissue effect. This allows for the phase-correlated RF energy to be adjustable, providing potential for new control modes to dynamically alter in real-time the crest factor and other parameters of the delivered RF waveshape within a given applied energy activation period.

25 The sense processor 36 is coupled to a voltage sensor 41 and a current sensor 43. The voltage sensor 41 includes a resistor element 45 that provides an RF current weighted

5 measurement of the delivered RF voltage to the terminals 30 and 32. A current transformer
47 then converts the weighted value of the RF voltage to provide a voltage sense signal to the
sense processor 36 for processing. The current sensor 43 similarly provides a current sense
signal to the sense processor 36.

The sense processor 36 then transmits the voltage and current sense signals to the
10 controller 24, which adjusts RF output parameters in response to algorithm controls within a
given RF activation period in real-time. In particular, the controller 24 adjusts the amplitude,
frequency, waveshape and time-dependent configuration of the RF arbitrary source 34 during
the given RF activation period to deliver a variety of RF treatment modes. The treatment
modes may include waveforms having a duty cycle from about 5% to about 100% and may be
15 either continuous waves or variant duty cycle RF bursts, or alternate in single or multiple
combinations between modes to create a specific RF mode sequence. In embodiments, the
controller 24 is configured to control the RF arbitrary source 34, the RF amplifier 28a and
28b, and/or the HVPS 27 in response to a selected electrosurgical operational mode, which
may be selected from a plurality of electrosurgical operational modes. Each electrosurgical
20 operational mode may be associated with at least one radio frequency input signal
corresponding to a desired output electrosurgical waveform.

The controller 24 may include a microprocessor operably connected to a memory,
which may be volatile type memory (e.g., RAM) and/or non-volatile type memory (e.g., flash
media, disk media, etc.). The controller 24 may also include a plurality of output ports that
25 are operably connected to the HVPS 27 and the RF amplifiers 28a and 28b allowing the
controller 24 to control the output of the generator 20. More specifically, the controller 24

5 adjusts the operation of the HVPS 27 and the RF amplifiers 28a and 28b in response to a control algorithm that is implemented to track output of the RF amplifiers 28a and 28b to provide for sufficient power from the HVPS 27. In particular, as discussed in more detail below with respect to Fig. 4, the controller 24 supplies gain and phase control signals to each of the RF amplifiers 28a and 29b. In embodiments, a control algorithm may also inhibit or
10 limit the output of RF amplifiers 28a and 28b to fit within the power supply limitations.

Fig. 4 illustrates the components of the RF amplifier 28a. The circuit design of RF amplifier 28b is substantially similar to the RF amplifier 28a, with the exception for the phase relationship, as discussed above, accordingly, only the RF amplifier 28a is discussed. The RF amplifier 28a is a non-resonant multi-frequency transconductance amplifier configured to
15 generate an RF current output for an applied RF voltage input. The RF voltage input signal may have an arbitrary waveshape as provided by the RF arbitrary source 34 as discussed above.

The RF amplifier 28a is configured to operate with two RF control loops 100a and 100b to control each of the components of an electrosurgical waveform, e.g., each half of an
20 applied two-quadrant sinusoidal or non-sinusoidal arbitrary RF signal input, having symmetric or non-symmetric waveshape and variable timing, to address user configurable operating modes for achieving the desired clinical effect. RF control loops 100a and 100b are closed loop controlled RF channels where each positive or negative half of the applied sinusoidal input is processed independently. Control loop 100a processes the negative half-
25 cycle of the applied sinusoidal input, driving a power component 102a to create a positive half cycle source current at the primary side 38a of the patient isolation transformer 38.

5 Control loop 100b processes the positive half-cycle of the applied sinusoidal input, driving a power component 102b to create a negative half cycle source current at the primary side 38a of the patient isolation transformer 38. The power components 102a and 102b are shown as p-type and n-type metal-oxide semiconductor field-effect transistors, respectively. In
10 embodiments, the power components 102a and 102b may be any p-type or n-type transistor, MOSFET, insulated gate bipolar transistor, (IGBT), relay, and the like. The patient isolation transformer 38 combines the developed RF current from the RF amplifiers 28a and 28b at the secondary winding 38b to generate the arbitrary sinusoidal RF output that is the supplied to the terminals 30 and 32 for delivery to the tissue site.

Only the control loop 100a is discussed in detail, since the control loop 100b is
15 substantially identical with like components being labeled with same identifiers having a letter "b." The arbitrary RF signal from the RF arbitrary source 34 is applied at an input 104 of a phase compensator 108. In addition, a phase control signal from the controller 24 is applied at an input 106 at the phase compensator 108. The phase compensator 108 establishes the output phase of the RF amplifier 28a, which may be set to the desired phase
20 (e.g., 0°) reference relative to the applied arbitrary RF signal input 104 in response to the phase control signal from the controller 24.

The phase compensator 108 provides a reference signal to an error correction amplifier 110a (or error correction amplifier 110b) at a positive input 112a. The error correction amplifier 110a is configured as an RF error correction amplifier that utilizes the
25 reference signal at the positive input 112a to control the output current, which is sensed by an RF current sensor 116a and supplied to a negative input 114a of the error correction amplifier

5 110a. The error correction amplifier 110a outputs an RF control signal as a function of the reference signal and the detected output current. The RF current sensor 116a may be a current transformer, which may be a component of the current sensor 43. The RF current sensor 116a monitors the developed RF output current by converting the RF current to a signal voltage, which is then returned to the negative input 114a of the error correction
10 amplifier 110a. A second frequency compensation network 126a provides frequency stability feedback compensation to the developed RF output current.

The first loop 100a also includes a gain selector 118a that provides a gain control adjustment to the output current control signal based on the gain controls signal supplied by the controller 24. The gain selector 118a is connected to the negative input 114a of the error
15 correction amplifier 110a and provides gain modification to the RF current sensor 116a. The gain selector 118a is coupled to a first frequency compensating network 120a, which is used by the error correction amplifier 110a to map the output current to the applied reference voltage from the phase compensator 108. The frequency compensating network 120a provides stability corrected at the applied fundamental operating frequency of the arbitrary RF
20 signal input to the sensed return signal detected by the RF current sensor 116a.

The error-corrected output signal of the error correction amplifier 110a is supplied to a gain amplifier 122a, which is configured as an RF gain cell to provide a forward path gain for the error correction output signal. The output of the gain amplifier 122a then drives the gate of the power component 102a through a resistor element 124a and RF coupler components
25 128a as the drive signal is elevated to the operating voltage of the HVPS 27. RF coupler components 128a may include, but are not limited to, a capacitor, a transformer, an optical

5 coupler, combinations thereof, and the like. The gain amplifier 122a also drives a second frequency compensating network 126a to provide a second level of frequency compensation for the developed RF output current.

The power component 102a is shown as a MOSFET device having a gate contact 134a, a source contact 136a and a drain contact 138a. The power component 102a presents a
10 transconductance gain, converting the drive voltage from the gain amplifier 122a to an RF output current, which is applied to the primary winding 38a. The power component 102a is coupled to a resistor element 130a at the gate contact 134a and a resistor element 132a at the +V HVPS power. The resistor element 130a establishes the DC bias operating level of the power component 102a and the resistor element 132a provides source degeneration to the
15 developed current of the power component 102a.

The RF amplifier 28a also includes a stabilization amplifier 140, which is configured as a DC stabilization amplifier for monitoring the output DC voltage level generated by the output DC bias currents of the power components 102a and 102b flowing into a shunted resistor element 142. The DC voltage through the resistor element 142 is maintained at
20 approximately 0 V DC by introducing steering error correction currents 144a and 144b via the stabilization amplifier 140 to the resistor elements 130a and 130b, respectively.

The stabilization amplifier 140 also provides a DC bias set point that establishes a relative transconductance gain match between power components 102a (e.g., p-channel MOSFET) and power component 102b (n-channel MOSFET), such that the positive and
25 negative output peak currents delivered to the patient isolation transformer are symmetrically balances over the minimum and maximum dynamic range of the output current signal level.

5 Conventional electrosurgical generators have a slower response time in delivery of RF energy to the tissue, which results in less than optimal tissue effect. In particular, the response is slowed by the high voltage power supply, which controls the rate of change with which RF energy can be delivered to the tissue site. In such designs, a controller initially drives the high voltage power source, which then drives the RF output stage.

10 Further, conventional generators are based on various resonant output topologies. Resonant RF energy source operate at a unique switching frequency, which delivers both a fundamental RF operating frequency as well as additional switching frequency harmonics. The harmonic frequency components deliver an uncontrolled corruptive level of energy to the tissue, which may result in undesirable tissue effects. The harmonic frequency components
15 also increase the RF high frequency leakage present in energy delivered to the patient.

 Resonant-based RF generators also include reactive LC (inductor/capacitor) components to establish resonant operation. The LC components act as energy storage components due to resonant switching operation and may also discharge the stored energy into the tissue, thereby also resulting in undesirable tissue effects.

20 While several embodiments of the disclosure have been shown in the drawings and/or discussed herein, it is not intended that the disclosure be limited thereto, as it is intended that the disclosure be as broad in scope as the art will allow and that the specification be read likewise. Therefore, the above description should not be construed as limiting, but merely as exemplifications of particular embodiments.

25

The embodiments of the present invention for which an exclusive property or privilege is claimed are defined as follows:

1. A radio-frequency (RF) amplifier for outputting at least one electrosurgical waveform, comprising:

a phase compensator coupled to an RF arbitrary source, the phase compensator configured to generate a reference signal as a function of an arbitrary RF signal from the RF arbitrary source and a phase control signal;

at least one error correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal;

at least one power component coupled to the at least one error correction amplifier and to a high voltage power source configured to supply high voltage direct current thereto, the at least one power component configured to operate in response to the control signal to generate at least one component of the at least one electrosurgical waveform; and

at least one stabilization amplifier coupled to the at least one power component, the at least one stabilization amplifier configured to output an error correction current based on DC bias current flowing from the at least one power component.

2. The RF amplifier according to claim 1, further comprising:

a gain selector configured to provide a gain control adjustment to the control signal based on a gain control signal.

3. The RF amplifier according to claim 1, further comprising:

at least one gain amplifier coupled to the at least one error correction amplifier and the gain selector, the at least one gain amplifier configured to adjust the control signal based on the gain control adjustment.

4. The RF amplifier according to claim 1, further comprising:

at least one current sensor coupled to the at least one power component, the at least one current sensor configured to provide a signal representative of the at least one electrosurgical waveform to the at least one error correction amplifier.

5. The RF amplifier according to claim 1, comprising:
 - at least one current sensor configured to measure current of the at least one electrosurgical waveform and to operate with the at least one power component to output a current control signal as a function of the measured current;
 - a patient isolation transformer coupled to the RF amplifier, the patient isolation transformer including a primary winding coupled to the at least one power component, wherein the patient isolation transformer is the only isolation transformer coupling component for delivering the at least one electrosurgical waveform to a patient and is configured to operate in a phase-correlated manner with the at least one electrosurgical waveform of the RF amplifier; and
 - a high voltage power source configured to supply the high voltage direct current to the RF amplifier.
6. The RF amplifier according to claim 5, further comprising:
 - at least one frequency compensation network coupled to the at least one current sensor.
7. An electrosurgical generator comprising:
 - a high voltage power source configured to supply high voltage direct current;
 - an radio-frequency (RF) arbitrary source configured to generate an arbitrary RF signal;
 - a radio-frequency (RF) amplifier configured to output at least one electrosurgical waveform, the RF amplifier including:
 - a phase compensator coupled to the RF arbitrary source, the phase compensator configured to generate a reference signal as a function of the arbitrary RF signal from the RF arbitrary source and a phase control signal;
 - at least one error correction amplifier coupled to the phase compensator, the at least one error correction amplifier configured to output a control signal at least as a function of the reference signal;
 - at least one power component coupled to the at least one error correction amplifier and to the high voltage power source, the at least one power component configured to operate in response to the control signal to generate at least one component of the at least one electrosurgical waveform;

at least one stabilization amplifier coupled to the at least one power component, the at least one stabilization amplifier configured to introduce an error correction current into the electrosurgical waveform based on DC bias current flowing from the at least one power component; and

a controller configured to adjust at least one of the arbitrary RF signal and the phase control signal in response to at least one selected electrosurgical operational mode.

8. The electrosurgical generator according to claim 7, wherein the RF amplifier includes:
a gain selector configured to provide a gain control adjustment to the control signal based on a gain control signal provided by the controller.
9. The electrosurgical generator according to claim 8, wherein the RF amplifier includes:
at least one gain amplifier coupled to the at least one error correction amplifier and the gain selector, the at least one gain amplifier configured to adjust the control signal based on the gain control adjustment.
10. The electrosurgical generator according to claim 7, wherein the RF amplifier includes:
at least one current sensor coupled to the at least one power component, the at least one current sensor configured to provide a signal representative of the at least one electrosurgical waveform to the at least one error correction amplifier.
11. The electrosurgical generator according to claim 10, wherein the RF amplifier includes:
at least one frequency compensation network coupled to the at least one current sensor.
12. The electrosurgical generator according to claim 7, further comprising:
a patient isolation transformer coupled to the RF amplifier, the patient isolation transformer including a primary winding coupled to the at least one power component.
13. An electrosurgical generator comprising:
a high voltage power source configured to supply high voltage direct current;
an radio-frequency (RF) arbitrary source configured to generate an arbitrary RF signal;
at least one radio-frequency (RF) amplifier configured to output at least one electrosurgical waveform, the at least one RF amplifier including:

a phase compensator coupled to the RF arbitrary source, the phase compensator configured to generate a reference signal as a function of the arbitrary RF signal from the RF arbitrary source and a phase control signal;

a first control loop including:

a first error correction amplifier coupled to the phase compensator, the first error correction amplifier configured to output a first control signal at least as a function of the reference signal; and

a first power component coupled to the first error correction amplifier and to the high voltage power source, the first power component configured to operate in response to the first control signal to generate a first component of the at least one electrosurgical waveform;

a second control loop including:

a second error correction amplifier coupled to the phase compensator, the second error correction amplifier configured to output a second control signal at least as a function of the reference signal; and

a second power component coupled to the second error correction amplifier and to the high voltage power source, the second power component configured to operate in response to the second control signal to generate a second component of the at least one electrosurgical waveform; and

a controller configured to adjust at least one of the arbitrary RF signal and the phase control signal in response to at least one selected electrosurgical operational mode.

14. The electrosurgical generator according to claim 13, wherein the RF amplifier includes:
- a first gain selector configured to provide a first gain control adjustment to the first control signal based on a first gain control signal provided by the controller; and
 - a second gain selector configured to provide a second gain control adjustment to the second control signal based on a second gain control signal provided by the controller.

15. The electrosurgical generator according to claim 14, wherein the RF amplifier includes:
- a first gain amplifier coupled to the first error correction amplifier and the first gain selector, the first gain amplifier configured to adjust the first control signal based on the gain control adjustment; and

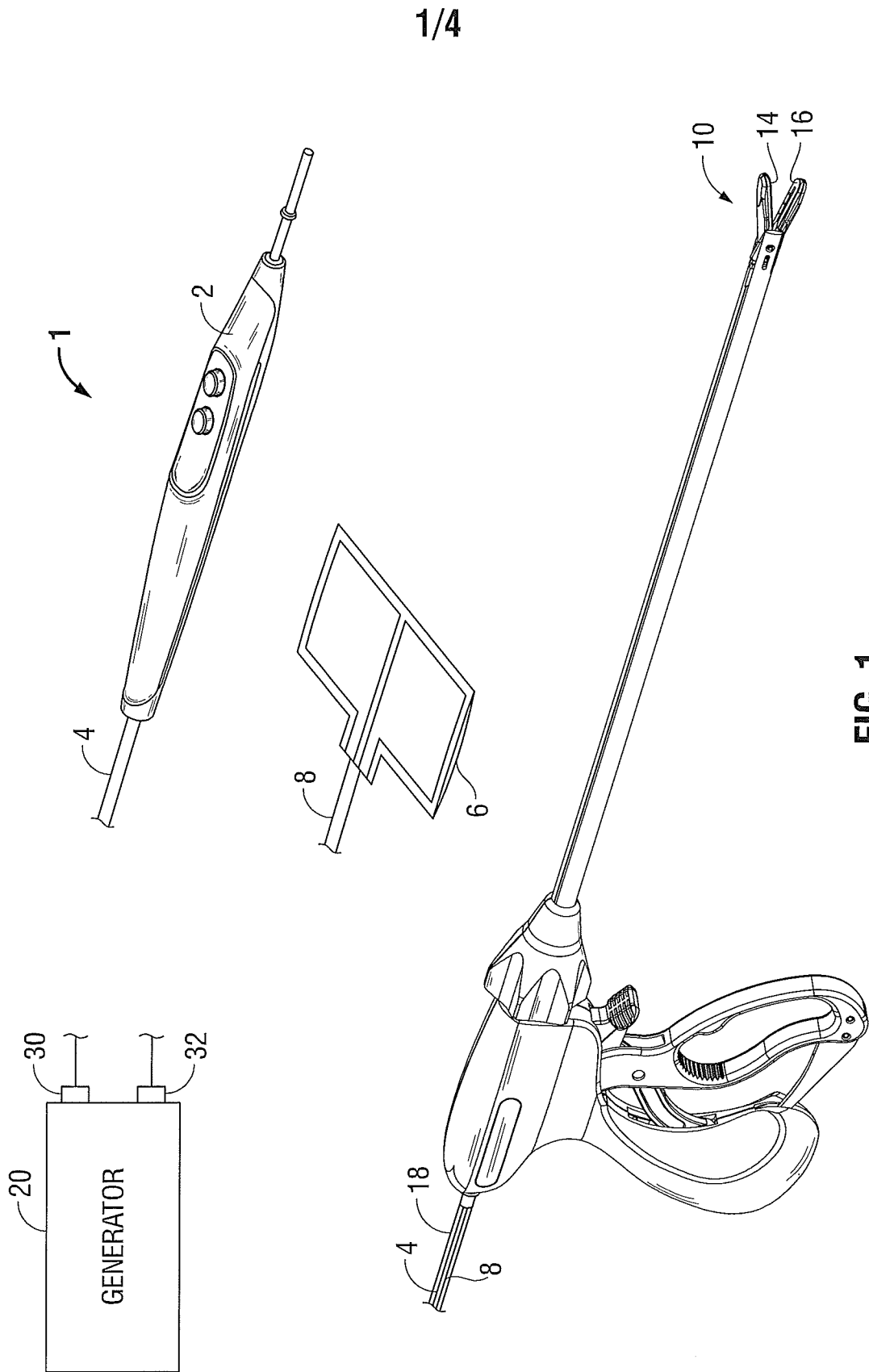
a first gain amplifier coupled to the first correction amplifier and the first gain selector, the first gain amplifier configured to adjust the first control signal based on the gain control adjustment.

16. The electrosurgical generator according to claim 13, wherein the RF amplifier includes:
a first stabilization amplifier coupled to the first power component, the first stabilization amplifier configured to output an error correction current based on DC bias current flowing from the first power component.

17. The electrosurgical generator according to claim 13, wherein the RF amplifier includes:
a first current sensor coupled to the first power component, the first current sensor configured to provide a signal representative of the first electrosurgical waveform to the first error correction amplifier; and
a second current sensor coupled to the second power component, the second current sensor configured to provide a signal representative of the second electrosurgical waveform to the second error correction amplifier.

18. The electrosurgical generator according to claim 17, wherein the RF amplifier includes:
a first frequency compensation network coupled to the first current sensor; and
a second frequency compensation network coupled to the second current sensor.

19. The electrosurgical generator according to claim 7, further comprising:
a patient isolation transformer coupled to the RF amplifier, the patient isolation transformer including a primary winding coupled to the first and second power components.



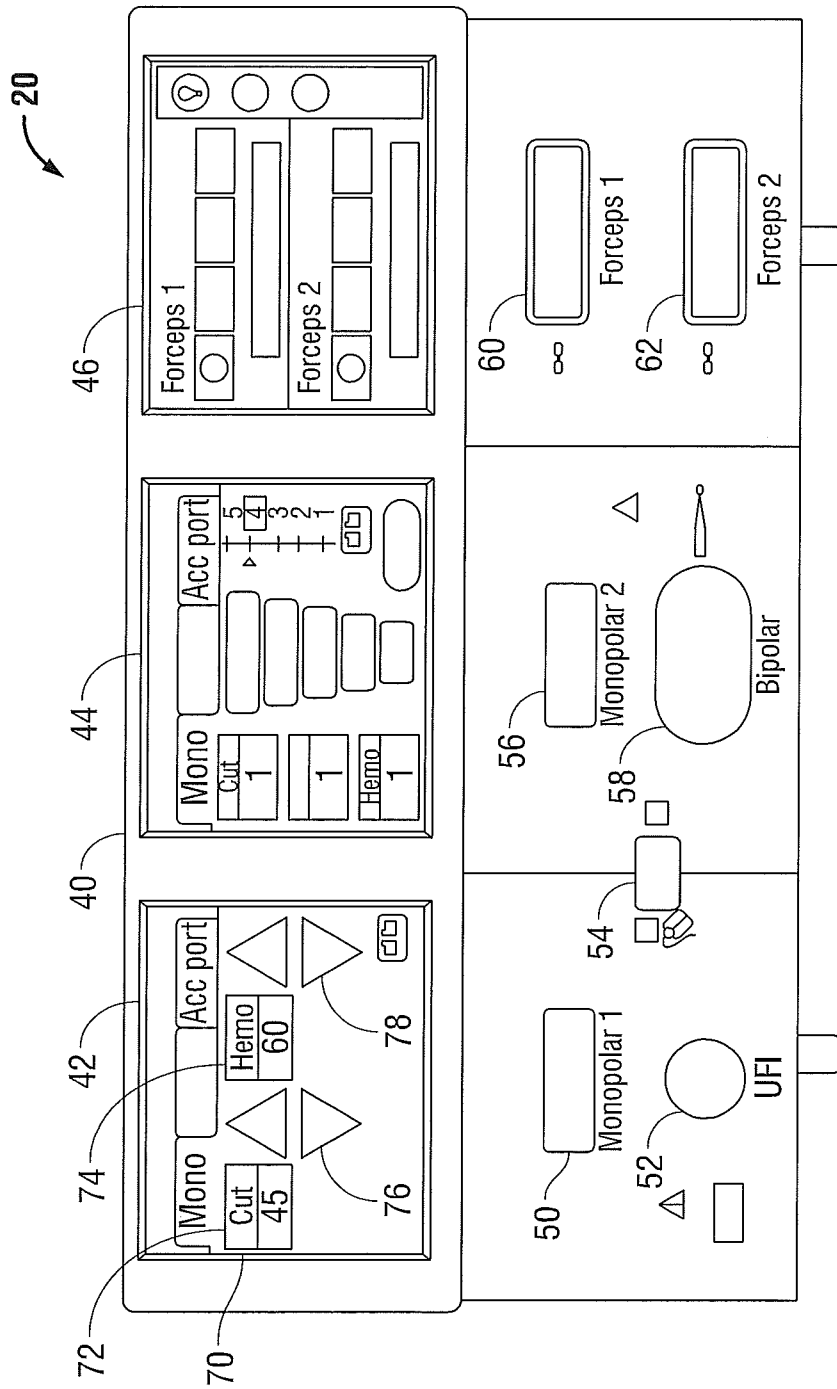


FIG. 2

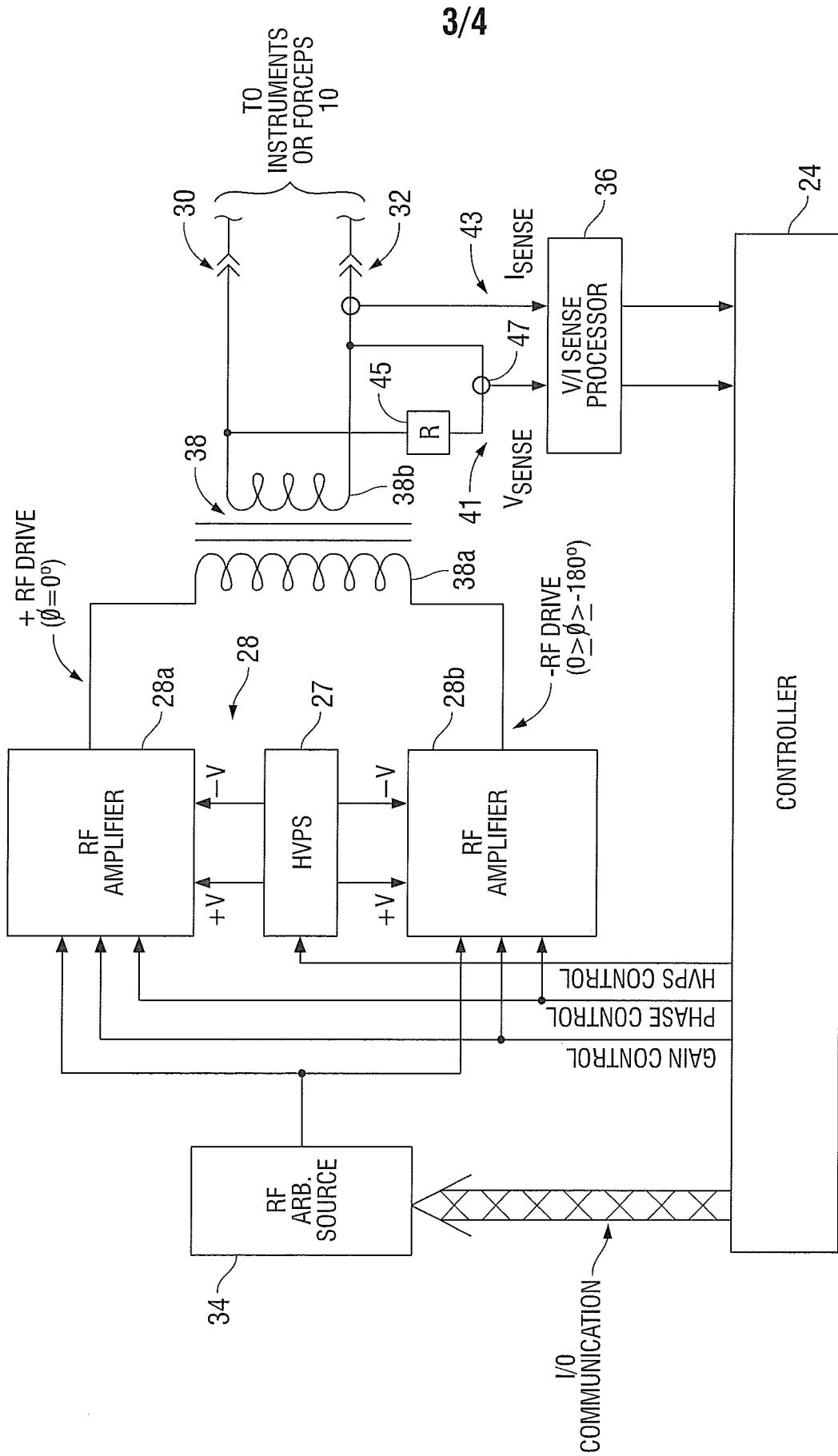


FIG. 3

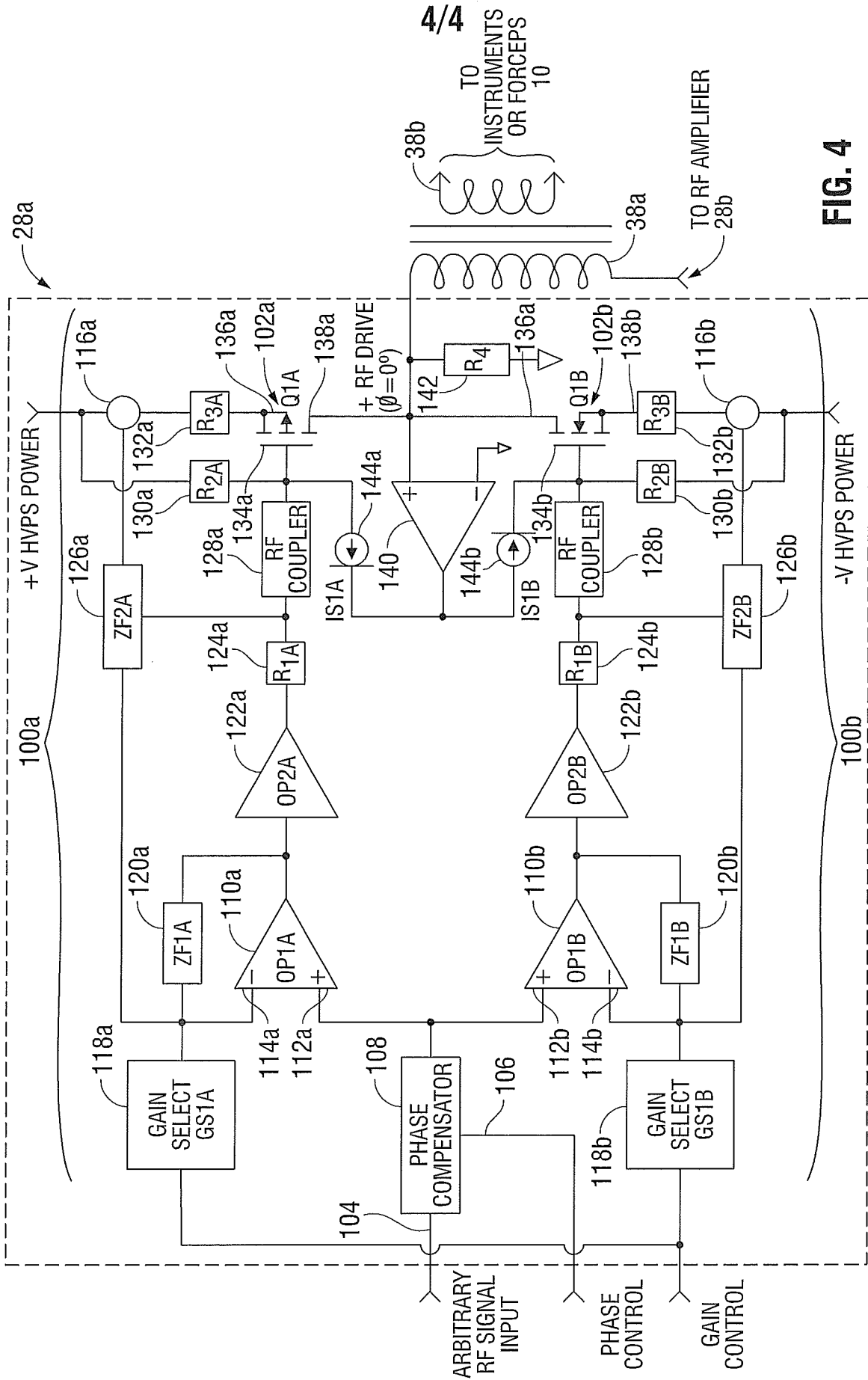


FIG. 4

