(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 March 2007 (29.03.2007)

PCT

(10) International Publication Number
WO 2007/035216 A1

(51) International Patent Classification:
H02M 5/458 (2006.01) *C01B 13/11* (2006.01)
H02M 7/537 (2006.01)

(21) International Application Number:
PCT/US2006/031664

(22) International Filing Date: 14 August 2006 (14.08.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/708,445 16 August 2005 (16.08.2005) US

(71) Applicant *(for all designated States except US)*: **MKS INSTRUMENTS, INC.** [US/US]; 90 Industrial Way, Wilmington, MA 01887 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **ELKIN, Igor** [IL/US]; 145 Glenwood St., Malden, MA 02148 (US). **MILLNER, Alan, Roy** [US/US]; 48 North Street, Lexington, MA 02420 (US). **TRAN, Ken** [US/US]; 2 Waterford Pl., North Chelmsford, MA 01863 (US). **JOSHI, Madhuwanti** [IN/US]; 105 Westgate Dr., Unit 6, Burlington, MA 01803 (US).

(74) Agent: **MARAIA, Joseph, M.**; Proskauer Rose LLP, One International Place, Boston, MA 02110 (US).

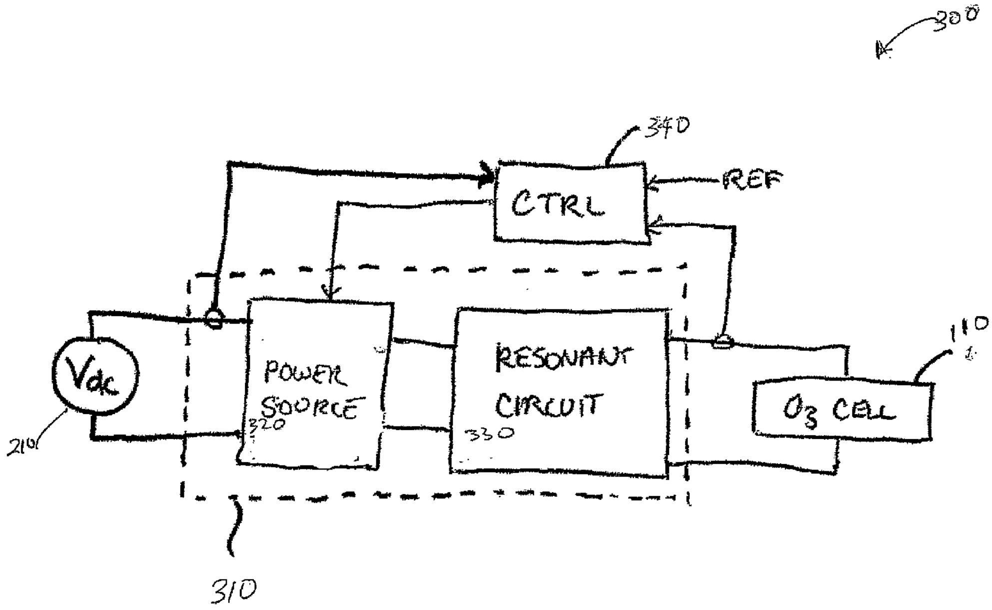
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

[Continued on next page]

(54) Title: LOAD RESONANT TYPE POWER SUPPLY FOR OZONIZER



(57) Abstract: A resonant power supply (300) is provided for ozone generation. The power supply (300) advantageously reduces costs and increases reliability of ozone generators. The power supply (300) provides a first AC voltage from a power source (320) to a resonant circuit (330) and the resonant circuit (330) provides a second AC voltage to the ozone generating unit (110), the second AC voltage being greater than the first AC voltage. A controller (340) for the power supply (300) that adapts to the resonance of the circuit to provide control with a wide tolerance for the high Q circuit component values of the circuit.

WO 2007/035216 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LOAD RESONANT TYPE POWER SUPPLY FOR OZONIZER

BACKGROUND

Ozone is useful for numerous applications that require a high level of oxidation. For example, ozone is useful for disinfection of drinking water and has been used for water treatment since the early 1900s. More recently, ozone has been used for semiconductor device processing. One application for ozone in semiconductor device processing is forming insulating layers on semiconductor wafers by growing insulating films or by oxidizing thin films on the wafer. For example, high deposition rate chemical vapor deposition of high quality SiO_2 can be accomplished by using a TEOS/ozone process.

Another application for ozone in semiconductor device processing is for cleaning semiconductor wafers and the processing chambers of semiconductor processing equipment. Ozone is particularly useful for removing hydrocarbons from the surface of semiconductor wafers or from processing chambers. Using ozone for cleaning is advantageous because it avoids the use of dangerous chemicals which require costly disposal. In contrast, ozone does not present a toxic waste disposal problem because ozone decays to oxygen without residues.

SUMMARY

Ozone can be generated from oxygen according to a so-called "silent discharge principle." For instance, ozone can be generated by exposing high purity oxygen to an electrical discharge or an electrical flux. The discharge or flux excites the oxygen molecules, breaking them into their atomic state. The atoms then recombine into a mixture of ozone (O_3) and oxygen (O_2).

Ozone (O_3) is typically produced by passing oxygen through an ozone cell where it is acted upon by an electrical discharge causing the dissolution and recombination of the oxygen atoms into ozone molecules. The electrical discharge or electrical flux needed for ozone generation is produced by applying a high voltage AC power across opposing plates of the ozone cell. The high voltage AC power is produced from transformer-based power oscillators.

Disadvantages of a transformer-based power supply (an oscillator) typically include high cost, limited reliability, and limited range of operation. For example, the high cost is typically due to the high-voltage transformer with multiple windings and special potting requirements for cooling and insulation. Limited reliability is typically due to the topology of the self-oscillator, high voltage corona caused by the dependence of the potting quality, and use of single source unique parts. Limited range of operation with respect to the regulated output voltage is typically due to the self-oscillator topology and use of transformer feedback for the transistor's gate drive.

The present invention is directed to a method and apparatus for supplying power using a power supply including transformer-less high voltage power oscillators for ozone generation. Embodiments of the present invention can reduce cost, increase reliability and operation range of ozone generators.

One embodiment includes a power supply having a power source and a resonant circuit coupled to the power source, the power source providing a first AC voltage to the resonant circuit, the resonant circuit providing a second AC voltage for use by an ozone generating unit, the second AC voltage being greater than the first AC voltage. The resonant circuit can apply a substantially resonant voltage to the ozone generating unit in response to the first AC voltage having a frequency substantially close to the resonant frequency of the resonant circuit.

In some embodiments, the resonant circuit can be a series resonant circuit including a resonant inductor coupled in series with a resonant capacitor. The resonant capacitor can be an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit. The resonant circuit has a q-factor greater than or equal to 10. In other embodiments, the resonant circuit can be a parallel resonant circuit including a resonant inductor coupled in parallel with a resonant capacitor. The resonant capacitor can be an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit.

The power source can be a half bridge inverter, a full bridge inverter, and/or a switching power source. The switching elements can be MOSFETs, BJTs, IGBTs, and/or any other type of switching elements.

The power supply can further include a controller providing signals to the power source that cause the power source to modulate the first AC voltage, resulting in the second AC voltage having a desired voltage magnitude. The first AC voltage can be modulated using pulse width modulation and/or frequency modulation. The controller can provide signals to the power source that allows the resonant circuit to operate at its maximum operating resonant frequency. The controller can tune to the maximum operating frequency of the resonant circuit by comparing a sensed input DC current to a set point input current. The controller can control a resonant voltage of the ozone generating unit during self-tuning to the maximum operating frequency of the resonant circuit by comparing a sensed resonant current to a set point resonant current.

Embodiments of the invention also include a power supply for ozone generation. Other embodiments of the invention may be applied for supplying power for generation of any reactive gases.

Advantages of the embodiments of the invention include reduced cost and increased reliability and operation range of ozone generators by eliminating the need for a transformer.

Using a high Q resonant circuit ($Q \geq 10$ typically for an ozone generator) instead of a transformer implies that the circuit resonant frequency peak is narrow. Since its center frequency depends on circuit elements with tolerances often wider than the resonance peak width, control of such a circuit can be a problem. A circuit to control high Q resonant circuits allows realization of the advantages above in both ozone generators and in resonant power supplies for other applications.

BRIEF DESCRIPTIONS OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a diagram illustrating a typical ozone generator;

FIG. 2 is a diagram that illustrates a transformer-based power supply used in an ozone generator according to the prior art;

FIG. 3 is a diagram illustrating a power supply having a transformer-less power oscillator for ozone generation in a single ozone cell according to one embodiment;

FIG. 4 is a diagram illustrating a power supply having a transformer-less power oscillator for ozone generation in a single ozone cell according to a particular embodiment;

FIG. 5A shows a detailed schematic of one embodiment of a frequency modulation controller;

FIG. 5B shows a detailed schematic of one embodiment of a pulse-width modulation controller;

FIG. 6 shows a graph showing the relationship between set point power and resonant frequency;

FIG. 7 is a diagram illustrating a power supply having multiple transformer-less power oscillators for ozone generation across multiple ozone cells according to one embodiment; and

FIGS. 8A and 8B are diagrams illustrating a power supply having a transformer-less power oscillator for ozone generation in a single ozone cell according to other particular embodiments.

DETAILED DESCRIPTION

FIG. 1 is a diagram illustrating a typical ozone generator 100. The ozone generator 100 includes a bank of ozone generating units, referred to herein as ozone cells 110a...110n. Oxygen (O_2) is supplied to each ozone cell 110 through an oxygen inlet 120 for conversion into a mixture of ozone (O_3) and oxygen (O_2). The resulting ozone mixture flows out of the ozone generator 100 through an ozone outlet 130.

Components of the ozone cell 110 typically include opposing electrode plates (not shown) and a dielectric barrier (not shown). The dielectric barrier is positioned against one of the electrode plates, forming a channel between the dielectric barrier and the opposing electrode plate. In operation, oxygen (O_2) passing through the channel is acted upon by an electrical discharge causing the dissolution and recombination of the oxygen atoms into ozone molecules. To cause the electrical discharge or flux, high voltage AC power is applied across the opposing electrode plates of each ozone cell 110.

The high voltage AC power is provided by a bank of power oscillators 140a...140n with each oscillator 140 supplying power to a respective ozone cell 110. The power oscillators 140 are coupled to a common DC power supply 150 that can convert single-phase or three-phase AC line voltage 152 into a regulated DC voltage (Vdc). Each oscillator 140, in turn, converts the regulated DC voltage (Vdc) into high voltage AC power that is supplied to a corresponding/respective ozone cell 110, resulting in the electrical discharge or electrical flux needed for ozone generation. An exemplary embodiment of the ozone cell 110 can be found in U.S. Patent 5,932,180, the entire contents of which are incorporated herein by reference.

Generally, the power oscillators 140 are implemented using transformers to generate high voltage AC power. FIG. 2 is a diagram that illustrates a transformer-based power supply 200 used in an ozone generator according to the prior art. The illustrated power supply 200 consists of a DC power supply 210 and two additional stages: (1) a buck converter 220 for regulation of output power and (2) a self oscillating push-pull converter 230 that includes a transformer 232 to generate the high voltage AC power across the ozone cell 110.

FIG. 3 is a diagram illustrating a power supply 300 having a transformer-less power oscillator 310 for ozone generation in a single ozone cell 110 according to one embodiment. The power oscillator 310 includes a power source 320 coupled to a resonant circuit 330. The resonant circuit 330 is coupled, in turn, to the ozone cell 110. The power source 320 can be a switching power source.

In operation, the power source 320 converts a regulated DC voltage (Vdc) from a DC voltage source 210 into a first AC voltage that is supplied to the resonant circuit 330. Preferably, the first AC voltage from the power source 320 has a frequency substantially close to the resonant frequency of the resonant circuit 330. In response, the resonant circuit 330 applies a substantially resonant second AC voltage to the ozone cell 110 causing an electrical discharge or flux within the ozone cell 110. Thus, by coupling the resonant circuit 330 to the power source 320, the power supply 300 is able to provide high voltage AC power (a second AC voltage) needed for ozone generation in the ozone cell 110 without the use of a transformer.

With reference to FIG. 3, a controller 340 provides control signals to the power source 320 that cause the power source 320 to modulate the frequency and/or duty cycle of the first AC voltage resulting in the resonant circuit 330 providing a substantially second AC resonant voltage having a desired magnitude to the ozone cell 110. In some embodiments the second resonant AC voltage can be 4.5 kVpk at 30 kHz.

In operation, the controller 340 compares a reference current REF with a sensed input current at the power source 320 and sends control signals (gate control signals) to the power source 320 to make adjustments to the operating frequency or duty cycle of the power source 320 to obtain the desired magnitude. The first AC voltage can be modulated by the controller 340 using pulse-width modulation and/or frequency modulation. In some embodiments, the controller 340 can be configured to sense voltage, current, or a combination thereof to determine and control the desired resonant voltage.

FIG. 4 is a diagram illustrating a power supply 400 having a transformer-less power oscillator 404 for ozone generation in a single ozone cell 110 according to a particular embodiment. In the illustrated embodiment, the resonant circuit 420 is a series resonant circuit including a resonant inductor 422 coupled in series with a resonant capacitor 424 The ozone cell 110 is coupled in parallel with the resonant capacitor 424. The resonant capacitor 424 can be a separate individual capacitor, the natural capacitance of the ozone cell 110, or a combination thereof. In the illustrated embodiment, the power source 410 is a half bridge inverter including two switching elements 412a, 412b connected in series. The switching elements 412a, 412b can be MOSFETs, BJTs, IGBTs and/or any other type switching elements known in the art. The electrical connection between the switching elements 412a, 412b is connected to the resonant circuit 420. The power source 410 can also be a full bridge inverter as shown in FIGS. 8A and 8B.

In operation, a DC power supply 210 supplies a regulated DC voltage (Vdc) to the power source/half bridge inverter 410. Control signals from the controller 340 are provided to a gate driver 540 (FIGS. 5A and 5B) that causes the switches 412a, 412b to turn on and off resulting in the half bridge inverter 410 supplying the first AC voltage having a frequency substantially close to the resonant frequency of the series resonant circuit 420. Particularly, the first AC voltage applied to the resonant circuit 420 can be square wave pulses with a controlled duty cycle. The control signals can also change the duty cycle of the half bridge inverter 410 to alter the magnitude of the second resonant AC voltage applied to the ozone cell 110. In response to receiving the first AC voltage from the half bridge inverter 410, the series resonant circuit 420 provides a resonant or substantially second resonant AC voltage across the ozone cell 110 such that an electrical discharge or flux is provided within the cell to effect conversion of oxygen (O_2) to ozone (O_3). Particularly, the resonant circuit 420 converts the applied square wave pulses with a controlled duty cycle to a high voltage sine wave of controlled amplitude. According to one embodiment, the frequency and magnitude of the second resonant AC voltage is approximately 4.5 kVpk at 30 kHz.

The ratio of ozone (O_3) to oxygen (O_2) depends on the amount of power supplied to the ozone cells 110. The power applied to the ozone cell 110 increases in proportion to the voltage applied to the ozone cell 110 and is regulated by the controller 340 in accordance with the reference signal REF as described above. Thus, by changing the operating frequency or duty cycle of the half bridge inverter 410, the controller 340 can alter the concentration of ozone. Further, the resonant frequency changes with even a small variation in inductance and capacitance. Thus, the resonant circuit 420 should have a high Q factor (greater than or equal to 10) to eliminate the need for transformer. Therefore, the controller 340 should be independent of the resonant component variation.

FIGS. 5A and 5B show a detailed schematic of embodiments of a controller 500. The major components of the controller 500 include a pulse-width modulated integrated circuit (PWM IC) 510, a first operational/error amplifier 520, a second operational/error amplifier 530, a gate driver circuit 540, a first resistor 550, and a second resistor 560.

FIG. 5 A shows one embodiment of a frequency modulated controller 500'. In operation, the operational amplifier/error amplifier 520 compares the sensed DC input current 522 with the set point DC current 524. The resistors 550, 560 control the frequency of the PWM IC 510. The output of the error amplifier 520 controls the current flowing through the resistor 550 by pulling it up or down and thus controls the frequency of the controller 510. The controller 500' includes an auto tuning circuit that ensures the initial frequency generated by the error amplifier 520 is the maximum operating frequency of the resonant circuit 420 (FIG. 4).

The tuning circuit includes a resistor 526, a capacitor 528, and a small offset voltage at the sensed input of the error amplifier 520. In operation, when the tuning circuit powers up, the DC current set point 524 slowly increases from zero to its set point through a delay created by the resistor 526 and capacitor 528. In that time, the offset voltage at the error amplifier 520 ensures that the frequency generated by the error amplifier is the maximum operating frequency of the circuit. The maximum resonant frequency is determined by considering the maximum tolerance on the resonant circuit elements and the capacity of the switching devices.

FIG. 6 shows a graph showing the relationship between the set point power and the resonant frequency. As shown, as the set point power increases, the pulse-width modulation frequency starts reducing from its maximum value toward maximum power. That is, pulse-width modulation frequency walks over the resonant curve to achieve the maximum power.

It is important to control the ozone cell 110 voltage because the ozone cell 110 voltage can rise to a very high voltage during auto-tuning of the frequency for maximum power. Thus, the controller 500' includes a second operational amplifier/error amplifier 530. The error amplifier 530 controls the resonant voltage of the ozone cell 110 by comparing the sensed resonant current 532 to the set point resonant current 534.

The resonant current can also be controlled by using pulse-width modulation. FIG. 5B shows one embodiment of a pulse-width modulation controller 500''. The operation of the pulse-width modulation controller 500'' is similar to the operation with respect to the frequency modulated controller 500' as described above.

FIG. 7 is a diagram illustrating a power supply 600 having multiple transformer-less power oscillators 404a...404n for ozone generation across multiple ozone cells 110a...110n according to one embodiment. In the illustrated embodiment, the regulated DC voltage (Vdc) (e.g. approximately 400V) is provided by a known full bridge high frequency converter 610. The high frequency converter 610 includes a rectifier stage 612, a full bridge switching stage 614, a transformer stage 616, and a filter stage 618. Other circuits known to those skilled in the art can also be implemented to provide the regulated DC voltage. The power oscillators 404a...404n are coupled to a corresponding/respective ozone cell 110a...110n to provide the high voltage AC power. Each oscillator 404 includes a power source 410 coupled to a resonant circuit 420. In the illustrated embodiment, the power sources 410 are half bridge inverters implemented using MOSFET switching devices 412a, 412b. Other switching devices known to those skilled in the art may also be utilized. Also, mixed implementations of half-bridge oscillators, full-bridge oscillators, and other known devices may be employed. The operation of the illustrated embodiment is similar to the operation described with respect to FIGS. 1 and 4.

FIGS. 8A and 8B are diagrams illustrating a power supply 700 having a transformer-less power oscillator for ozone generation in a single ozone cell 110 according to other particular embodiments. In both embodiments, the power source 710 is implemented as a full bridge converter with four switching elements 712a, 712b, 712c, 712d coupled as shown.

As shown in FIG. 8A, a voltage supply 210 supplies regulated DC voltage (Vdc) to the full bridge converter 710. The full bridge converter 710 is coupled to a series resonant circuit 720 having a resonant inductor 722 coupled in series with a resonant capacitor 724. The resonant circuit 720 is coupled, in turn, to an ozone cell 110 as shown.

As shown in FIG. 8B, a current supply 730 supplies a regulated DC current (Idc) to the full bridge converter 710. The full bridge converter 710 is coupled to a parallel resonant circuit 740 having a resonant inductor 742 coupled in parallel to a resonant capacitor 744. The resonant circuit 740 is coupled, in turn, to an ozone cell 110 as shown.

In either embodiment, the resonant capacitor can be a separate individual capacitor or can be the natural capacitance of the ozone cell 110 or combination of both an individual capacitor and natural capacitance of the cell.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

CLAIMS

What is claimed:

1. A power supply, comprising:

   a power source; and

   a resonant circuit coupled to the power source;

   the power source providing a first AC voltage to the resonant circuit, the resonant circuit providing a second AC voltage for use by an ozone generating unit, the second AC voltage being greater than the first AC voltage.

2. The power supply of Claim 1, wherein the resonant circuit applies a substantially resonant voltage to the ozone generating unit in response to the first AC voltage having a frequency substantially close to the resonant frequency of the resonant circuit.

3. The power supply of Claim 1, wherein the resonant circuit is a series resonant circuit including a resonant inductor coupled in series with a resonant capacitor.

4. The power supply of Claim 3, wherein the resonant capacitor is an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit.

5. The power supply of Claim 3, wherein the resonant circuit has a q-factor greater than or equal to 10.

6. The power supply of Claim 1, wherein the resonant circuit is a parallel resonant circuit including a resonant inductor coupled in parallel with a resonant capacitor.

7. The power supply of Claim 6, wherein the resonant capacitor is an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit.

8. The power supply of Claim 1, wherein the power source is a half bridge inverter.

9. The power supply of Claim 1, wherein the power source is a full bridge inverter.

10. The power supply of Claim 1, wherein the power source is a switching power source.

11. The power supply of Claim 10, wherein the switching elements are MOSFETs, BJTs, or IGBTs.

12. The power supply of Claim 1, further comprising:

    a controller providing signals to the power source that cause the power source to modulate the first AC voltage, resulting in the second AC voltage having a desired voltage magnitude.

13. The power supply of Claim 12, wherein the first AC voltage is modulated using pulse width modulation.

14. The power supply of Claim 12, wherein the first AC voltage is modulated using frequency modulation.

15. The power supply of Claim 12, wherein the controller provides signals to the power source that allows the resonant circuit to operate at or near its resonant frequency.

16. The power supply of Claim 15, wherein the controller tunes to the maximum operating frequency of the resonant circuit and approaches the resonant frequency of the circuit to obtain the desired operating level, by comparing a sensed input DC current to a set point input current.

17. The power supply of Claim 16, wherein the controller controls a resonant voltage of the ozone generating unit during self-tuning to the maximum operating frequency of the resonant circuit and approaches the resonant frequency of the circuit by comparing a sensed resonant current to a set point resonant current.

18. A method of supplying power for ozone generation, comprising:

coupling a resonant circuit between a power source and an ozone generating unit;

providing a first AC voltage from the power source to the resonant circuit; and

providing a second AC voltage from the resonant circuit to the ozone generating unit, the second AC voltage being greater than the first AC voltage.

19. The method of Claim 18, further comprising:

providing a substantially resonant voltage from the resonant circuit to the ozone generating unit in response to the first AC voltage having a frequency substantially close to the resonant frequency of the resonant circuit.

20. The method of Claim 18, further comprising:

forming a series resonant circuit by coupling a resonant inductor in series with a resonant capacitor.

21. The method of Claim 20, wherein the resonant capacitor is an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit.

22. The method of Claim 20, wherein the resonant circuit has a q-factor greater than or equal to 10.

23. The method of Claim 18, further comprising:

forming a parallel resonant circuit by coupling a resonant inductor in parallel with a resonant capacitor.

24. The method of Claim 23, wherein the resonant capacitor is an individual capacitor, a natural capacitance of the ozone generating unit, or a combination of both an individual capacitor and natural capacitance of the ozone generating unit.

25. The method of Claim 18, wherein the power source is a half bridge inverter.

26. The method of Claim 18, wherein the power source is a full bridge inverter.

27. The method of Claim 18, wherein the power source is a switching power source.

28. The method of Claim 27, wherein the switching elements are MOSFETs, BJTs, or IGBTs.

29. The method of Claim 18, further comprising:

providing signals to the power source;

in response to the signals, modulating the first AC voltage, resulting in the second AC voltage having a desired voltage magnitude.

30. The method of Claim 29, wherein modulating the first AC voltage comprises:

modulating pulse width of the first AC voltage.

31. The method of Claim 29, wherein modulating the first AC voltage comprises:

modulating frequency of the first AC voltage.

32. The method of Claim 29, wherein the provided signals to the power source allow the resonant circuit to operate at or near its resonant frequency.

33. The method of Claim 32, further comprising tuning to the maximum operating frequency of the resonant circuit and approaching the resonant frequency of the circuit to obtain the desired operating level, by comparing a sensed input DC current to a set point input current.

34. The method of Claim 33, further comprising:

controlling a resonant voltage of the ozone generating unit during tuning to the maximum operating frequency of the resonant circuit; and

approaching the resonant frequency of the circuit by comparing a sensed resonant current to a set point resonant current.

35. A method for supplying power for ozone generation, comprising:

coupling a plurality of resonant circuits between a plurality of power sources and a plurality of ozone generating units;

providing a first AC voltage from each of the plurality of power sources to a respective resonant circuit; and providing a second AC voltage from each respective resonant circuit to a respective ozone generating unit, the second AC voltage being greater than the first AC voltage.

36. A power supply for ozone generation, comprising:

a plurality of power sources;

a plurality of resonant circuits coupled between the plurality sources and a plurality ozone generating units; and

each of the plurality of power sources providing a first AC voltage to a respective resonant circuit, the respective resonant circuit providing a second AC voltage to a respective ozone generating unit, the second AC voltage being greater than the first AC voltage.

37. A method of supplying power for ozone generation, comprising:

means for coupling a resonant circuit between a power source and an ozone generating unit;

means for providing a first AC voltage from the power source.to the resonant circuit; and

means for providing a second AC voltage from the resonant circuit to the ozone generating unit, the second AC voltage being greater than the first AC voltage.

38. A power supply, comprising:

a power source; and

a resonant circuit coupled to the power source; and

an ozone generator coupled to the resonant circuit.

39. A switch-mode power supply, comprising:

a high Q resonant circuit; and

a controller coupled to the high Q resonant circuit, wherein the controller modulates the frequency by (i) starting from an extreme high or low value, (ii) approaching the resonant frequency of the high Q resonant circuit to obtain a desired level of output, and (iii) providing for a wide tolerance in the resonant component values.

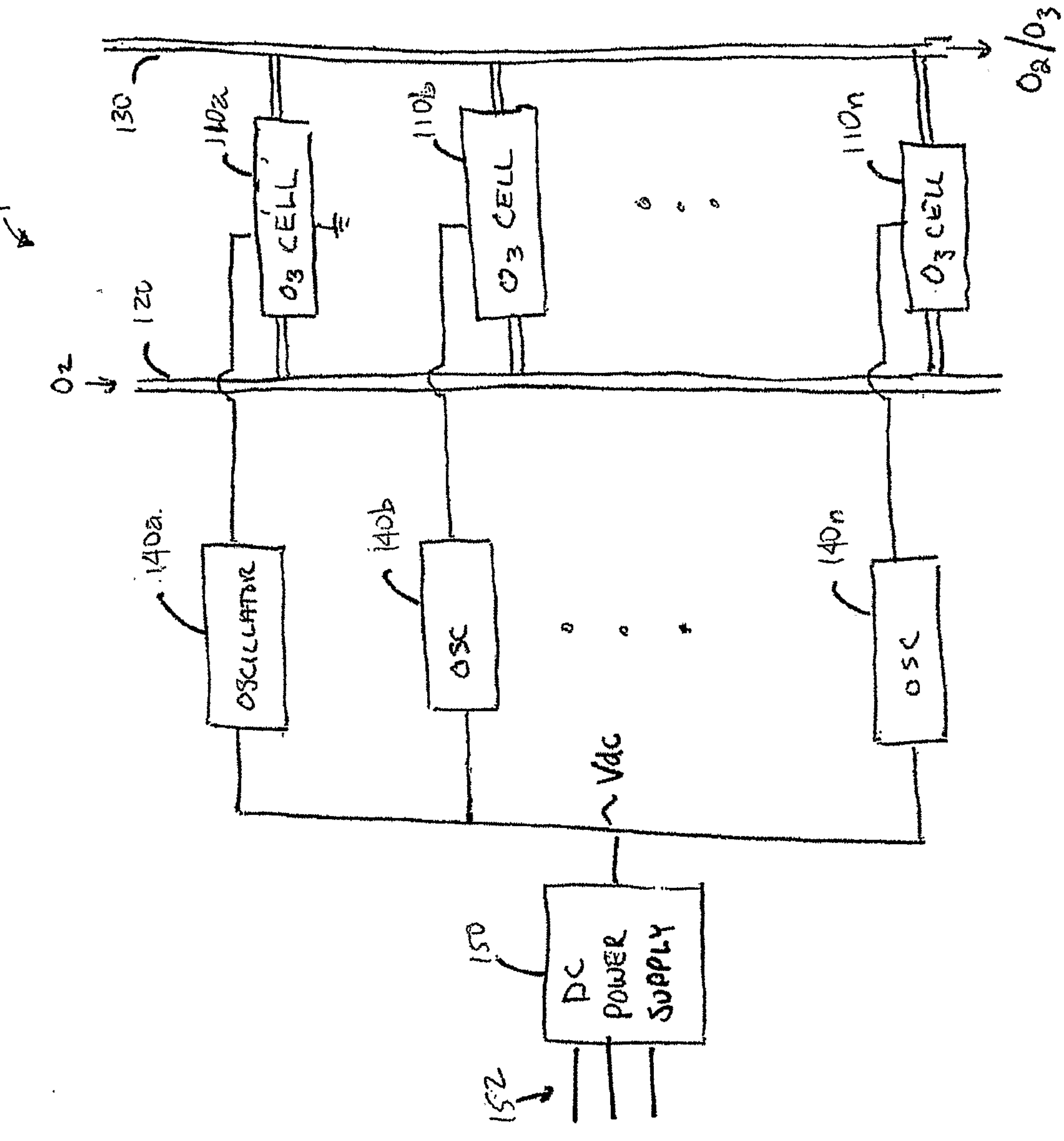

100
130
120
O_2
O_2/O_3
110b
110n
O_3 CELL
O_3 CELL
O_3 CELL
140a
140b
140n
OSCILLATOR
OSC
OSC
~Vdc
150
DC POWER SUPPLY
152

FIG. 1

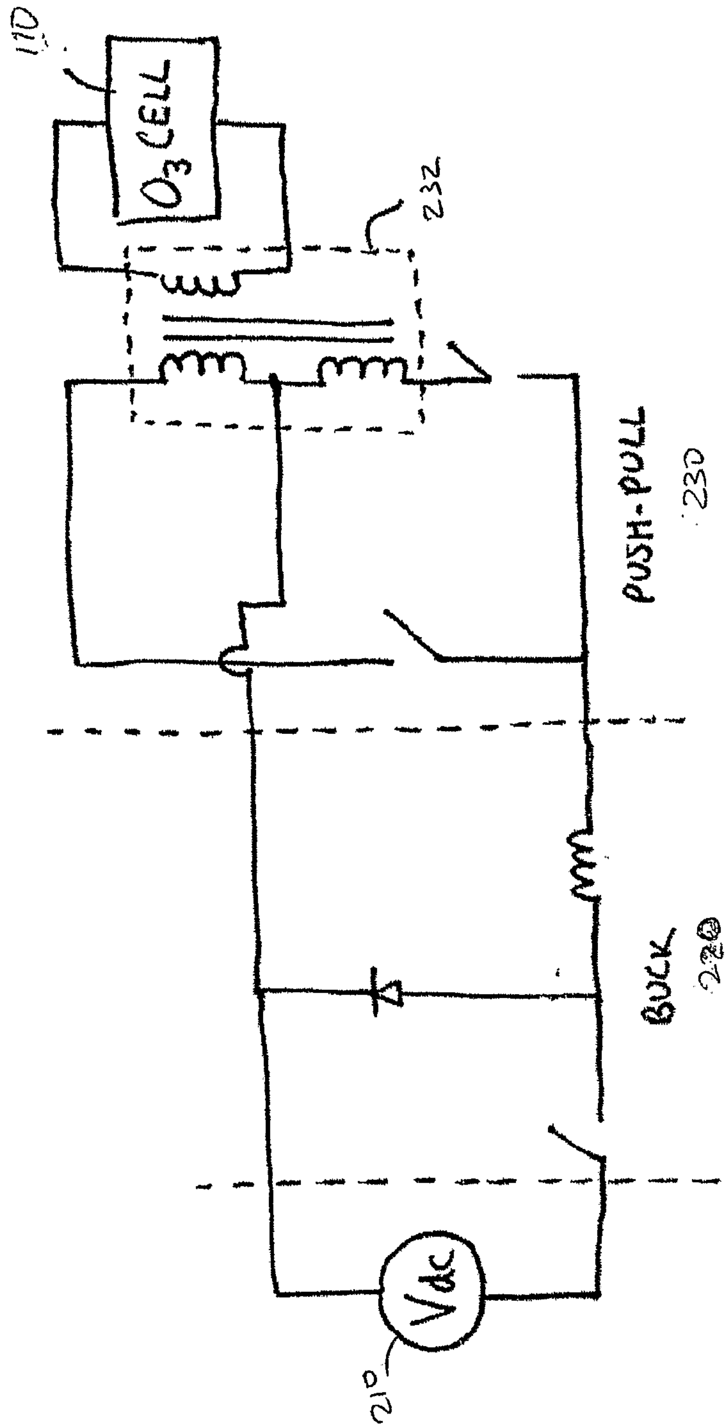


FIG. 2

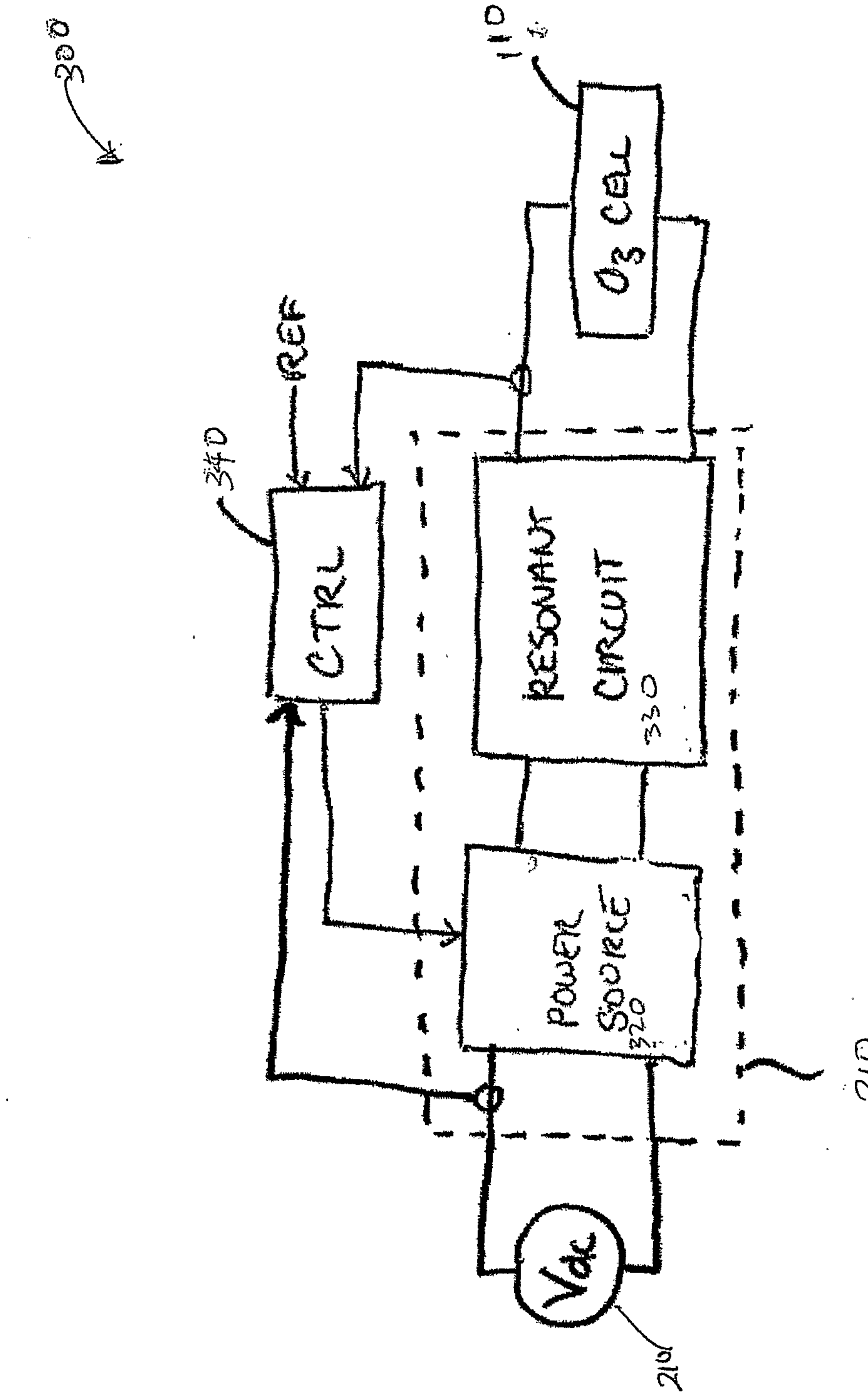

300
340
CTRL
REF
110
O3 CELL
RESONANT CIRCUIT
330
POWER SOURCE
320
310
Vdc
210

FIG. 3

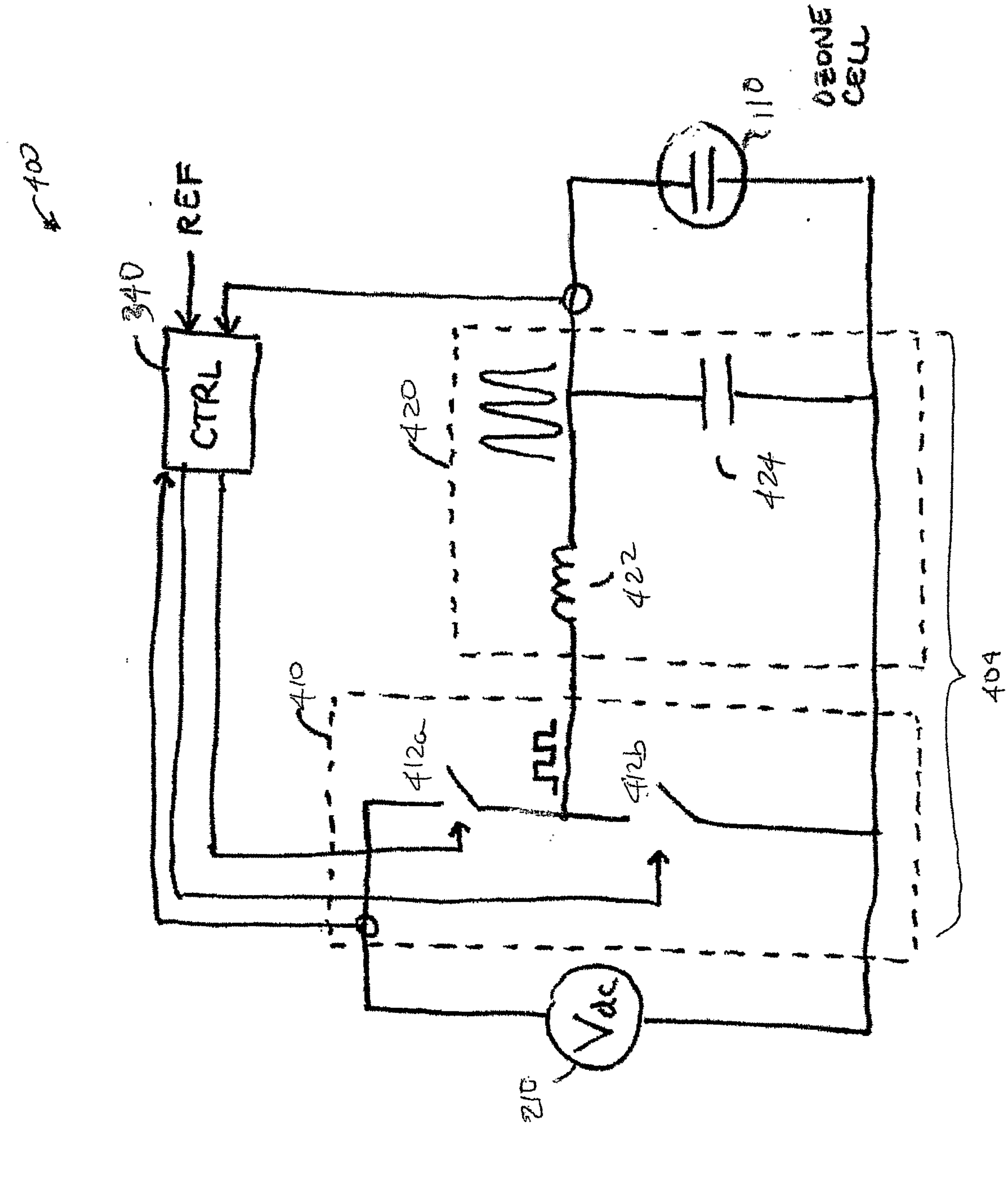

400
340
REF
CTRL
110
OZONE CELL
420
424
422
410
412a
412b
404
Vdc
210

FIG. 4

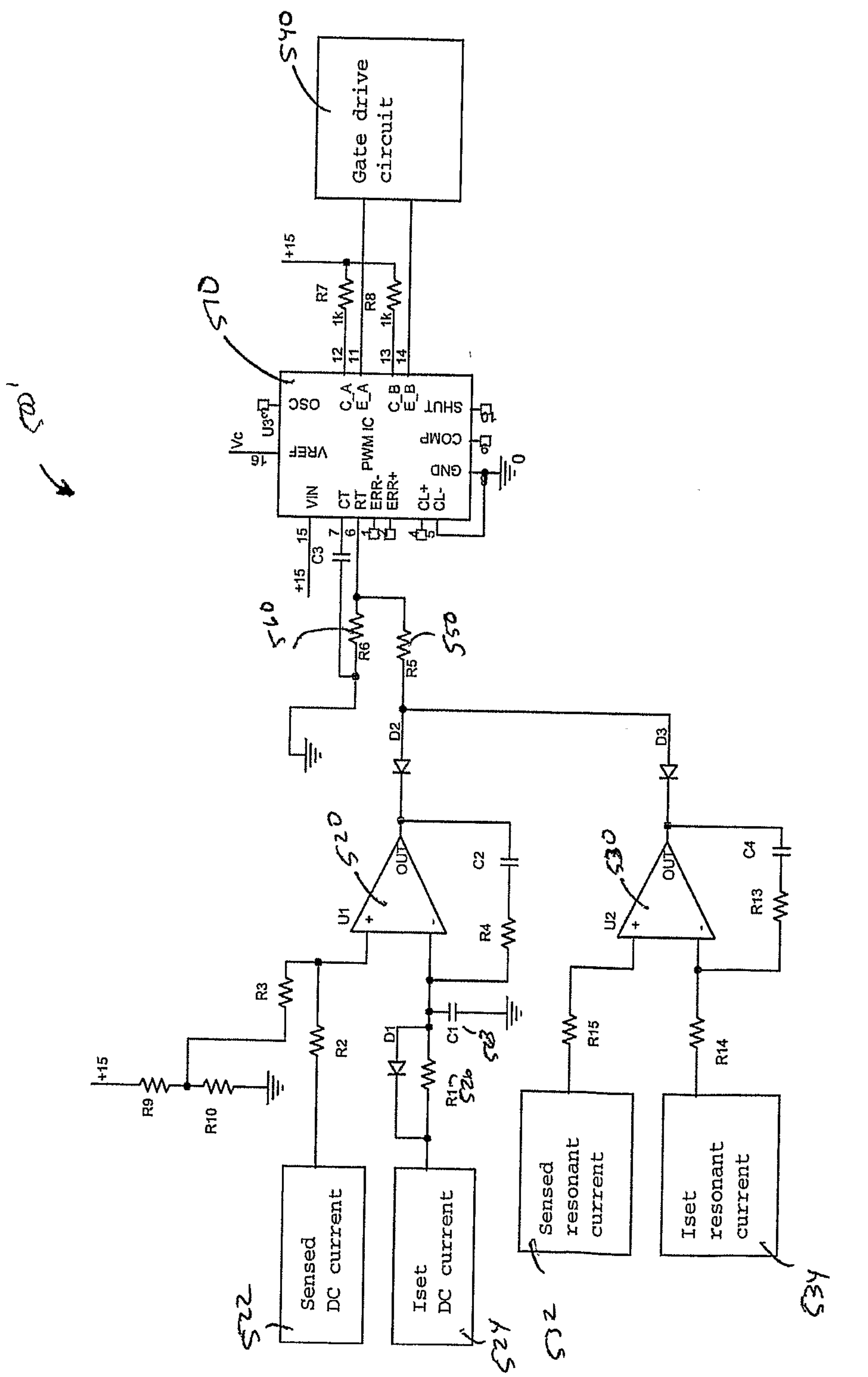

Gate drive circuit
540
510
PWM IC
VREF
OSC
VIN
CT
RT
ERR-
ERR+
CL+
CL-
GND
COMP
SHUT
C_A
E_A
C_B
E_B
R7
R8
1k
+15
Vc
U3
C3
R6
R5
560
550
D2
D3
U1
U2
520
530
OUT
C2
C4
R4
R13
R3
R2
R9
R10
D1
C1
R12
R14
R15
Sensed DC current
Iset DC current
Sensed resonant current
Iset resonant current
522
524
532
534

FIG. 5A

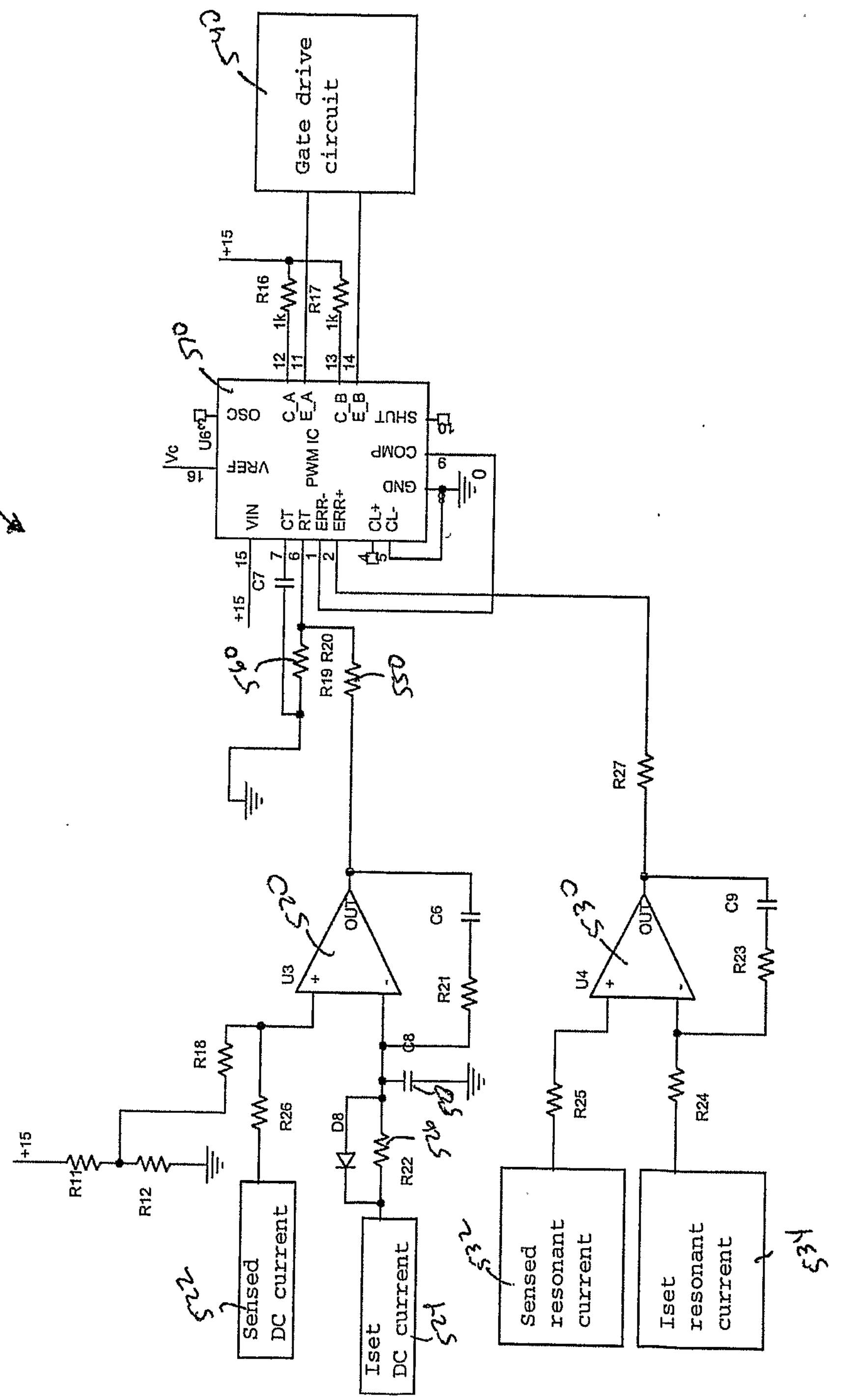

Gate drive circuit
PWM IC
VREF
OSC
C_A
E_A
C_B
E_B
SHUT
COMP
GND
VIN
CT
RT
ERR-
ERR+
CL+
CL-
R16
R17
1k
R19 R20
R27
C7
U3
U4
OUT
C6
C9
R21
R23
R18
R26
C8
D8
R22
R11
R12
R25
R24
+15
Sensed DC current
Iset DC current
Sensed resonant current
Iset resonant current

FIG. 5B

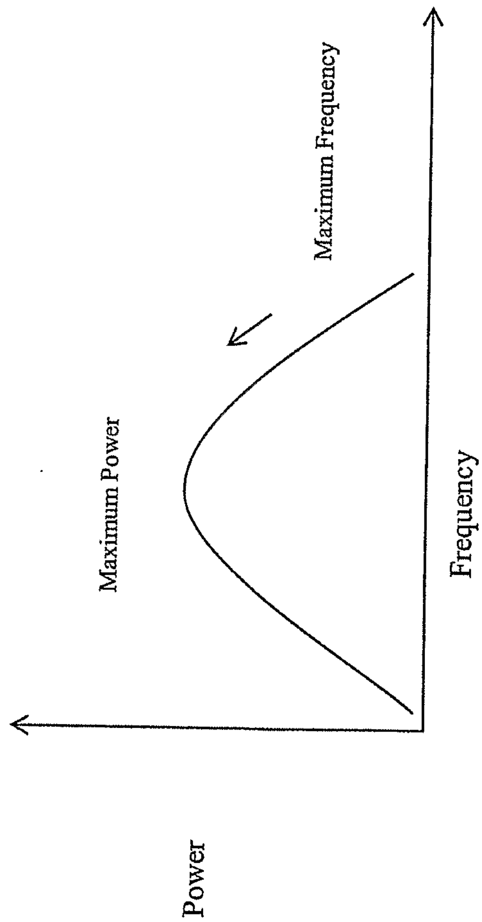


FIG. 6

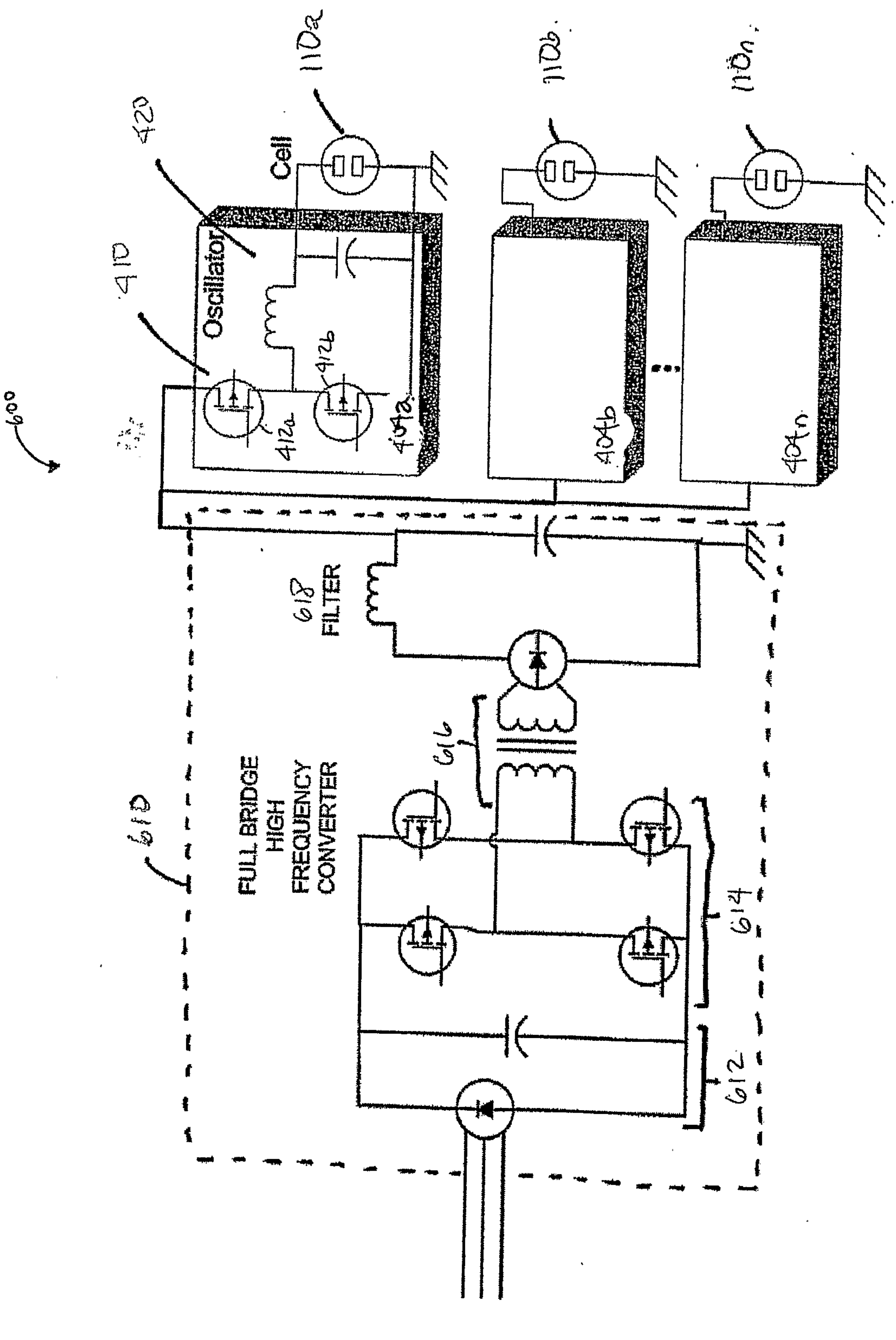

600
410
420
Oscillator
Cell
110a
110b
110n
412a
412b
404a
404b
404n
610
FULL BRIDGE HIGH FREQUENCY CONVERTER
616
618 FILTER
614
612

FIG. 7

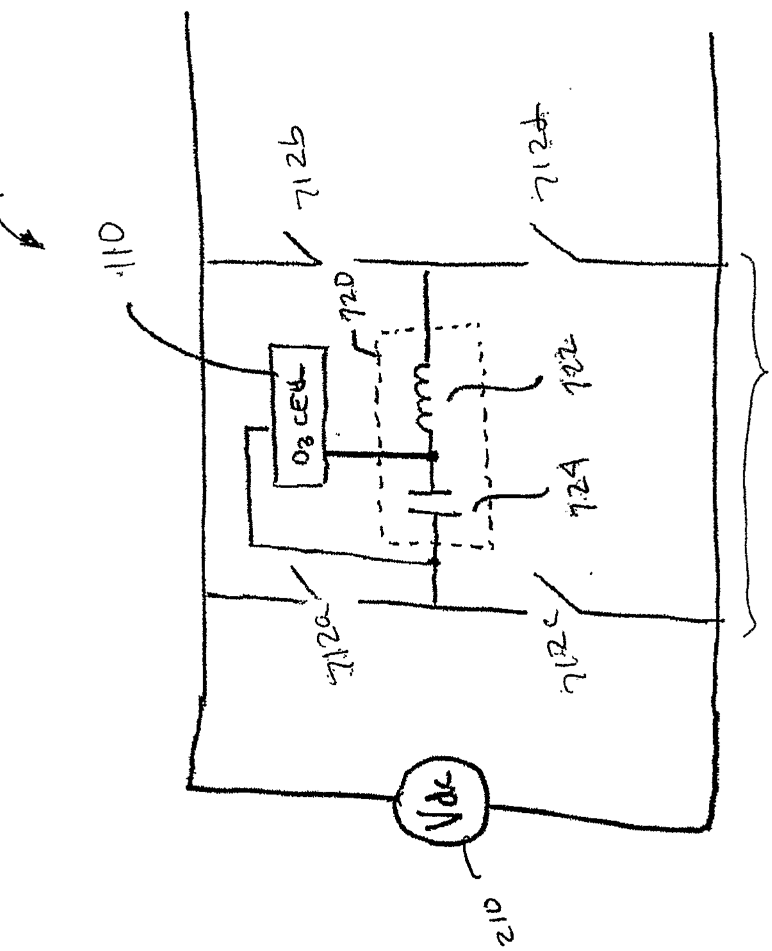


FIG. 8A

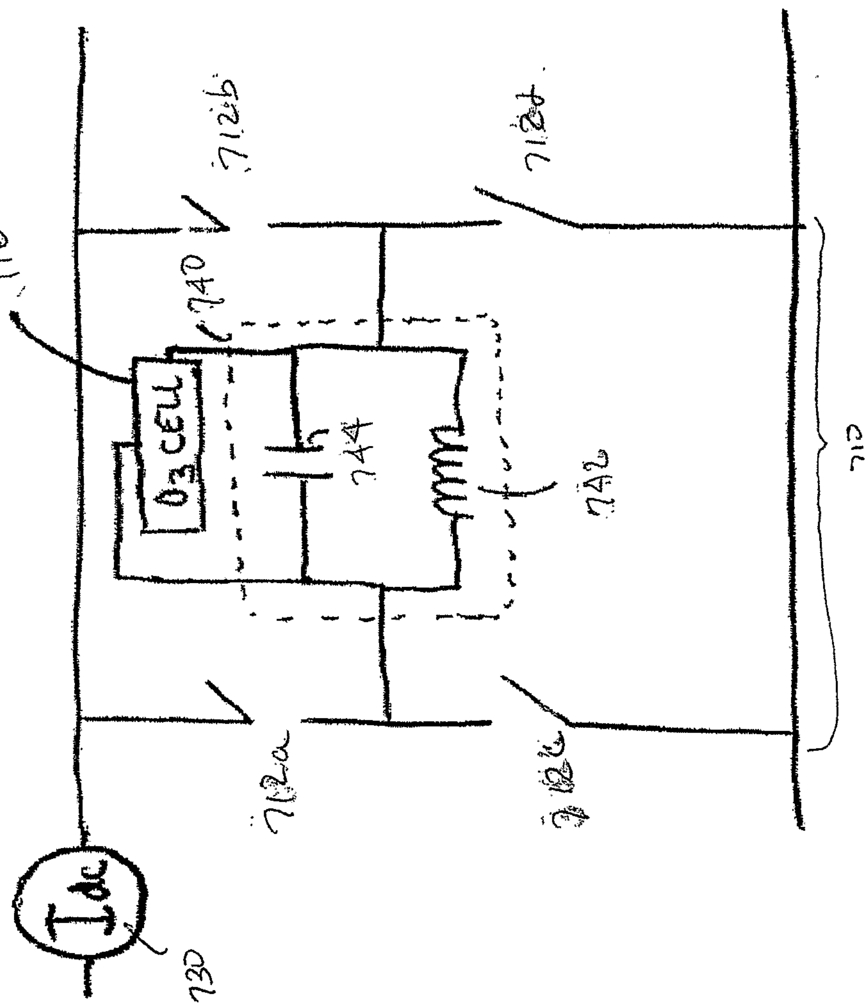


FIG. 8B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/031664

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02M5/458 H02M7/537 C01B13/11

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02M C01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KIFUNE H ET AL: "Novel constant frequency time ratio controlled series load resonant high frequency soft switching inverter" 33RD.ANNUAL IEEE POWER ELECTRONICS SPECIALISTS CONFERENCE. PESC 2002. CONFERENCE PROCEEDINGS. CAIRNS, QUEENSLAND, AUSTRALIA, JUNE 23 - 27, 2002, ANNUAL POWER ELECTRONICS SPECIALISTS CONFERENCE, NEW YORK, NY : IEEE, US, vol. VOL. 2 OF 4. CONF. 33, 23 June 2002 (2002-06-23), pages 1892-1897, XP010596025 ISBN: 0-7803-7262-X the whole document -----	1-5,8, 10-15, 18-22, 25, 27-32, 37-39

-/--

[X] Further documents are listed in the continuation of Box C.

[ ] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 February 2007	21/02/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Braccini, Roberto

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/031664

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ALONSO J M ET AL: "Analysis, design and experimentation of a high voltage power supply for ozone generation based on the current-fed parallel-resonant push-pull inverter" INDUSTRY APPLICATIONS CONFERENCE, 2004. 39TH IAS ANNUAL MEETING. CONFERENCE RECORD OF THE 2004 IEEE SEATTLE, WA, USA 3-7 OCT. 2004, PISCATAWAY, NJ, USA,IEEE, vol. 4, 3 October 2004 (2004-10-03), pages 2687-2693, XP010735542 ISBN: 0-7803-8486-5 the whole document -----	1,2,6-8, 10-15, 18,19, 23-25, 27-32, 37-39
X	OLEG KOUDRIAVTSEV ET AL: "A Novel Pulse-Density-Modulated High-Frequency Inverter for Silent-Discharge-Type Ozonizer" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 38, no. 2, March 2002 (2002-03), XP011073428 ISSN: 0093-9994 the whole document -----	1-5, 9-15, 18-22, 26-32
X	HUANG YUSHUI ET AL: "Load resonant type power supply of the ozonizer based on a closed-loop control strategy" APPLIED POWER ELECTRONICS CONFERENCE AND EXPOSITION, 2004. APEC '04. NINETEENTH ANNUAL IEEE ANAHEIM, CA, USA 22-26 FEB. 2004, PISCATAWAY, NJ, USA,IEEE, 22 February 2004 (2004-02-22), pages 1642-1646, XP010704335 ISBN: 0-7803-8269-2 the whole document -----	1-5, 9-15, 18-22, 26-32, 37-39