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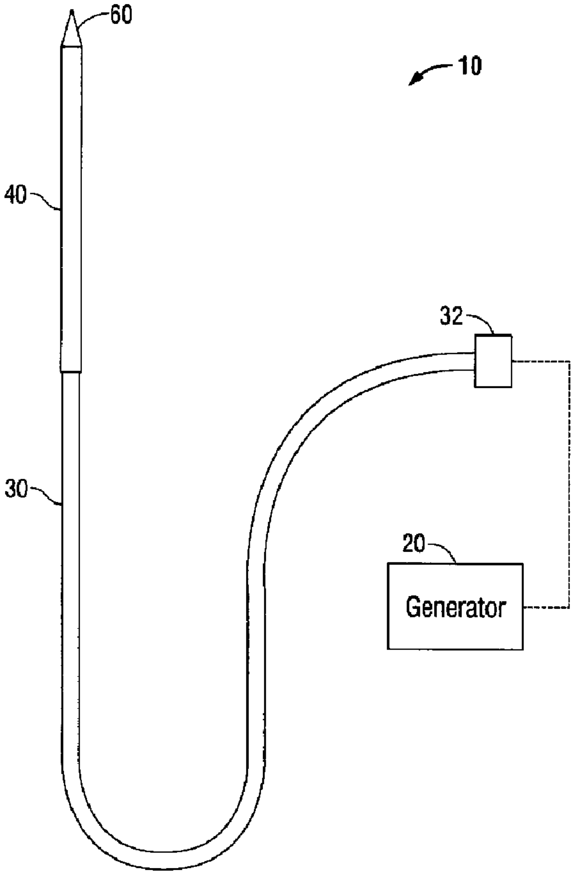
(54) **Titre : AMPLIFICATEUR HYPERFREQUENCE A HAUT RENDEMENT**
(54) **Title: HIGH EFFICIENCY MICROWAVE AMPLIFIER**



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Disclosed is an apparatus and method for operating a microwave amplifier with improved efficiency and reduced harmonic emissions. The disclosed amplifier includes a variable rail voltage supply and a variable input drive stage. A controller continually

(57) **Abrégé(suite)/Abstract(continued):**

monitors the amplifier output and adjusts the rail voltage and input drive signal to achieve high efficiency and low harmonic emissions. The amplifier may include a dynamic bias controller configured to operate the gain elements outside the linear region. Efficiencies of over 70% may be achieved by the disclosed amplifier.

ABSTRACT

Disclosed is an apparatus and method for operating a microwave amplifier with improved efficiency and reduced harmonic emissions. The disclosed amplifier includes a variable rail voltage supply and a variable input drive stage. A controller continually monitors the amplifier output and adjusts the rail voltage and input drive signal to achieve high efficiency and low harmonic emissions. The amplifier may include a dynamic bias controller configured to operate the gain elements outside the linear region. Efficiencies of over 70% may be achieved by the disclosed amplifier.

HIGH EFFICIENCY MICROWAVE AMPLIFIER

BACKGROUND

1. Technical Field

[0001] The present disclosure relates to systems and methods for providing energy to biological tissue and, more particularly, to improved apparatus and methods for amplifying microwave energy for use during surgical procedures.

2. Background of Related Art

[0002] Energy-based tissue treatment is well known in the art. Various types of energy (e.g., electrical, ultrasonic, microwave, cryogenic, thermal, laser, etc.) are applied to tissue to achieve a desired result. Electrosurgery involves application of high radio frequency electrical current to a surgical site to cut, ablate, coagulate or seal tissue. In monopolar electrosurgery, a source or active electrode delivers radio frequency energy from the electrosurgical generator to the tissue and a return electrode carries the current back to the generator. In monopolar electrosurgery, the source electrode is typically part of the surgical instrument held by the surgeon and 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.

[0003] In tissue ablation electrosurgery, the radio frequency energy may be delivered to targeted tissue by an antenna or probe. In this instance, a high radio frequency electrical current in a microwave range of about 900 MHz to about 5 GHz is applied to a targeted tissue site to create an ablation volume, which may have a particular size and shape. Typically, microwave apparatus for use in ablation procedures include a microwave generator, which functions as an energy source, and a microwave surgical instrument having an antenna assembly for directing the energy to the target tissue. The microwave generator and surgical instrument are typically operatively coupled by a cable assembly having a plurality of conductors for transmitting microwave energy from the generator to the instrument, and for communicating control, feedback and identification signals between the instrument and the generator.

[0004] The microwave generator commonly includes a microwave oscillator coupled to a power amplifier. The microwave oscillator generates a relatively low-power surgical signal that is amplified by a microwave amplifier to produce a signal of sufficient power to achieve the desired effect, e.g., tissue ablation. A user, typically a surgeon, may specify a particular output level, which may be accomplished by varying the amplitude of the relatively low-power input surgical signal to the microwave amplifier. With decreasing input levels, an amplifier operates in linear mode where efficiency decreases, e.g., thermal power dissipation increases. Conversely, with increasing input levels, an amplifier operates at or near saturation mode where maximum efficiency is achieved and thermal power dissipation is at a minimum.

[0005] Commonly used microwave power amplifiers are known to be inefficient. For example, a class AB microwave power amplifier typically exhibits an efficiency of about 35%. That is, to achieve a surgical signal of 250W, a class AB power amplifier requires about 714W of power, of which 464W is dissipated as thermal energy. The resulting heat becomes difficult to manage and may require the use of bulky and costly cooling systems, e.g., fans and heat sinks. Additionally, the excess heat may cause thermal stress to other components of the generator, shortening generator life, decreasing reliability, and increasing maintenance costs.

[0006] Additionally, a class AB amplifier may exhibit crossover distortion that introduces undesirable harmonics into the surgical signal, which are known to cause radiofrequency interference in excess of acceptable limits.

SUMMARY

[0007] The present disclosure provides a method and apparatus for an improved microwave ablation amplifier having a push-pull configuration which exhibits improved efficiency over a wide range of power output levels. A generator in accordance with the present disclosure may also exhibit reduced harmonics in the high-power surgical output signal, which reduces undesirable radiofrequency interference. In accordance with the present disclosure, a low power input signal is maintained at a constant, relatively high level, while the output level of the amplifier is adjusted, at least partially, by varying the supply voltage (e.g., the "rail" voltage) of a push-pull class B amplifier output stage. At least one LDMOS (laterally diffused metal oxide semiconductor) transistor, such as without limitation, a BLC6G10LS-160, manufactured by NXP Semiconductors of Eindhoven, The Netherlands, may be included in the amplifier output stage.

[0008] Also presented is a method and apparatus for controlling the disclosed microwave generator. A disclosed amplifier control unit is in operable communication with at least one sensor configured to receive a sensor signal indicative of one or more operating condition of the generator and/or amplifier circuit. The amplifier control unit is operably coupled to a rail voltage control unit and a drive control unit. The rail voltage control unit is configured to receive a rail voltage control signal and in response thereto provide a rail control voltage in accordance therewith to an amplifier output stage. The drive control unit is configured to receive a drive control signal and in response thereto provide a drive signal in accordance therewith to an input of the amplifier output stage. The drive control unit may also include an input to receive a relatively low power microwave signal. Additionally or alternatively, a signal source may be included within the drive control unit.

[0009] The amplifier control unit, in response to an at least one sensor signal, dynamically varies an operating parameter, e.g., a rail voltage and/or an input level, to achieve efficient and stable operation of the generator over a range of output power levels. The control unit may impose a rail voltage minima on the presently disclosed amplifier. For example, the rail voltage may be held to greater than about 14V in order to avoid undesirable increases in the internal capacitance of an LDMOS device, such as without limitation a BLC6G10LS-160 UHF power LDMOS transistor manufactured by NXP B.V. of The Netherlands, which may cause the amplifier to detune and/or become unstable. The minimum rail voltage is dependent upon the LDMOS utilized in an embodiment, and embodiments utilizing LDMOS devices other than a BLC6G10LS-160 may require a minimum rail voltage that is greater than, or less than, about 14V. In another example, at a lower portion of the amplifier's operating power, the controller may be configured to increase power output by first causing the drive attenuation control unit to output a signal of sufficient amplitude to cause the LDMOS device(s) to operate outside the linear operating region thereof, thereby achieving improved operating efficiency. When the LDMOS devices are operating outside the linear region, output power may be further increased by increasing the rail voltage. The drive signal may be correlated to the rail voltage, e.g., the drive signal may be increased proportionally to the rail voltage.

[0010] The controller may include a processor having the capability of executing a set of programmed instructions for executing a method of controlling a microwave ablation generator as disclosed herein.

[0011] In an embodiment, the disclosed electromagnetic signal amplifier includes a gain stage electrically disposed between a supply rail and a return rail. The gain stage includes an input and an output. A rail voltage controller is coupled to the supply rail and/or the return rail, wherein the rail voltage controller includes is configured to provide a rail voltage responsive to a rail voltage control signal. A drive controller is coupled to the gain stage input and provide an input signal to the gain stage in response to a drive control signal. The disclosed electromagnetic signal amplifier includes a sensor configured to sense an operational parameter of the amplifier, such as an output voltage, and to provide a corresponding sensor signal to an amplifier controller. The amplifier controller is configured to provide a rail voltage control signal to the rail voltage controller, and a drive control signal to the drive controller.

[0012] The present disclosure is also directed to a method for controlling a microwave amplifier that includes setting a rail voltage to a minimum value and a drive signal to a minimum amplitude. The resultant output signal level is measured and compared to a desired output signal level. The desired output signal level may be determined by the user. If the output signal is not equal (or not substantially equal to) the desired output level, the value of the drive signal is examined. If the drive signal is not at a maximum value, the drive signal is increased. If the drive signal equals (or substantially equals) a maximum value, the rail voltage is increased.

[0013] Also disclosed is a method of controlling a microwave amplifier that includes setting a rail voltage to an initial value, which may be a minimum value. A rail current is measured and compared to a target criteria, e.g., 0.1A. If the rail current does not meet (e.g., not equal to or substantially not equal to) the target criteria, the bias voltage is increased. If the rail current meets (e.g., equal to or substantially equal to) the target criteria, the bias voltage value is stored, and the rail voltage is increased. If the rail voltage does not meet the target criteria, then the bias voltage is adjusted accordingly until the target voltage is met. The rail current is again measured and the process iterates until the rail voltage is at a maximum value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The above and other aspects, features, and advantages of the present disclosure will become more apparent in light of the following detailed description when taken in conjunction with the accompanying drawings in which:

[0015] Fig. 1 shows a diagram of a microwave ablation system having an electromagnetic surgical ablation probe in accordance with the present disclosure;

[0016] Fig. 2 is a block diagram of an amplifier having rail voltage and drive attenuation control in accordance with the present disclosure;

[0017] Fig. 3 is a flow diagram of a method of controlling rail voltage and drive attenuation of an amplifier in accordance with the present disclosure;

[0018] Fig. 4 shows a block diagram of an amplifier having rail voltage and bias control in accordance with the present disclosure;

[0019] Fig. 5 is a flow diagram of a method of controlling rail voltage and bias voltage of an amplifier in accordance with the present disclosure;

[0020] Fig. 6 is a graph illustrating a relationship between rail current and rail voltage in accordance with the present disclosure;

[0021] Fig. 7 is a graph illustrating a relationship between capacitance and drain-to-source voltage in accordance with the present disclosure;

[0022] Fig. 8 is a circuit diagram illustrating actual and equivalent inductive and capacitive elements of a gain stage of an amplifier in accordance with the present disclosure;

[0023] Fig. 9A is a graph illustrating the harmonic power distribution of a prior-art amplifier;

[0024] Fig. 9B is a graph illustrating the harmonic power distribution of an amplifier in accordance with the present disclosure;

[0025] Fig. 10A is a graph illustrating a relationship between output power and efficiency of a prior-art amplifier;

[0026] Fig. 10B is a graph illustrating a relationship between output power and efficiency of an amplifier in accordance with the present disclosure;

[0027] Fig. 11A is a graph illustrating the harmonic power distribution of a prior-art amplifier operating at about half-power; and

[0028] Fig. 11B is a graph illustrating the harmonic power distribution of an amplifier in accordance with the present disclosure operating at about half-power.

DETAILED DESCRIPTION

[0029] Particular embodiments of the present disclosure are described hereinbelow with reference to the accompanying drawings; however, it is to be understood that the disclosed embodiments are merely exemplary of the disclosure, which may be embodied in various forms. Well-known functions or constructions are not described in detail to avoid obscuring the present disclosure in unnecessary detail. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present disclosure in virtually any appropriately detailed structure.

[0030] Fig. 1 shows an embodiment of a microwave ablation system 10 in accordance with the present disclosure. The microwave ablation system 10 includes an electromagnetic surgical ablation probe 40 connected by a cable 30 to a connector 32, which may further operably connect the probe 40 to a generator assembly 20. Generator assembly 20 may include a source of ablation energy, e.g., microwave or RF energy in the range of about 500 MHz to about 5 GHz.

[0031] With reference to Fig. 2, a block diagram of a push-pull amplifier 100 having a push-pull output stage 140 is presented. Output stage 140 may be configured as a class B push-pull output stage having a complementary pair of transistors 142, 144. Transistor 142 may be an NPN transistor that is configured to supply current from supply rail 125 to an output load, e.g., a microwave ablation probe 105. Transistor 144 may be a PNP transistor that is configured to sink current from the output load to a ground rail 126. Ground rail 126 may be alternatively be configured as a negative supply rail.

[0032] Amplifier 100 includes amplifier controller 110 that is configured to receive at least one sensor signal and in response thereto output at least one corresponding control signal to at least one of a rail voltage controller 120 and a drive controller 130. Amplifier controller 110 is operably coupled to at least one sensor 150 that is adapted to sense an electrical property of an output signal, e.g., voltage, current, impedance. Additionally or alternatively, sensor 150 may sense an instantaneous, peak, RMS, or moving average property of an output signal. Amplifier controller 110 may be configured to perform a method of controlling a push pull amplifier 100 as will be described in further detail hereinbelow.

[0033] Rail voltage controller 120 is configured to provide a variable output voltage to supply rail 125 in response to a rail voltage control signal (not explicitly shown) received from amplifier controller 110. The rail voltage control signal may be any suitable signal, e.g., an analog or digital signal. Rail voltage controller 120 may include a power supply having a fixed or variable output voltage. It is envisioned that rail voltage controller 120 may encompass any suitable manner of voltage regulation, such as, and without limitation, an LM317 voltage regulator integrated circuit manufactured by National Semiconductor Corp. of Santa Clara, California, US. In an embodiment supply rail 125 is referenced to ground at return rail 126. Rail voltage controller 120 may be configured to provide a bipolar supply wherein e.g., a positive voltage is provided by rail voltage controller 120 to supply rail 125 and a negative voltage is provided by rail voltage controller 120 to return rail 126.

[0034] Drive controller 130 is configured to provide an input signal to the output stage 140. Drive controller 130 may include an oscillator 134 configured to generate a radiofrequency ablation signal that is operable coupled to an output thereof to an attenuation network 136. In an embodiment, drive controller 130 may include an RF signal input (not explicitly shown) that is operably coupled to an oscillator. Drive controller 130 includes a drive control input that is adapted to receive a drive control signal from amplifier controller 110. Attenuation network 136 is responsive to the drive control signal, whereby the drive control signal defines the degree of attenuation provided by attenuation network 136. Drive controller 130 may provide signal attenuation by any suitable manner of attenuation, for example, and without limitation, voltage-controlled amplifier (e.g., a unity gain voltage controlled amplifier), a digital potentiometer, or a digitally-switched voltage dividing network

[0035] Turning to Fig. 3, a rail voltage control method 200 for operating push-pull amplifier 100 shows initial step 210 which is an entry point wherein initialization may be performed. In the step 215, the rail voltage and drive level are set to a minimum. In an embodiment, amplifier controller 110 causes rail voltage controller 120 to output a minimum voltage, which may be in a range of about 0V to about 30V, e.g., 14V, and amplifier controller 110 may additionally or alternatively cause drive controller 130 to be set to a minimum drive level (i.e., maximum drive attenuation.) In the step 220, a desired output level is set, e.g., wherein a user selects a desired output level, which may be, for example and without limitation, an output voltage, output current, or other signal property. In the step 225, a main operational loop is entered wherein an output level is measured. For example, amplifier controller 110 may poll an input thereof corresponding to an output of sensor 150. Sensor 150 may provide a signal to amplifier controller 110 in analog format, or in digital format. In one embodiment, the step 225 may include an analog-to-digital conversion of the sensed output.

[0036] In the step 230, the measured level is compared to the desired level to determine whether the output level equals the desired level. It is to be understood that comparisons performed by the methods disclosed herein may include a tolerance within which the values being compared are evaluated, e.g., quantities may be within a range and/or substantially equal to be deemed equal. If a positive determination is made (e.g., output level is acceptably equal to the desired level as described herein) the process iterates to the step 225.

[0037] If a negative determination is made, that is, the output level does not equal the desired level, the step 235 is performed wherein a determination is made whether the drive level is set to a maximum value (or alternatively, within a tolerance range of, or substantially equal to, a maximum value.) If it is determined the drive level is set to a maximum value (i.e., minimum drive attenuation), the step 245 is performed wherein the rail voltage is increased. For example, amplifier controller 110 causes rail voltage controller 120 to increase the output voltage thereof. The output voltage may be increased by a predetermined amount. Subsequent to step 245, the process iterates to step 225. Conversely, if it is determined the drive level is not set to a maximum value, the step 240 is performed wherein the drive level is increased (i.e., drive attenuation is reduced). Subsequent to step 240, the process iterates to the step 225. In an embodiment, step 240 or step 245 includes a time delay.

[0038] With reference now to Fig. 4, an amplifier stage 300 according to the present disclosure includes a gain element 330, which may be a field effect transistor (FET), a gallium nitride (GaN) high electron mobility transistor (HEMTs), gallium arsenide (GaAs) FET, or a laterally diffused metal oxide semiconductor transistor (LDMOS), such as without limitation, a BLC6G10LS-160 as described hereinabove. Unless stated otherwise, in the following description is it to be understood that gain element 330 is an N channel device, such as a BLC6G10LS-160. Gain element 330 may alternatively be a P-channel device. Gate 331 of gain element 330 may be slightly biased at about 0.1A of the rail current. However, as seen in Fig. 6 rail current will increase as rail voltage is increased. To address this, amplifier stage 300 includes a current sensor 310 that is adapted to measure a bias current of gain element 330 and communicate a value corresponding thereto to amplifier controller 110'. Amplifier 300 includes bias controller 320 that is in operable communication with amplifier controller 110'. Bias controller 320 is responsive to a bias control signal received from amplifier controller 110' to provide a bias current to gain element 330 in accordance with a method described below.

[0039] As shown in Fig. 5, a biasing method 400 for biasing a gain stage 300 begins at step 410 which is an entry point wherein initialization may be performed. In step 415, the rail voltage is set to an initial value, which may be a minimum value, e.g., 14V. In step 420, the rail current is measured and compared to a target current, e.g., 0.1A, to determine whether the rail current equals the target rail current. If the measured current does not equal the target current, step 425 is performed wherein the bias voltage is increased. In an embodiment, the bias voltage is increased by a fixed amount. Steps 420 and 425 are repeated iteratively until the rail current equals the target current.

[0040] If the measured rail current equals the target current, step 430 is performed wherein the bias voltage is stored. Step 435 is then performed wherein the rail voltage is increased. A comparison is performed in step 440 to determine whether the rail voltage equals a maximum voltage. If the rail voltage equals a maximum voltage, the bias adjustment is complete and the process concludes in step 465.

[0041] If, however, the rail voltage does not equal a maximum voltage, step 445 is performed wherein it is determined whether the rail current equals a target current value, e.g., 0.1A. If the rail current is determined to equal the target current, the process iterates at step 430 wherein the bias voltage is stored and the process continues as described herein. If the rail current does not equal the target current value, the rail current is tested in the step 450 to determine whether the rail current is less than the target current value. If it is determined the rail current is less than the target current value, the step 455 is performed wherein the bias voltage is increased, whereupon the process iterates to step 445. Conversely, if it is determined the rail current is not less than (e.g., greater than) the target current value, the step 460 is performed wherein the bias voltage is decreased, whereupon the process iterates to step 445.

[0042] In embodiments wherein the gain element 330 is P-channel device, the bias voltage is adjusted in an opposite manner, e.g., decreased in the step 455 and/or increased in the step 460, in accordance with the characteristics of a P-channel device.

[0043] Fig. 7 illustrates a relationship between internal capacitances C_{iss}, C_{oss}, and C_{rss} exhibited by a gain element, e.g., a FET, and a drain-to-source voltage V_{DS}, e.g., a rail voltage. As can be seen, as V_{DS} decreases, the internal capacitances C_{iss}, C_{oss}, and C_{rss} of the FET increase. The capacitance increases exponentially as V_{DS} approaches zero. In a tuned gain stage 700 such as illustrated in Fig. 8, reducing V_{DS}, e.g., the rail voltage, lower than about 14V would result in a significant detuning of gain stage 700, which may result in decreased efficiency and instability. Accordingly, the present disclosure contemplates a minimum rail voltage of about 14V.

[0044] A comparison between a prior art amplifier, and an amplifier in accordance with the present disclosure, is shown in Fig. 9A which illustrates a graph of the power spectrum of a prior art single stage (class B) amplifier operating at 915 MHz at full power of about +52.55 dBm. As can be seen, a +9.341 dBm second harmonic is present at 1.83 GHz and a third harmonic of -12.63 dBm is present at 2.745 GHz. Fig. 9B illustrates an amplifier according to the present disclosure operating on a similar 915 MHz input signal as the Fig. 9A example. At full power of about +52.67dBm, which for illustration purposes only is effectively the same as the prior art example (i.e., within .12 dBm of the prior art example), the Fig. 9B spectrum of the presently disclosed amplifier exhibits a second harmonic of 5.339 dBm, and a third harmonic of -27.32 dBm. This represents an improvement over the prior art of about a 4 dBm reduction in second-order harmonics and of about a 14.7 dBm reduction in third-order harmonics.

[0045] A comparison of harmonic performance at about half-power is illustrated with reference to Figs. 11A and 11B, which correspond to a prior art amplifier and an amplifier in accordance with the present disclosure, respectively. As can be seen, the present amplifier exhibits an improvement of about a 3 dBm reduction in second-order harmonics. Third-order harmonics, however, increase about 12 dBm in the present amplifier.

[0046] Continuing the comparison, Fig. 10A is a graph representing a relationship between output power and efficiency to increasing input power level of a prior art amplifier, while Fig. 10B represents a relationship between output power and efficiency to increasing rail voltage of an amplifier according to the present invention. As will be readily appreciated, an amplifier according to the present invention exhibits a much higher and flatter efficiency curve than that of the prior art amplifier. For example, and with reference to Fig. 10A, a prior art amplifier at about 50% output power exhibits an efficiency of about 40%. In contrast, and with reference to Fig. 10B, an amplifier in accordance with the present disclosure at about 50% output power exhibits an efficiency of out 70%. As can be seen, the prior art amplifier has an efficiency which can be as low as 15%, while the efficiency of the presently disclosed amplifier never drops below 68% over an entire operating range thereof.

[0047] 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. The claims can encompass embodiments in hardware, software, or a combination thereof. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.

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

1. An electromagnetic signal amplifier, comprising:

a gain stage electrically disposed between a supply rail and a return rail, wherein the gain stage includes an input and an output;

a rail voltage controller operably coupled to at least one of the supply rail and the return rail, the rail voltage controller being configured to provide a rail voltage responsive to a rail voltage control signal;

a drive controller operably coupled to the gain stage input and configured to provide an input signal thereto responsive to a drive control signal;

at least one sensor configured to sense an operational parameter of the amplifier and to provide a sensor signal corresponding thereto;

an amplifier controller adapted to receive the at least one sensor signal and in response thereto provide at least one of the rail voltage control signal to the rail voltage controller and the drive control signal to the drive controller;

set the rail voltage to a minimum value;

set the drive signal to a minimum amplitude;

measure an output signal;

determine whether the output signal meets a predetermined criteria;

respond to a determination the output signal does not meet the predetermined criteria by determining whether the drive signal is set to a maximum value;

respond to a determination the drive signal is not set to the maximum value by increasing the drive signal; and

respond to a determination the drive signal is set to the maximum value by increasing the rail voltage.

2. The electromagnetic signal amplifier in accordance with claim 1, wherein the amplifier controller is adapted to receive an input corresponding to a target output level.

3. The electromagnetic signal amplifier in accordance with claim 1 or 2, wherein the gain stage comprises at least two gain elements arranged in a push-pull configuration.

4. The electromagnetic signal amplifier in accordance with claim 3, wherein the at least two gain elements are selected from the group consisting of transistors, field-effect transistors, and laterally diffused metal oxide semiconductors.

5. The electromagnetic signal amplifier in accordance with any one of claims 1 to 4, wherein the sensor is configured to sense an output voltage.

6. The electromagnetic signal amplifier in accordance with any one of claims 1 to 4, wherein the sensor is configured to sense a bias current.

7. The electromagnetic signal amplifier in accordance with claim 6, wherein:

the gain stage includes a bias circuit;

the electromagnetic signal amplifier further comprises a bias controller operably coupled to the bias circuit and configured to provide a bias voltage thereto responsive to a bias control signal and wherein the amplifier controller provides the bias control signal to the bias controller in response to the at least one sensor signal.

8. The electromagnetic signal amplifier in accordance with claim 7, wherein the amplifier controller:

sets the rail voltage to an initial value;

measures a rail current;

determines whether the rail current meets a target criteria;

increases the bias voltage in response to a determination that the rail current does not meet the target criteria;

stores the bias voltage in response to a determination that the rail current meets the target criteria; and

increases the rail voltage.

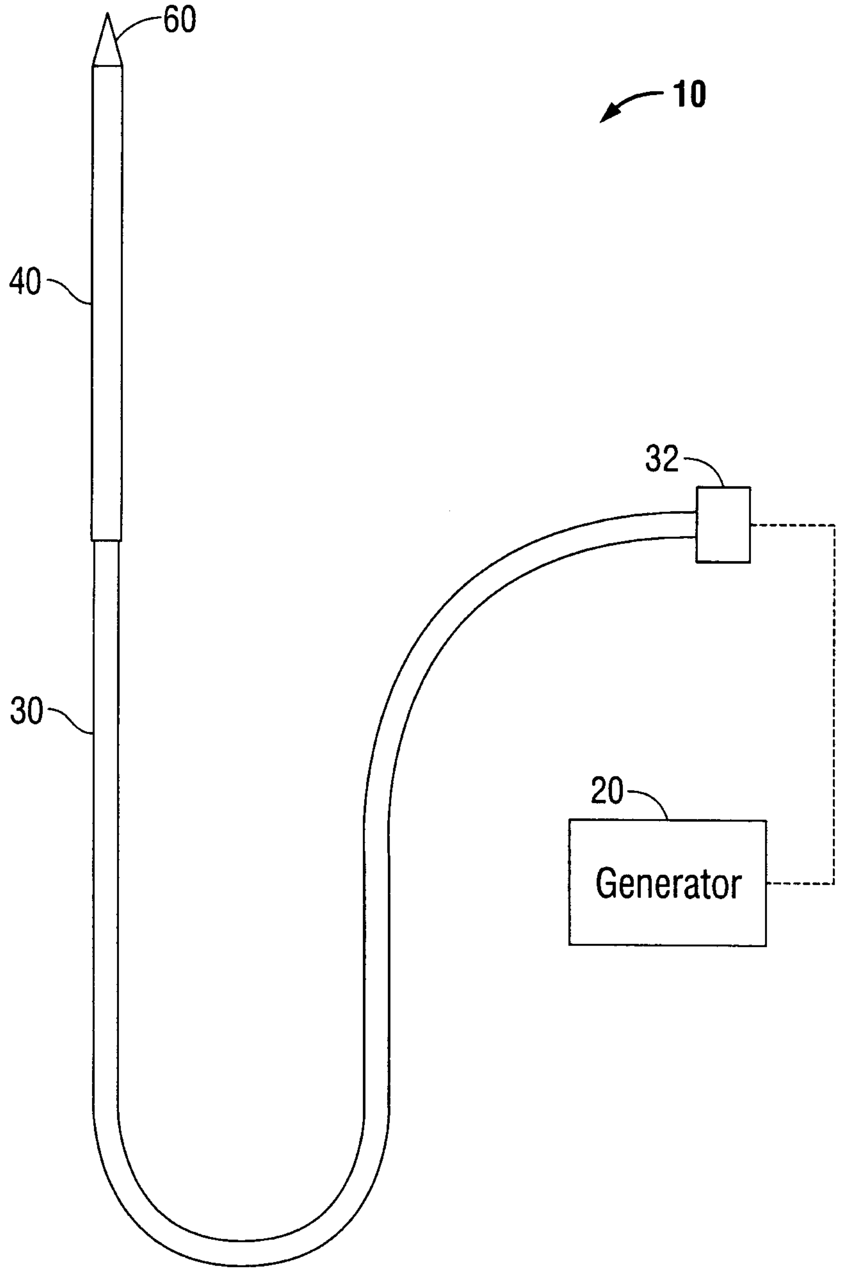


FIG. 1

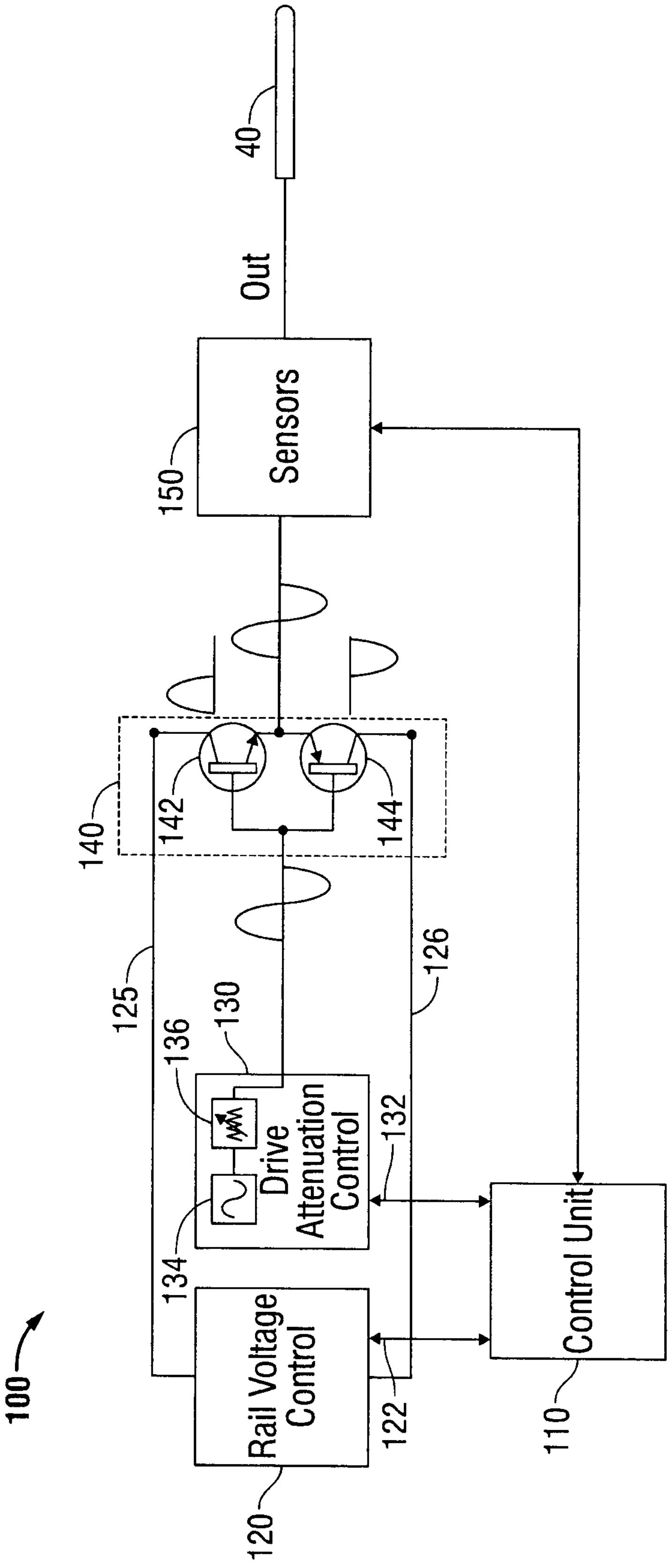

100
Rail Voltage Control
120
122
Control Unit
110
134
Drive Attenuation Control
136
130
132
125
126
140
142
144
Sensors
150
Out
40

FIG. 2

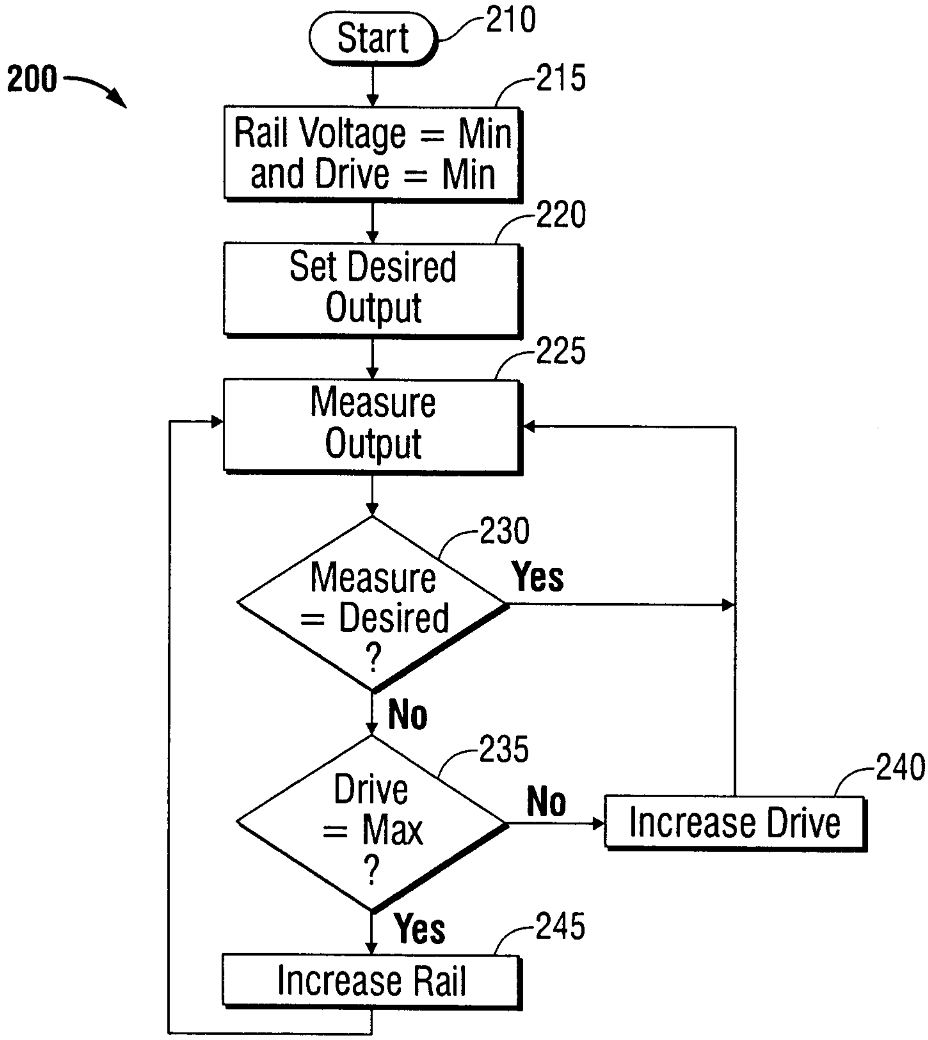

200
Start
210
Rail Voltage = Min and Drive = Min
215
Set Desired Output
220
Measure Output
225
Measure = Desired ?
230
Yes
No
Drive = Max ?
235
No
Increase Drive
240
Yes
Increase Rail
245

FIG. 3

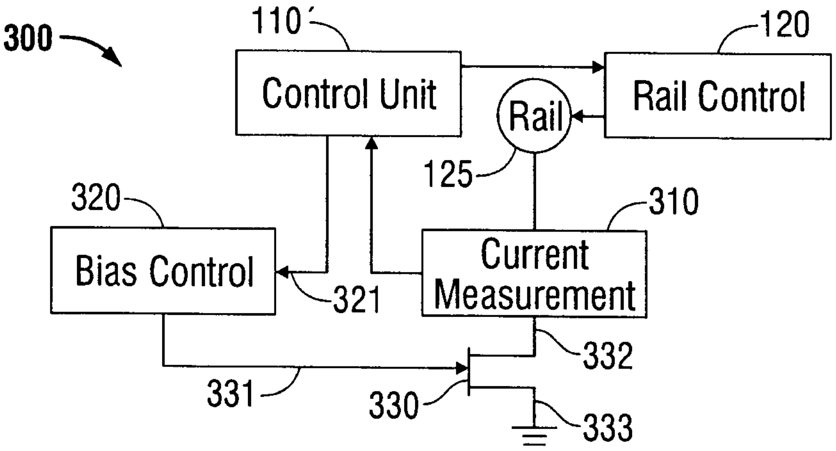

300
110
Control Unit
120
Rail Control
Rail
125
320
Bias Control
321
310
Current Measurement
332
331
330
333

FIG. 4

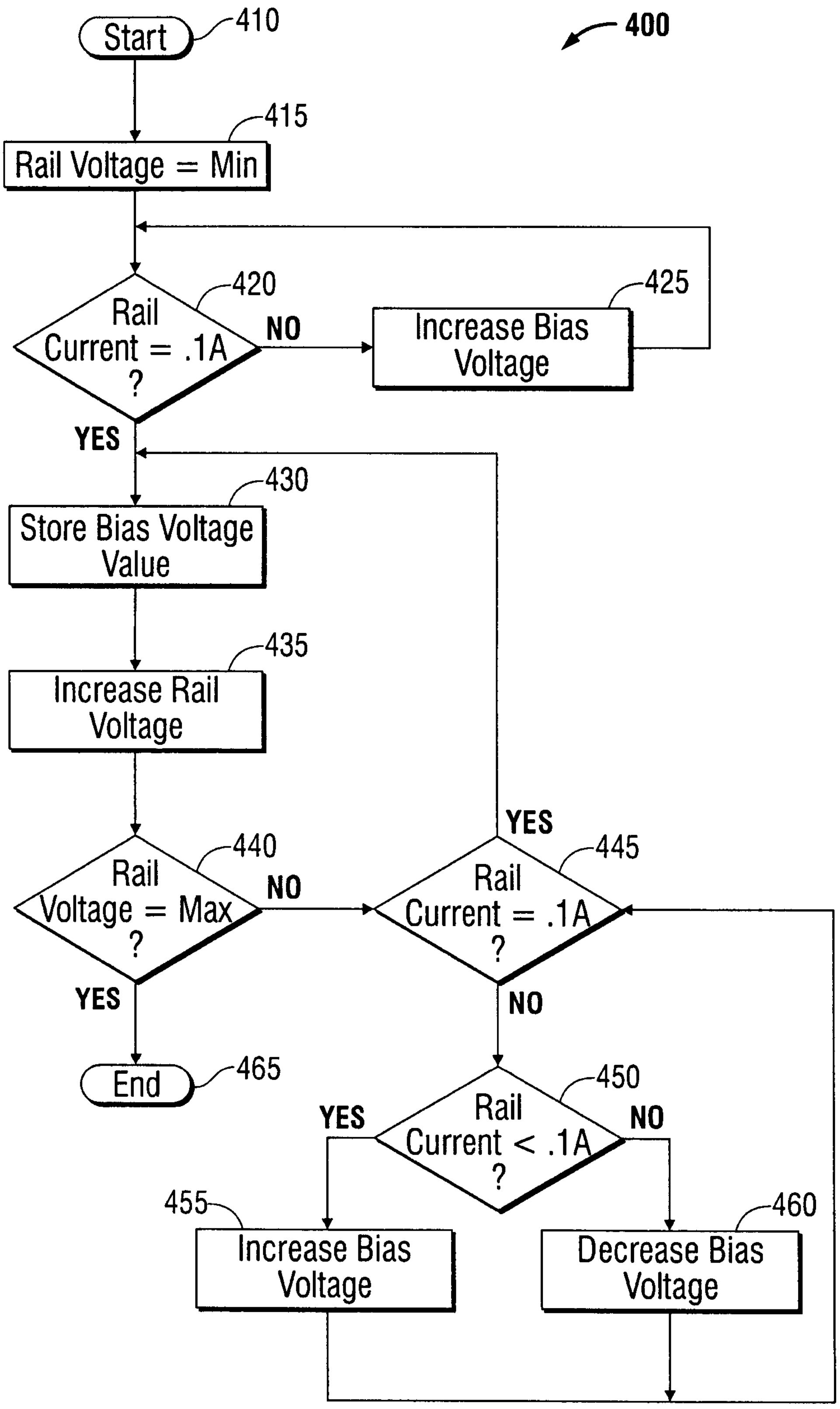

400
Start
410
Rail Voltage = Min
415
Rail Current = .1A ?
420
NO
Increase Bias Voltage
425
YES
Store Bias Voltage Value
430
Increase Rail Voltage
435
Rail Voltage = Max ?
440
NO
YES
End
465
Rail Current = .1A ?
445
YES
NO
Rail Current < .1A ?
450
YES
NO
Increase Bias Voltage
455
Decrease Bias Voltage
460

FIG. 5

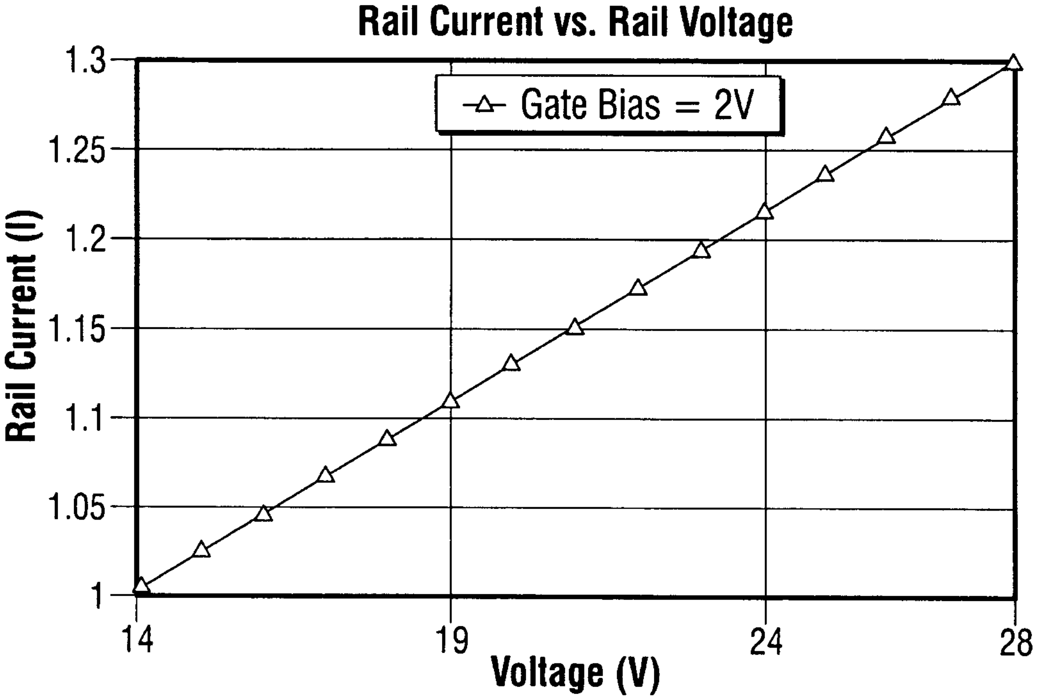

Rail Current vs. Rail Voltage
Gate Bias = 2V
Rail Current (I)
1.3
1.25
1.2
1.15
1.1
1.05
1
14
19
24
28
Voltage (V)

FIG. 6

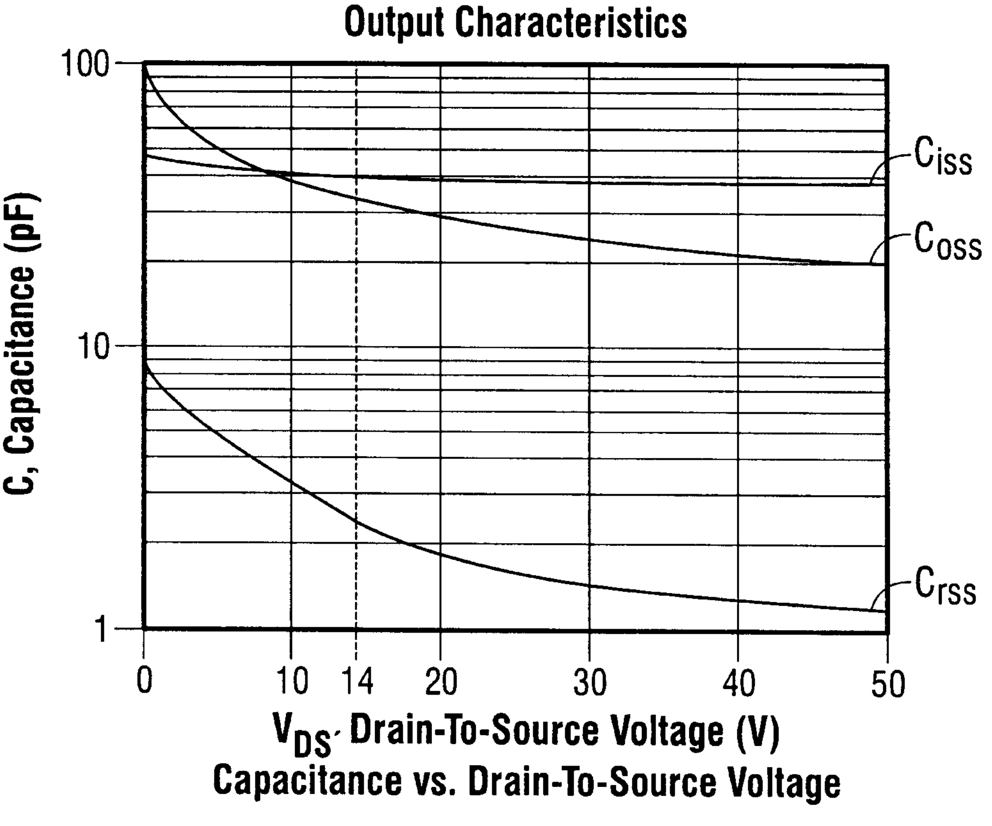

Output Characteristics
C, Capacitance (pF)
100
10
1
Ciss
Coss
Crss
0
10
14
20
30
40
50
VDS, Drain-To-Source Voltage (V)
Capacitance vs. Drain-To-Source Voltage

FIG. 7

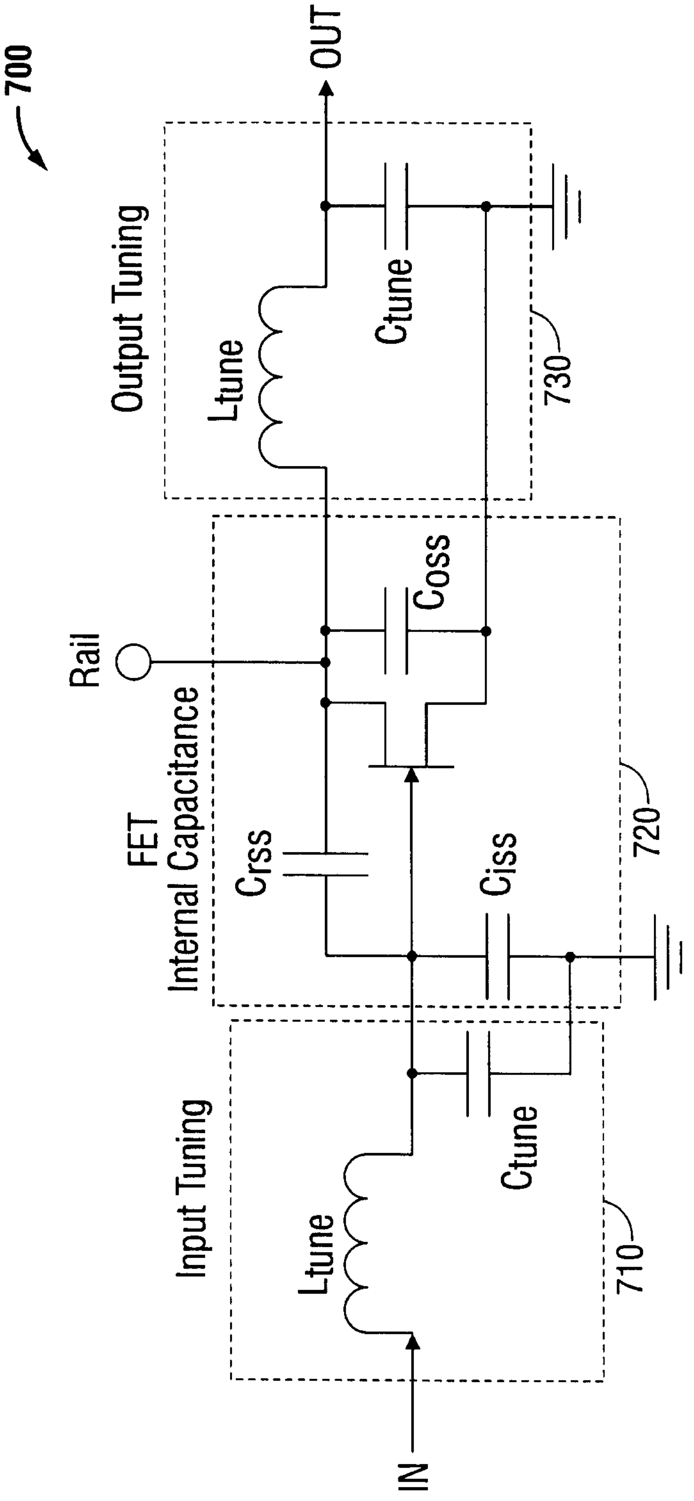

IN
Input Tuning
Ltune
Ctune
710
FET
Internal Capacitance
Crss
Ciss
720
Rail
Coss
Output Tuning
Ltune
Ctune
730
OUT
700

FIG. 8

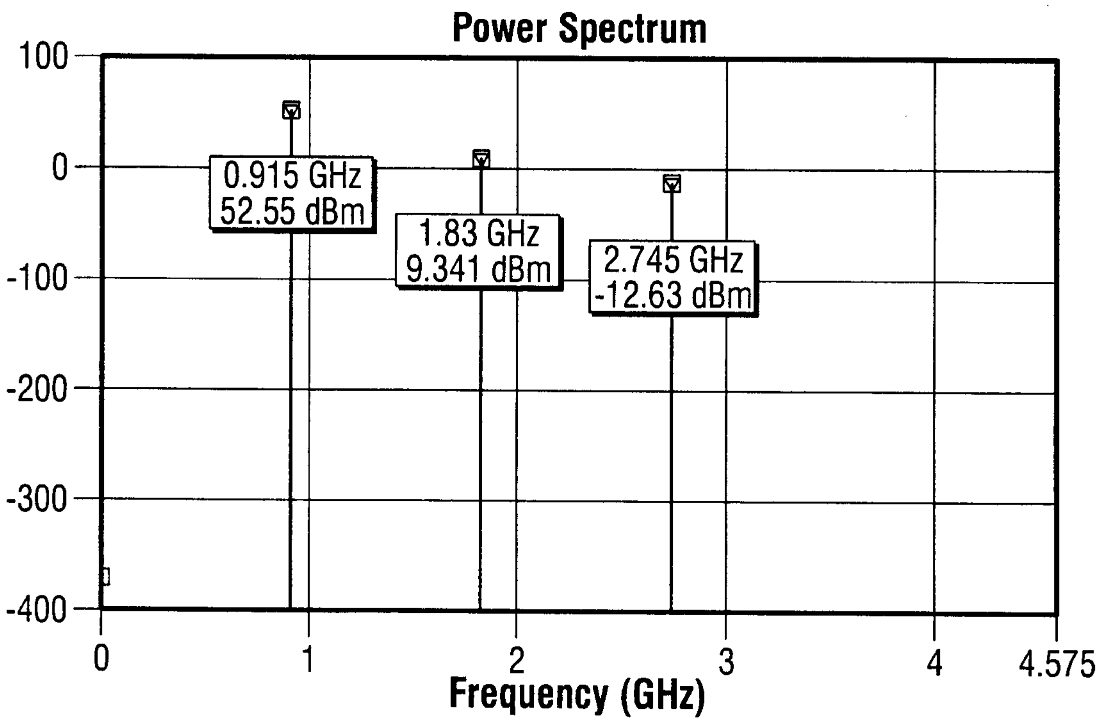


FIG. 9A
Prior Art

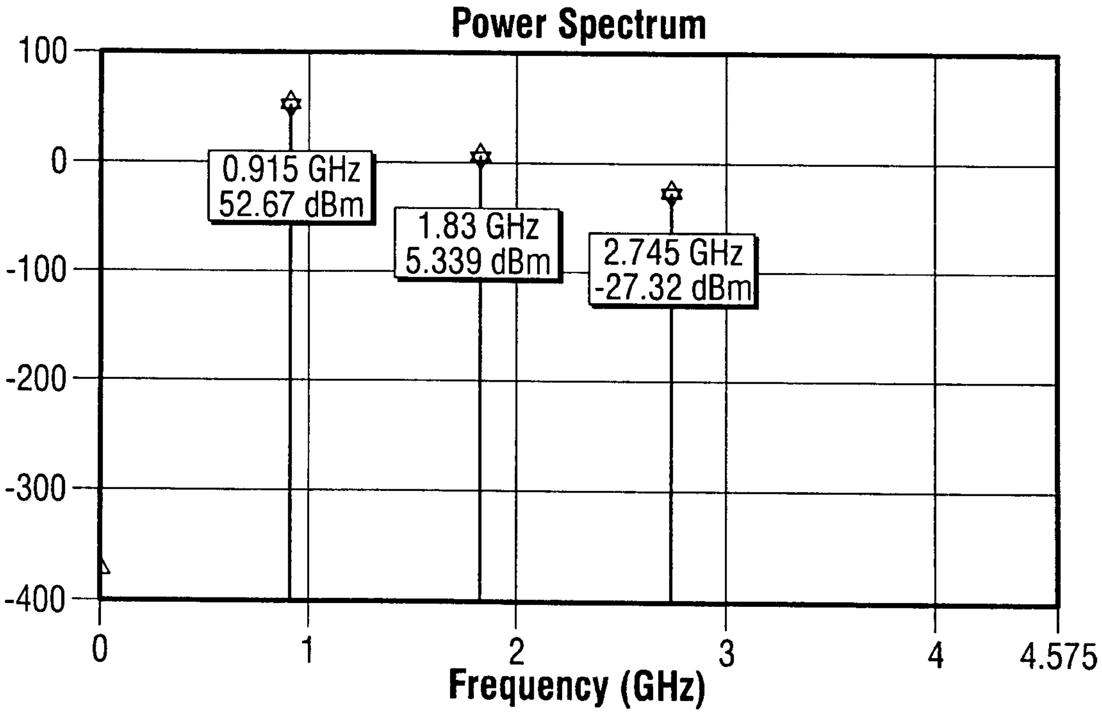


FIG. 9B

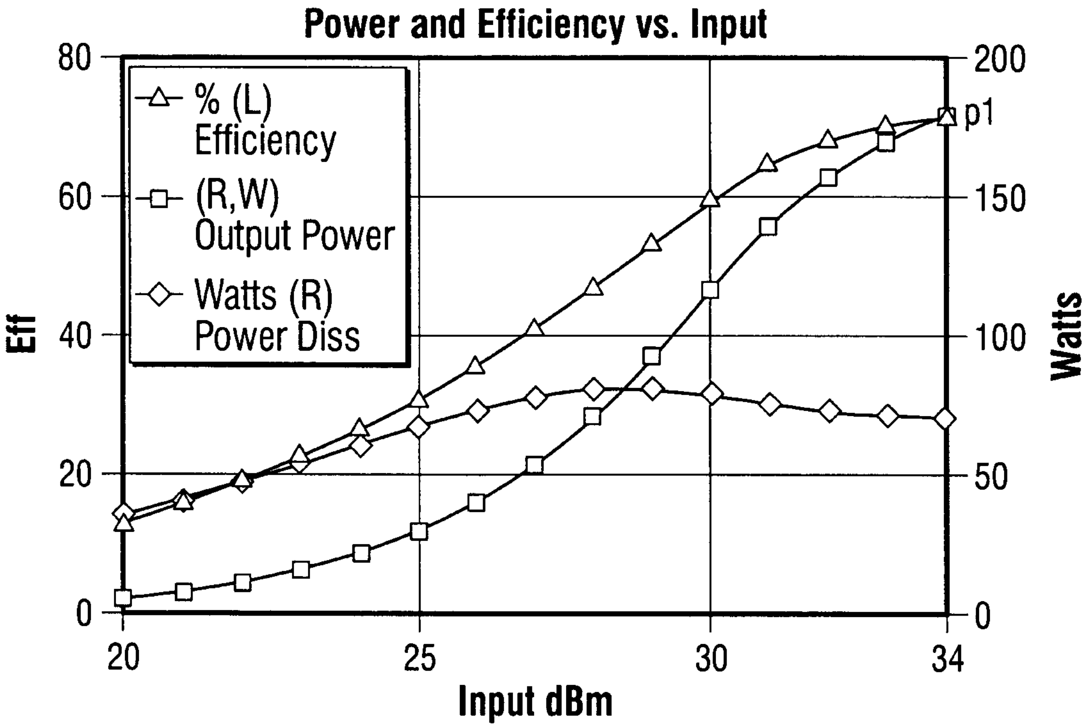


FIG. 10A
Prior Art

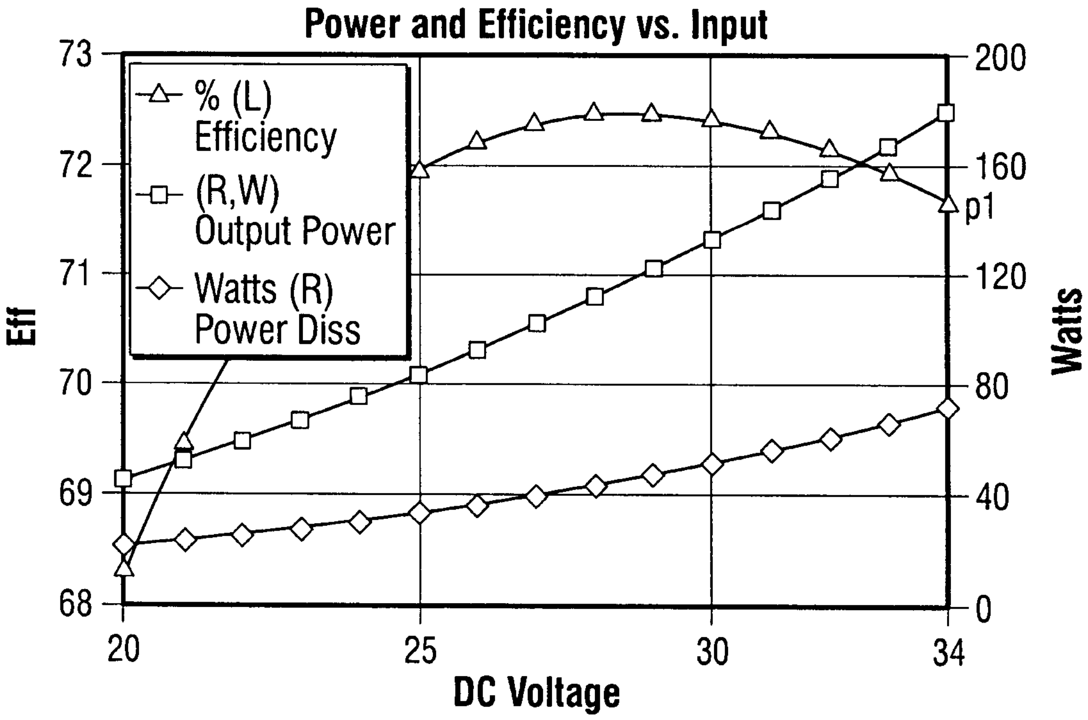


FIG. 10B

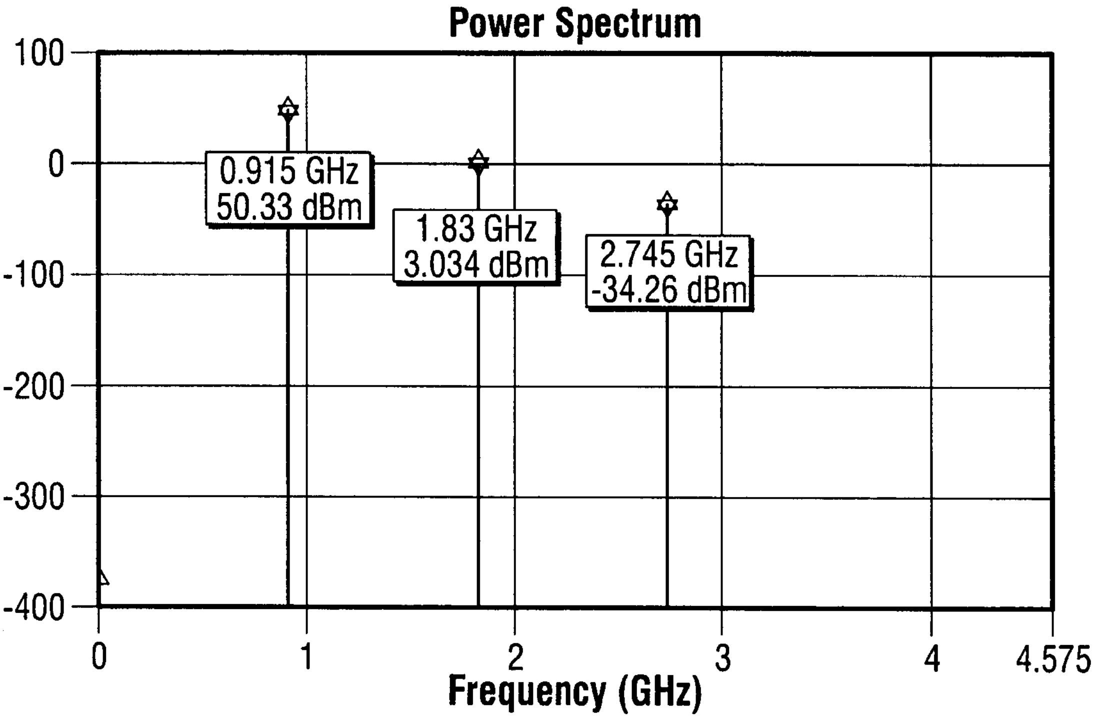


FIG. 11A
Prior Art

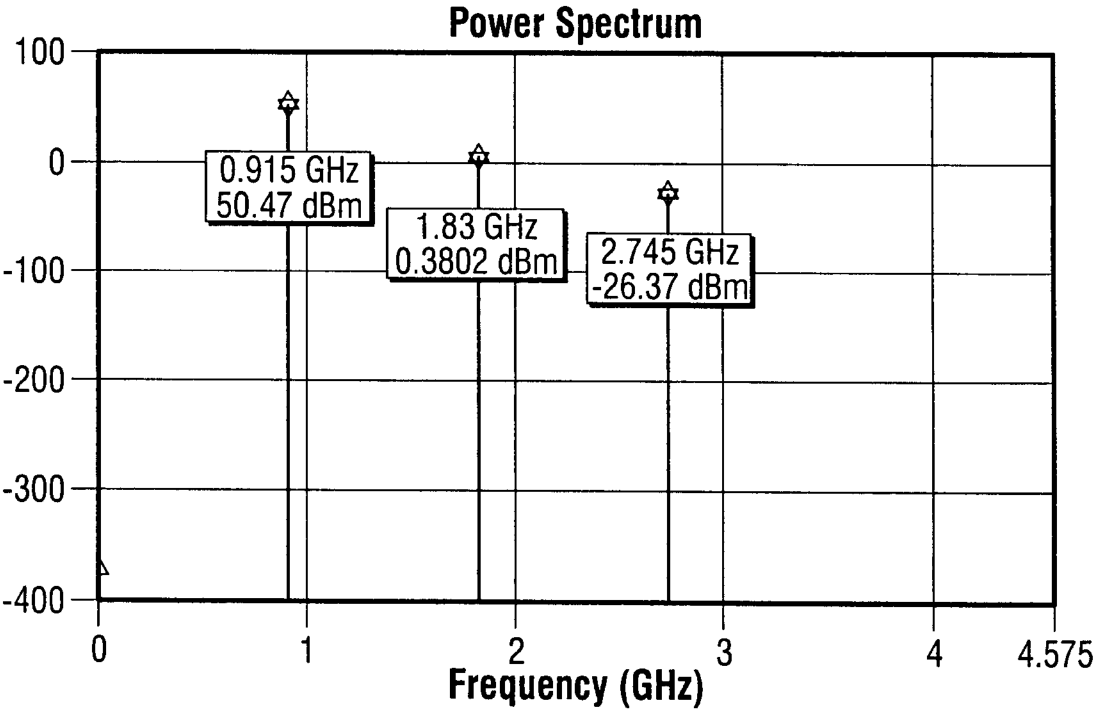
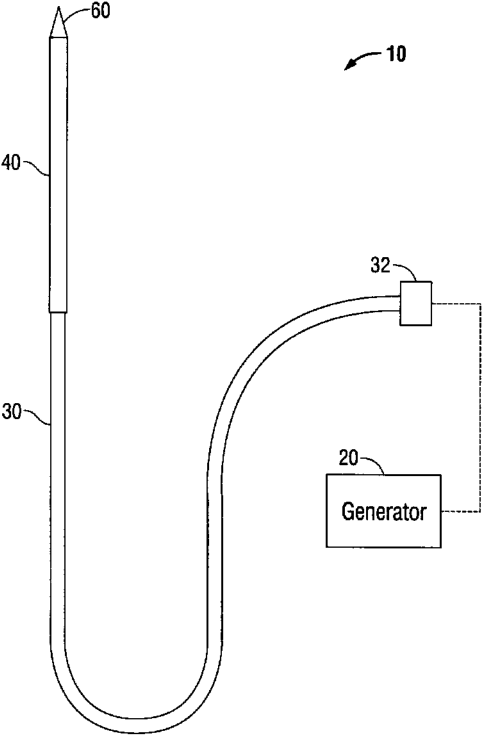


FIG. 11B


60
10
40
32
30
20
Generator