

RF POWER AMPLIFIER STABILITY NETWORK

FIELD

[0001] The present disclosure relates to a system and method for
5 stabilizing radio frequency (RF) power amplifiers in a plasma processing system.

BACKGROUND

[0002] The statements in this section merely provide background
information related to the present disclosure and may not constitute prior art.

10 [0003] Plasma processing systems are used in semiconductor
fabrication. The system employs a plasma chamber that changes the electrical
characteristics of a raw material (e.g. silicon) to manufacture semiconductor
components. Examples of such components include transistors, medium and
large state inductors, microprocessors, and random-access memory. The
15 plasma chamber can perform sputtering, plasma etching, plasma deposition,
and/or reactive ion etching in the manufacturing process.

[0004] In operation, the plasma chamber holds a semiconductor work-
piece. Gas is then introduced into the plasma chamber at low pressure. An RF
power generator applies RF power to the plasma chamber. The RF power
20 changes the gas from a gaseous state to plasma. The plasma comprises
electrically-charged ions that react with exposed regions of the semiconductor
work-piece. A combination of these operations is performed on the work-piece
to produce a particular semiconductor component.

[0005] Referring now to FIG. 1, portions of a typical plasma processing
25 system 10 are shown. An RF power generator includes one or more output
transistors 12. A direct current (DC) power supply provides power B+ to
transistor 12. In some embodiments the DC power supply includes a switching
power supply or power amplifier (PA). Output transistor 12 develops the RF
power in accordance with an RF drive signal 14. The RF power communicates
30 with an impedance matching network 16. An output of impedance matching
network 16 communicates with an input of a plasma chamber 20, which typically
has an input impedance of 50 ohms. Some installations include one or more

dissipative bandpass filters 22 that connect in the feed line between transistor 12 and a load, shown as plasma chamber 20.

[0006] Transistor 12 typically generates the RF power at a single center frequency f_0 . During operation the input impedance of plasma chamber 20 varies continuously and spontaneously due to natural properties of the plasma. These input impedance variations cause drops in the power coupling efficiency between transistor 12 and plasma chamber 20. The input impedance variations can also cause RF energy to reflect from plasma chamber 20 back to transistor 12. The reflected RF energy can cause instability in the power delivery system and damage transistor 12. Filter 22 can be used to dissipate the reflected energy that occurs at frequencies outside of a passband of centered at center frequency f_0 . Examples of filters 22 are disclosed by Chawla et al. in U.S. Patent No. 5,187,457, entitled "Harmonic and Subharmonic Filter", assigned to the assignee of the present invention.

[0007] In applications where B+ is provided by a switching power supply the reflected RF energy can also cause the power supply to become unstable. Examples of filters 22 to address such situations are disclosed by Porter et al. in U.S. Patent No. 5,747,935, entitled "Method and Apparatus for Stabilizing Switch Mode Powered RF Plasma Processing".

[0008] Referring now to FIG. 2, a non-limiting example of a test measurement illustrates effects of the variations that the impedance of the plasma has on the stability of the system. A horizontal axis represents frequency over a range centrally located around a frequency f_0 . A vertical axis represents power coupled into plasma chamber 20. A peak at 44 represents desirable power coupling at center frequency f_0 . The plasma chamber input impedance variations contribute to peaks 46 at frequencies above center frequency f_0 and peaks 48 at frequencies below center frequency f_0 . The peaks 46 and 48 indicate power at frequencies other than the fundamental frequency 44, such frequencies being generally undesirable. FIG. 3 depicts a Smith chart 50 illustrating the varying nature of the impedance match between transistor 12 and plasma chamber 20. A plot 51 of the impedance match crosses the real

(horizontal) axis of Smith chart 50 at points 53 and 55. The crossings indicate resonance in chamber 20.

[0009] Referring now to FIG. 4 a non-limiting example of a test measurement illustrates an example of harmonic distortions that cause a loss of fidelity in the RF power over a frequency range. Fidelity generally refers to the undistorted propagation of the RF power from transistor 12 to the input of plasma chamber 20. The horizontal axis represents frequency, and the vertical axis represents power output by the power amplifier. A first peak 54 occurs at center frequency f_0 . A second peak 56, third peak 58, and fourth peak 60 occur at increasing integer multiples of center frequency f_0 . The amplitudes of second peak 56, third peak 58, and fourth peak 60 are progressively less than the amplitude of first peak 54. Energy at the second peak 56, third peak 58, and fourth peak 60 indicates that the RF power would be distorted at plasma chamber 20 without additional filtering. The fidelity is therefore less than ideal.

SUMMARY

[0010] In accordance with a first aspect of the present invention, there is provided a radio frequency generator for applying RF power to a load, comprising: a DC power supply; at least one switch that generates the RF power at a center frequency; and a low-pass terminated network connected between the DC power supply and the switch and having a first cutoff frequency that is less than the center frequency, the low-pass terminated network providing offline impedance control at a frequency less than the center frequency; and a high-pass filter interposed between an output of the switch and the load, the high-pass filter having a second cutoff frequency less than the center frequency, the high-pass filter providing inline isolation of the switch from the load at a frequencies less than the center frequency.

[0011] In accordance with a second aspect of the present invention, there is provided a radio frequency generator for applying RF power to a plasma

chamber, comprising: a DC power supply; a radio frequency transistor that generates the RF power at a center frequency; and a stability network including: a low-pass terminated network connected inline with the DC power supply and the transistor, the low-pass terminated network having a first cutoff frequency less than the center frequency; and a high-pass filter inline with the RF power, the high-pass filter having a second cutoff frequency less than the center frequency, low-pass terminated network and high-pass filter cooperating with the low-pass terminated network to control an impedance at the transistor over a predetermined frequency of operation below the center frequency.

[0011a] In accordance with a third aspect of the present invention, there is provided a radio frequency generator for applying RF power to a plasma chamber, comprising: radio frequency transistors that generate RF power at a center frequency; low-pass dissipative terminated networks connected between respective ones of the transistors and associated DC power sources; and a combiner that generates an RF power signal based on the RF power from the radio frequency transistors, wherein the RF power signal is applied to the load; and wherein the low-pass filter dissipative terminated networks have a first cutoff frequency that is less than the center frequency.

[0011b] In accordance with a fourth aspect of the present invention, there is provided a radio frequency generator for applying RF power to a plasma chamber, comprising: radio frequency transistors that generate RF power at a center frequency; high-pass filters in series with respective RF power from the transistors and including a first cutoff frequency that is less than the center frequency; and a combiner that generates an RF power signal based on the RF power from the radio frequency transistors, wherein the RF power signal is applied to the plasma generator.

[0011c] In accordance with a fifth aspect of the present invention, there is provided a radio frequency generator for applying RF power to a plasma chamber, comprising: radio frequency transistors that generate RF power at a

center frequency; a combiner that generates an RF power signal based on the RF power from the radio frequency transistors; and a stability network including a high-pass filter inline with the RF power and located in close proximity to an output of the radio frequency transistor, the high-pass filter having a first cutoff frequency less than the center frequency.

[0012] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0013] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present teachings in any way.

5 [0014] FIG. 1 is a functional block diagram of a plasma processing system according to the prior art;

[0015] FIG. 2 is a test measurement of power perturbations due to the out-of-band interactions between the output transistor and the load;

[0016] FIG. 3 is a Smith chart of example power reflections in a plasma processing system;

10 [0017] FIG. 4 is test measurement of power coupling due to harmonic distortion;

[0018] FIG. 5 is a functional block diagram of a plasma processing system that includes a stability network;

15 [0019] FIG. 6 is a functional block diagram of the plasma processing system of FIG. 5 wherein the stability network includes a high-pass terminated network and a low-pass harmonic load-isolation filter;

[0020] FIG. 7 is a schematic diagram of a stability network;

[0021] FIG. 8 is a Smith chart of power reflections in the plasma processing system with a stability network;

20 [0022] FIG. 9 is a test measurement of power perturbations due to spurious input impedance variations in a plasma chamber with a stability network;

[0023] FIG. 10 is a test measurement of mass load harmonic distortion with inline mode isolation and a offline harmonic terminated;

25 [0024] FIG. 11 is functional block diagram of a push-pull plasma processing system;

[0025] FIG. 12 is a functional block diagram of second push-pull plasma processing system; and

30 [0026] FIG. 13 depicts a block diagram of a plasma processing system having multiple power amplifiers.

DETAILED DESCRIPTION

[0027] The following description of various embodiments is merely exemplary in nature and is in no way intended to limit the present teachings, application, or uses. Throughout this specification, like reference numerals will
5 refer to similar elements.

[0028] Referring now to FIG. 5 one of several embodiments of a plasma processing system 100 is shown. A direct current (DC) voltage B+ can be generated by a half-bridge and/or full bridge switching power supply. A low-pass terminated DC feed network (LPT network) 101 inline with the DC feed
10 couples B+ to a drain or collector of an RF transistor 102. LPT network 101 is reactive in-band and dissipates RF power occurring below a first cutoff frequency f_{c1} . In various embodiments, the first cutoff frequency f_{c1} is generally less than center frequency f_0 . LPT network 101 is described below in more detail.

[0029] Transistor 102 is shown as a single metal-oxide-silicon field
15 effect transistor (MOSFET), however it should be appreciated that other transistor arrangements and types may be employed. For example, transistor 102 may be any three terminal semiconductor device where one of the terminals controls a conductance through and/or voltage across the other two terminals. Transistor 102 may also be implemented as a single chip and/or a single die
20 MOSFET transistor. In some embodiments, transistor 102 can be implemented as a multiple-die kilowatt power transistor (KPT). Transistor 102 may also be implemented as one or more insulated-gate bipolar transistors (IGBT). The selection of a particular arrangement and type of transistor 102 can be based on factors such as a desired RF power magnitude, the voltage of B+, a frequency
25 range of the RF power, the ability to dissipate reflected energy, and so forth.

[0030] A gate or base of transistor 102 receives an RF drive signal 103 at the center frequency f_0 . When system 100 employs FM, the frequency of drive signal 103 modulates above and below center frequency f_0 . In some
30 embodiments, the range of modulation is between about +/-5% and +/-10% of center frequency f_0 , but it can incorporate larger ranges according to various embodiments. A source or emitter 104 of transistor 102 couples to ground. The drain couples to an input of an output network 106. In some embodiments,

output network 106 preserves fidelity of RF power that is generated at the drain of transistor 102. Details of output network 106 are provided below. Output network 106 communicates with an input of a high-pass sub-harmonic load isolation filter (HPSH filter) 108. HPSH filter 108 passes frequency components
5 that are greater than a second predetermined cutoff frequency f_{c2} . In various embodiments, the second predetermined cutoff frequency f_{c2} is generally less than center frequency f_0 and may approximately equal f_{c1} . Details of HPSH filter 108 are provided below.

[0031] The drain of transistor 102 also communicates with an offline
10 short 112. Offline short 112 operates at a frequency typically less than the center frequency f_0 , and, in some embodiments, operates at a frequency $f_0/2$. Offline short 112 will be described in greater detail below. An output of HPSH filter 108 communicates with an input to a plasma chamber 110. In some embodiments, an impedance matching network, such as shown in FIG. 1, can be
15 coupled in series with the input of plasma chamber 110.

[0032] LPT network 101 and HPSH filter 108 generally provide a pair of networks surrounding transistor 102 that cooperate to assist in providing a controlled out-of-band frequency response that is not affected by changes in the load, plasma chamber 110. LPT network 101 provides a low pass structure
20 offline from the RF path which enables low frequency impedance control for transistor 102. LPT network 101 works in conjunction with HPSH filter 108. HPSH filter 108 provides a high pass circuit in inline with the RF which isolates the load at sub-harmonic frequencies being controlled. The combination of LPT network 101 and HPSH filter 108 allows transistor 102 to experience the
25 impedance presented to it by LPT network 101. This allows control of the sub-harmonic impedances independent of load variation. LPT network 101 and HPSH filter 108 thus act in a complimentary manner to improve the stability of processing system 100. In some embodiments, it is not necessary to feed the DC component applied to transistor 102 through LPT network 101. Further,
30 HPSH filter 108 may be partially or entirely integrated into output network 106 in order to provide impedance matching functionality.

[0033] The configuration of FIG. 5 enables transistor 102 to operate under a controlled, load independent, real impedance in the sub-harmonic region, as impedance varies in accordance with the frequency. This prevents high frequency, sub-harmonic resonances created by the load, plasma chamber 110, from being transferred to the output node of transistor 102. This effectively isolates the load, plasma chamber 110, from transistor 102 below the frequency of operation. LPT 101 and HPSH filter 108 thus cooperate to improve the stability of processing system 100. Offline short 112 can further cooperate with LPT 101 and HPSH filter 108 to further condition the impedance at transistor 102 at sub-harmonic frequencies, thereby further improving stability of processing system 100.

[0034] Referring now to FIG. 6, one of several embodiments of processing system 100 is shown with a high-pass terminated network (HPT network) 120 and a low-pass harmonic load-isolation filter (LPHI filter) 122. HPT network 120 connects to the output of output network 106. LPHI filter 122 connects between output network 106 and HPSH filter 108. HPT network 120 dissipates RF power that occurs at frequencies above a third predetermined cutoff frequency f_{c3} . In some embodiments, the third predetermined cutoff frequency f_{c3} is generally in a frequency range of f_0 to $2f_0$. LPHI filter 122 passes RF energy that occurs below a fourth predetermined cutoff frequency f_{c4} . In various embodiments, the fourth predetermined cutoff frequency f_{c4} is greater than f_0 and may be generally approximately equal to f_{c3} . LPT network 101, output network 106, HPSH filter 108, HPT network 120, and LPHI filter 122 are collectively referred to as the stability network. It should be understood by one skilled in the art that the components of FIG. 6 can be arranged in different configurations. It will also be understood that the arranging of the components of FIG. 6 may result in different topologies of the individual components.

[0035] As discussed above, while LPT network 101 and HPSH filter 108 provide sub-harmonic isolation to transistor 102, HPT network 120 and LPHI filter 122 cooperate to provide isolation to transistor 102 above the frequencies of operation. This cooperation improves the fidelity of the output of processing system 100 while requiring minimal additional filter components. In some

embodiments, HPT network 120 and LPHI filter 122 operate in complimentary manner to provide high frequency impedance conditioning and terminated. The system of FIG. 6 isolates the load from the transistor both above and below the frequency of operation and provides a controlled, real impedance to transistor 5 102 within the bandwidth of operation. The inline circuits, LPHI filter 122 and HPSH filter 108, in some embodiments, can be configured to compensate for each other, allowing the amplifier system to achieve broadband operation and a high degree of load isolation below and above the frequency of operation. Further yet, the inline components, LPHI filter 122 and HPSH filter 108, in some 10 embodiments, may be designed to compensate each other, such as by phase compensation, so that the impedance for the frequency band of operation remains constant as a function of frequency. Such complimentary networks, enable processing system 100 to maintain a generally consistent efficiency over a broad range of frequencies.

15 **[0036]** Referring now to FIG. 7, a schematic diagram depicts various embodiments of the stability network. LPT network 101 includes an inductor L1, an inductor L2, an inductor L3, and an inductor L4 that are connected in series. B+ communicates with one end of inductor L1 and one end of a capacitor C1. The other end of capacitor C1 couples to ground. A series combination of a 20 resistor R1 and a capacitor C2 couples between ground and the junction of inductors L1 and L2. In some embodiments, resistor R1 may be replaced with a suitable dissipative element operating at a preselected frequency. Such dissipative element may be provided by suitable selection of the reactive elements in LPT network 101. A capacitor C3 couples between ground and the 25 junction of inductors L2 and L3. A capacitor C4 couples between ground and the junction of inductors L3 and L4. The other end of inductor L4 is the output of LPT network 101 and couples with the drain of transistor 102. The values of inductors L1-L4 and capacitors C1-C4 can be determined in accordance with the selection of f_{c1} .

30 **[0037]** Output network 106 includes a capacitor C5 that couples between ground and the drain of transistor 102. An inductor L6 couples between the drain of transistor 102 and first ends of a capacitor C7 and a capacitor C8. A

second end of capacitor C7 couples to ground. A second end of capacitor C8 couples to one end of an inductor L7 and provides the output of output network 106. The other end of inductor L7 couples to ground.

[0038] Offline short 112 includes a series-resonant combination of an inductor L5 and a capacitor C6 coupled between ground and the output of transistor 102. Inductor L5 and capacitor C6 form a shunt network to shunt RF current to ground at a particular frequency in a subharmonic band, such as a subharmonic $0.5*f_0$. The predetermined frequency may be selected in accordance with various design considerations. For example, some power amplifier systems exhibit undesired outcomes at particular, predetermined frequencies, and it is desirable to eliminate such frequencies. In some embodiments, the values of inductor L5 and capacitor C6 can therefore be chosen such that inductor L5 and capacitor C6 resonate at $0.5*f_0$. FIG. 8 depicts a Smith chart 114 demonstrating, by way of example, the effect of offline short 112. A plot 116 shows that offline short 112 generally shorts the subharmonics $0.5*f_0$ to ground.

[0039] Returning now to FIG. 7, HPT network 120 includes a capacitor C12, a capacitor C13, and a capacitor C14 connected in series. A resistor R2 couples between ground and the other end of capacitor C14. An inductor L11 couples between ground and the junction of capacitor C13 and capacitor C14. In some embodiments, resistor R2 may be replaced with a suitable dissipative element operating at a preselected frequency. Such dissipative element may be provided by suitable selection of the reactive elements in HPT network 120. An inductor L10 couples between ground and the junction of capacitor C12 and capacitor C13. The other end of capacitor C12 is the input of HPT network 120. In some embodiments, the values of inductors L10-L12 and capacitors C12-C14 can be determined based on f_{cs} and R2.

[0040] HPSH filter 108 includes a T-network formed from a series connection of a capacitor C10 and a capacitor C11. A center tap of the series connection couples with one end of an inductor L9. The other end of inductor L9 couples to ground. The other end of capacitor C10 is the input of HPSH filter 108. The other end of capacitor C11 is the output of HPSH filter 108.

[0041] LPHI filter 122 includes an inductor L8, a capacitor C9, inductor L7, and capacitor C12. Inductor L7 is therefore a component of output network filter 122 and HPSH filter 108. Similarly, capacitor C12 is therefore a component of LPHI filter 122 and HPT 20. A first end of inductor L8 communicates with inductor L7 and is the input of LPHI filter 122. A second end of inductor L8 connects to one end of capacitor C9 and the input of HPLI 108. The other end of capacitor C9 couples to ground.

[0042] Simulation results demonstrate the effectiveness of the system described herein for the input impedance (Z) of the stability network as seen by transistor 102. The simulation can include replacing plasma chamber 110 with a corresponding unterminated feed line having a length of 0λ , $1/8\lambda$, $1/4\lambda$, $1/2\lambda$, and $3/4\lambda$, respectively. Lambda (λ) is the wavelength of center frequency f_0 . In some simulations, the first and second cutoff frequencies f_{c1} and f_{c2} may be set to $0.6f_0$, and the third and fourth cutoff frequencies f_{c3} and f_{c4} may be set to $1.66f_0$. Removing plasma chamber 110 provides an infinite-to-one voltage standing wave ratio (VSWR) at the output of HPSH filter 108. The infinite-to-one VSWR presents the stability network with a worst-case load since the unterminated feed line is purely reactive and reflects all of the RF power.

[0043] According to various simulations, at the lowest frequencies, the impedance Z remains relatively constant due to the dissipative load provided by LPT network 101. HPSH filter 108 also helps to isolate the unterminated load from transistor 102 at the lowest frequencies. The impedance Z drops sharply at $0.5f_0$ due to the effects of offline short 112. The impedance Z rises again between $0.5f_0$ and $0.6f_0$ again due to LPT network 101 and HPSH filter 108. Between $0.6f_0$ and $1.66f_0$ the impedance Z varies with frequency and the length of the unterminated feed line. The varying impedance Z in this frequency range shows that the RF power is coupled to the load.

[0044] The impedance Z again stabilizes at frequencies above $1.66f_0$ due to the dissipative load provided by HPT network 120. LPHI filter 122 also helps isolate the unterminated load from transistor 102 at frequencies above $1.66f_0$. Various simulations, therefore, demonstrate that the stability network provides an unconditionally stable load to RF transistor 102 for frequency ranges

below f_{c1} and above f_{c3} . At frequencies between f_{c1} and f_{c3} the stability network couples transistor 102 to plasma chamber 110.

[0045] Referring now to FIG. 9, and by way of non-limiting example, a test measurement for various embodiments illustrates a lack of spurious distortions that can cause a loss of fidelity in the RF power. A horizontal axis represents frequency. A vertical axis represents power coupled into plasma chamber 20. A first peak 156 occurs at center frequency f_0 . Energy at frequencies other than f_0 indicates that the RF power is distorted at plasma chamber 20. The fidelity in FIG. 9 indicates an improvement over the fidelity of the test measurement of FIG. 4.

[0046] Referring now to FIG. 10, and by way of non-limiting example, a test measurement for various embodiments illustrates the match load harmonic distortion with inline load isolation and offline harmonic terminated. A horizontal axis represents frequency. A vertical axis represents power coupled into plasma chamber 20. As can be seen in FIG. 10, a first peak 162 appears at center frequency f_0 . A second peak 164 appears at a harmonic frequency of f_0 , and a third peak 166 appears at another harmonic of center frequency f_0 . FIG. 10 thus demonstrates the effectiveness of the combined inline load isolation and offline harmonic terminated. FIG. 10 thus demonstrates an improvement of combining match load harmonic distortion with inline load isolation and offline harmonic terminated.

[0047] Referring now to FIG. 11, a pair of stability networks is shown applied to an RF plasma processing system in a push-pull configuration. A first transistor 102-1 provides RF power and connects with a first one of the stability networks. A second transistor 102-2 provides RF power 180 degrees out of phase from first transistor 102-1. Second transistor 102-2 connects with a second one of the stability networks. A balun 160 combines the RF power that appears at the outputs of the stability networks and applies the combined RF power to plasma chamber 110. In some embodiments balun 160 can include a transformer.

[0048] Referring now to FIG. 12, the stability network is shown applied to an RF plasma processing system in a second push-pull configuration. First

transistor 102-1 connects with a first output network 106-1. Second transistor 102-2 connects with a second output network 106-2. Respective outputs of first and second output networks 106 are applied to inputs of balun 160. An output of balun 160 communicates with the inputs of HPT network 120 and LPHI filter 122.

- 5 An output of LPHI filter 122 communicates with the input of HPSH filter 108. The output of HPSH filter 108 communicates with the input of plasma chamber 110. Drains of first transistor 102-1 and second transistor 102-2 receive B+ through respective LPT networks 101.

[0049] FIG. 13 depicts a power generation system 170 for providing
10 power to a plasma chamber 110 utilizing a plurality of power amplifiers 172a, 172b, and 172c. Power amplifiers 172a, 172b, and 172c can generally be embodied as depicted using reference number 100 of FIGS. 5 and/or 6 and/or the configurations of FIGS 11 and/or 12. An input voltage/current module 174 provides an input voltage/current to each of power amplifiers 172a, 172b, and
15 172c. Each respective power amplifier 172a, 172b, and 172c receives the input voltage/current and amplifies the input to generate an amplified output applied to combiner 176. Combiner 176 combines the respective power outputs of amplifiers 172a, 172b, and 172c and generates a driving input to plasma chamber 110. A system controller 178 generates control signals to control at
20 least power amplifiers 172a, 172b, and 172c and, in some embodiments, provides control inputs and/or receives monitoring signals from each of the respective power amplifiers 172a, 172b, and 172c, input voltage/current module 174, and combiner 176. It will be understood by one skilled in the art that FIG. 13 is generally intended to show the combinability of the various circuit depicted
25 in FIGS. 5, 6, 11, and/or 12 in order to provide additional options for generating power to a plasma chamber 110.

[0050] The description herein is merely exemplary in nature and, thus, variations that do not depart from the gist of that which is described are intended to be within the scope of the teachings. Such variations are not to be regarded
30 as a departure from the spirit and scope of the teachings.

CLAIMS

What is claimed is:

1. A radio frequency generator for applying RF power to a load,
5 comprising:
a DC power supply;
at least one switch that generates the RF power at a center frequency;
and
a low-pass terminated network connected between the DC power supply
10 and the switch and having a first cutoff frequency that is less than the center
frequency, the low-pass terminated network providing offline impedance control
at a frequency less than the center frequency; and
a high-pass filter interposed between an output of the switch and the load,
the high-pass filter having a second cutoff frequency less than the center
15 frequency, the high-pass filter providing inline isolation of the switch from the
load at a frequencies less than the center frequency.
2. The RF generator of claim 1 wherein the low-pass terminated
network and high-pass filter are adapted to enable the RF generator to operate
20 at the center frequency or a band of frequencies below the center frequency.
3. The RF generator of claim 1 further comprising an output network
arranged in series with the high-pass filter.
- 25 4. The RF generator of claim 3 wherein the output network is
interposed between the switch and the high-pass filter.
5. The RF generator of claim 3 wherein the output network and high
pass filter include common components.
- 30 6. The RF generator of Claim 1 wherein the low-pass terminated
network includes a dissipative element.

7. The RF generator of Claim 1 wherein the low-pass terminated network presents an inductive load to the transistor.

5 8. The RF generator of Claim 1 wherein the first cutoff frequency is equal to about 0.6 times the center frequency.

9. The RF generator of Claim 1 wherein the second cutoff frequency is equal to about 0.6 times the center frequency.

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10. The RF generator of Claim 1 further comprising a high-pass terminated network connected offline from the RF power and having a third cutoff frequency that is greater than the center frequency, the high-pass terminated network providing offline impedance control for the switch at a
15 frequency greater than the center frequency.

11. The RF generator of Claim 10 wherein the high-pass terminated network includes a dissipative element.

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12. The RF generator of Claim 10 wherein the high-pass terminated network presents a reactance in a predetermined frequency range.

13. The RF generator of Claim 10 wherein the third cutoff frequency is equal to about 1.66 times the center frequency.

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14. The RF generator of Claim 1 further comprising a low-pass filter interposed between the load and the switch, the low-pass filter having a fourth cutoff frequency that is greater than the center frequency, the low-pass filter providing inline isolation of the switch from the load at a frequency greater than
30 the center frequency.

15. The RF generator of Claim 14 wherein the fourth cutoff frequency is equal to about 1.66 times the center frequency.

16. The RF generator of Claim 1 further comprising a shunt network
5 offline from the RF power and including a band-pass frequency.

17. The RF generator of Claim 16 wherein the band-pass frequency is 0.5 times the center frequency.

10 18. A radio frequency generator for applying RF power to a plasma chamber, comprising:

a DC power supply;

a radio frequency transistor that generates the RF power at a center frequency; and

15 a stability network including:

a low-pass terminated network connected inline with the DC power supply and the transistor, the low-pass terminated network and having a first cutoff frequency less than the center frequency; and

20 a high-pass filter inline with the RF power, the high-pass filter having a second cutoff frequency less than the center frequency, low-pass terminated network and high-pass filter cooperating with the low-pass terminated network to control an impedance at the transistor over a predetermined frequency of operation below the center frequency.

25 19. The RF generator of Claim 18 wherein the second cutoff frequency is equal to about 0.6 times the center frequency.

20. The RF generator of Claim 18 wherein the high-pass dissipative terminated network includes a dissipative element.

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21. The RF generator of Claim 18 further comprising a fidelity network including:

a high-pass terminated network connected offline from the RF power and having a third cutoff frequency that is greater than the center frequency; and

5 a low-pass filter inline with the RF power, the low-pass filter having a fourth cutoff frequency that is greater than the center frequency, the high-pass terminated network and low-pass filter cooperating to control an impedance at the transistor over a predetermined frequency of operation above the center frequency.

22. The RF generator of Claim 21 wherein the high-pass dissipative
10 terminated network presents a reactance in a predetermined frequency range of operation.

23. The RF generator of Claim 21 wherein the third cutoff frequency is equal to about 1.66 times the center frequency.

15 24. The RF generator of Claim 21 wherein the fourth cutoff frequency is equal to about 1.66 times the center frequency.

25. The RF generator of Claim 21 further comprising a band-pass filter
20 connected to the RF power and including a band-pass center frequency that is less than the center frequency.

26. The RF generator of Claim 25 wherein the band-pass center frequency is 0.5 times the center frequency.

25 27. A radio frequency generator for applying RF power to a plasma chamber, comprising:

radio frequency transistors that generate RF power at a center frequency;
low-pass dissipative terminated networks connected between respective
30 ones of the transistors and associated DC power sources; and

a combiner that generates an RF power signal based on the RF power from the radio frequency transistors, wherein the RF power signal is applied to the load; and

wherein the low-pass dissipative terminated networks have a first cutoff
5 frequency that is less than the center frequency.

28. The RF generator of Claim 27 wherein the low-pass dissipative terminated networks include a respective dissipative element.

10 29. The RF generator of Claim 27 wherein the low-pass dissipative terminated networks present a reactance in a predetermined frequency range.

30. The RF generator of Claim 27 wherein the first cutoff frequency is equal to about 0.6 times the center frequency.

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31. The RF generator of Claim 27 further comprising high-pass filters in series with respective RF power from the transistors and having a second cutoff frequency that is less than the center frequency.

20 32. The RF generator of Claim 31 wherein the second cutoff frequency is equal to about 0.6 times the center frequency.

33. The RF generator of Claim 27 further comprising high-pass dissipative terminated networks connected to respective RF power from the
25 transistors and including a third cutoff frequency that is greater than the center frequency.

34. The RF generator of Claim 33 wherein the high-pass dissipative terminated networks include respective dissipative elements.

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35. The RF generator of Claim 33 wherein the high-pass dissipative terminated networks present a reactance at a predetermined frequency range.

36. The RF generator of Claim 33 wherein the third cutoff frequency is equal to about 1.66 times the center frequency.

5 37. The RF generator of Claim 27 further comprising a low-pass filter in series with respective RF power from the transistors and including a fourth cutoff frequency that is greater than the center frequency.

38. The RF generator of Claim 37 wherein the fourth cutoff frequency
10 is equal to about 1.66 times the center frequency.

39. The RF generator of Claim 27 further comprising band-pass filters connected to respective RF power from the transistors and including a band-pass center frequency that is less than the center frequency.

15 40. The RF generator of Claim 39 wherein the band-pass center frequency is 0.5 times the center frequency.

41. The RF generator of Claim 27 further comprising a high-pass filter
20 in series with the RF power signal and including a second cutoff frequency that is less than the center frequency.

42. The RF generator of Claim 41 wherein the second cutoff frequency
is equal to about 0.6 times the center frequency.

25 43. The RF generator of Claim 27 further comprising a high-pass dissipative terminated network connected to the RF power signal and including a third cutoff frequency that is greater than the center frequency.

30 44. The RF generator of Claim 43 wherein the high-pass dissipative terminated network includes a dissipative element.

45. The RF generator of Claim 43 wherein the high-pass dissipative terminated network presents a reactance in a predetermined frequency range.

46. The RF generator of Claim 43 wherein the third cutoff frequency is
5 equal to about 1.66 times the center frequency.

47. The RF generator of Claim 27 further comprising a low-pass filter in series with the RF power signal and including a fourth cutoff frequency that is greater than the center frequency.
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48. The RF generator of Claim 47 wherein the fourth cutoff frequency is equal to about 1.66 times the center frequency.

49. The RF generator of Claim 27 further comprising a band-pass filter
15 connected to the RF power signal and including a band-pass center frequency that is less than the center frequency.

50. The RF generator of Claim 49 wherein the band-pass center frequency is 0.5 times the center frequency.
20

51. A radio frequency generator for applying RF power to a plasma chamber, comprising:
radio frequency transistors that generate RF power at a center frequency;
high-pass filters in series with respective RF power from the transistors
25 and including a first cutoff frequency that is less than the center frequency; and
a combiner that generates an RF power signal based on the RF power from the radio frequency transistors, wherein the RF power signal is applied to the plasma generator.

52. The RF generator of Claim 51 wherein the first cutoff frequency is
30 equal to about 0.6 times the center frequency.

53. The RF generator of Claim 51 further comprising high-pass dissipative terminated networks connected to the RF power from respective transistors and including a second cutoff frequency that is greater than the center frequency.

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54. The RF generator of Claim 53 wherein the high-pass dissipative terminated networks include a respective dissipative element.

55. The RF generator of Claim 53 wherein the high-pass dissipative terminated networks present a reactance in a predetermined frequency range.

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56. The RF generator of Claim 53 wherein the second cutoff frequency is equal to about 1.66 times the center frequency.

57. The RF generator of Claim 51 further comprising low-pass filters in series with the RF power from respective transistors and including a third cutoff frequency that is greater than the center frequency.

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58. The RF generator of Claim 57 wherein the third cutoff frequency is equal to about 1.66 times the center frequency.

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59. The RF generator of Claim 51 further comprising band-pass filters connected to the RF power from respective transistors and including a band-pass center frequency that is less than the center frequency.

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60. The RF generator of Claim 59 wherein the band-pass center frequency is 0.5 times the center frequency.

61. A radio frequency generator for applying RF power to a plasma chamber, comprising:

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radio frequency transistors that generate RF power at a center frequency;

a combiner that generates an RF power signal based on the RF power from the radio frequency transistors; and

5 a stability network including a high-pass filter inline with the RF power and located in close proximity to an output of the radio frequency transistor, the high-pass filter having a first cutoff frequency less than the center frequency.

62. The radio frequency generator of claim 61 further comprising a low-pass terminated network connected inline with the DC power supply and the transistors, the low-pass terminated network having a second cutoff frequency
10 less than the center frequency, the low-pass terminated network and high-pass filter cooperating with the low-pass terminated network to control an impedance at the transistor over a predetermined frequency of operation below the center frequency.

15 63. The RF generator of Claim 61 wherein the first cutoff frequency is equal to about 0.6 times the center frequency.

64. The RF generator of Claim 61 further comprising a high-pass dissipative terminated network connected offline from the RF power signal and
20 including a third cutoff frequency that is greater than the center frequency.

65. The RF generator of Claim 64 wherein the high-pass dissipative terminated network includes a dissipative element.

25 66. The RF generator of Claim 64 wherein the high-pass dissipative terminated network presents a reactance in a predetermined frequency range.

67. The RF generator of Claim 64 wherein the third cutoff frequency is equal to about 1.66 times the center frequency.

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68. The RF generator of Claim 62 further comprising a low-pass filter inline with the RF power signal and including a fourth cutoff frequency that is greater than the center frequency.

5 69. The RF generator of Claim 68 wherein the fourth cutoff frequency is equal to about 1.66 times the center frequency.

70. The RF generator of Claim 62 further comprising a band-pass filter connected to the RF power signal and including a band-pass center frequency
10 that is less than the center frequency.

71. The RF generator of Claim 70 wherein the band-pass center frequency is 0.5 times the center frequency.