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RF PULSE AMPLIFIER COMPRISING A DC/DC CONVERTER AND METHOD OF AMPLIFYING AN RF PULSE

Abstract

An RF pulse amplifying device includes an amplifier configured to amplify a pulsed RF signal, a DC link configured to supply a DC bus voltage, and an energy storage device connected to the DC link. The amplifier has an input for receiving a supply voltage. The input of the amplifier is connected to the DC link through a switched DC/DC converter, which is configured to step down the DC bus voltage, supplied at the converter input, to the supply voltage, applied to the converter output. A control unit is configured to operate the switched DC/DC converter during amplification of the RF pulse to control the supply voltage at a predetermined value.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure is related to radio frequency (RF) pulse amplifying devices, in particular comprising an RF amplifier and an energy storage device for providing the peak power during amplification of the pulse.

BACKGROUND

[0002] Pulsed RF applications, such as magnetic resonance imaging (MRI), require a high peak power for a short time in the order of several milliseconds to generate one pulse. The peak to average power ratio in these applications is typically in the range of 5 to 40. This requires either a large energy (capacitor) buffer, or a power supply capable of delivering the peak power. The latter solution is however not preferred due to the large impact on the grid capacity and the added cost and footprint of a power supply dimensioned based on the peak power instead of the average power.

[0003] One disadvantage of utilizing an energy buffer for delivering the peak power is that it results in voltage droop at the energy buffer when the rate of depletion of the buffer exceeds the rate of renewal from the power supply. This typically occurs during generation of the pulse. The RF output power is directly related to the DC voltage supplied to the amplifier by the energy buffer through the relation: P.sub.RF=V.sub.DD.sup.2/β, where β represents a constant depending on the load impedance and used transistor power capability. If the energy buffer is simply attached to the amplifier, the pulse power is reduced, resulting in an RF power droop. This phenomenon particularly occurs when the amplifier is operated in compression.

[0004] RF power droop problems have become more pronounced by the introduction of LDMOS (laterally-diffused metal-oxide semiconductor) transistor technology (supply voltage V.sub.DD=50V) in RF amplifiers compared to previously used VDMOS (vertical double-diffused metal-oxide semiconductor) transistor technology (supply voltage V.sub.DD=150V). The constant β for LDMOS is 9 times lower compared to VDMOS resulting in much higher supply currents for the same RF power. A supply voltage droop of 1V for a VDMOS RF amplifier typically results in 1.3% RF power droop, where 1V voltage droop for a LDMOS RF amplifier typically results in 4% RF power droop. In other words, for having equal RF power droop for LDMOS as compared to VDMOS, the supply voltage should be lower than 330 mV. RF power droop problems are also pronounced for GaN transistor devices, which also feature a 50 V supply voltage.

[0005] U.S. Pat. No. 6,072,315, 6 Jun. 2000 describes a RF magnetic field pulse generator comprising an energy storage device and a switched voltage regulator which regulates the supply voltage of the RF amplifier. The energy storage device is connected to the amplifier via the switched voltage regulator, which comprises a local storage capacitor. The supply voltage is defined by the voltage across the local storage capacitor. The switched voltage regulator controls when the local storage capacitor is charged from the energy storage device. The recharge logic is such that the local storage capacitor is charged in synchronism with a pulse train, and such that the local storage capacitor is not charged during a pulse, but only in between consecutive pulses. U.S. Pat. No. 6,072,315 appreciates that the supply voltage may change during the course of one pulse. However, the voltage regulator ensures that the supply voltage is restored to the correct level in time for the next pulse.

[0006] While the approach of U.S. Pat. No. 6,072,315 may be acceptable for very short pulses of the order of a few microseconds, it is not acceptable for longer pulses of the order of a few milliseconds, as is customary in e.g. MRI applications.

[0007] US 2017/0102441, 13 Apr. 2017 describes a pulsating load, such as an RF amplifier power supply, connected to the three-phase AC mains through a passive rectifier. An energy storage device, such as an ultracapacitor, is connected through a DC/DC converter to the DC link created by the passive rectifier. The energy storage device connects through the DC/DC converter downstream of the rectifier and upstream from the RF amplifier power supply. Power is shared between AC mains and the energy storage device during a pulsing period and power drawn during a non-pulsing period is utilized by the energy storage device to charge back. The release of energy from the energy storage device during peak load power duration, results in reducing the power and hence the current drawn from the AC mains.

[0008] One disadvantage of the above system, is that to prevent significant RF power droop, a large capacitor bank is required as the energy storage device, resulting in high cost and volume. Nevertheless, even in such cases, RF power droop cannot be completely avoided.

SUMMARY

[0009] There is hence a need in the art to provide RF pulse amplifiers that can overcome the disadvantages of the prior art. Specifically, there is a need for RF pulse amplifiers that can achieve better performance at reduced cost and volume.

[0010] According to a first aspect of the present disclosure, there is therefore provided a device for amplifying a radio frequency (RF) pulse. In aspects of the present disclosure, a RF pulse amplifying device comprises an amplifier configured to amplify a pulsed RF signal, a DC link configured to supply a DC bus voltage, and an energy storage device connected to the DC link. The amplifier comprises an input for receiving a supply voltage. The input of the amplifier is connected to the DC link (and hence to the energy storage device) through a switched (or switched-mode) DC/DC converter, which is configured to step down the DC bus voltage (supplied at the converter input) to the supply voltage (applied to the converter output). A control unit is configured to operate the switched DC/DC converter during operation of the RF amplifier (i.e. when amplifying the RF pulse) to control the supply voltage at a predetermined value. Advantageously, the control unit is configured to control the switched DC/DC converter to switch continuously, i.e., both during generation or amplification of a pulse and in between consecutive pulses of the pulsed RF signal. Hence, advantageously the switched DC/DC converter is configured to switch continuously during operation of the device, independently of whether a pulse is applied.

[0011] The device described in the present disclosure hence allows to efficiently control the supply voltage at the input of the amplifier to a predetermined value, irrespective of variations in the DC bus voltage of the DC link. This DC bus voltage may be allowed to vary in a wide range, relaxing the specifications required for the energy storage device and any upstream mains-to-DC converter in terms of voltage droop. At the same time, the supply voltage can be tightly controlled so that any occurring voltage droop at the DC link does not propagate to the output of the amplifier, effectively preventing RF output power droop. Hence, devices as described herein provide high performance at minimal cost and volume.

[0012] Advantageously, the switched DC/DC converter is configured to be operated (e.g. through the control unit) at a switching frequency, which is substantially higher than the repetition frequency of the RF pulse. A ratio of the switching frequency to the repetition frequency of the RF pulse is at least 10, preferably at least 20, preferably between 50 and 10000. This allows to effectively control the supply voltage to a stable value. Advantageously, the switched DC/DC converter is configured to be operated continuously. The switched DC/DC converter can be a non-isolating converter, e.g. a half bridge converter, which provides a very economical pulse generator with minimal volume while ensuring high performance. Alternatively, it can be an isolating converter.

[0013] Hence, in devices as described herein, the amplifier is connected to the energy storage device, which can comprise one or more storage capacitors, such as a capacitor bank, through the switched DC/DC converter. The energy storage device can be connected to the mains supply, e.g. an AC supply, through a mains-to-DC converter. The mains-to-DC converter advantageously comprises an output connected to the DC link. The mains-to-DC converter is advantageously configured to supply energy to the energy storage device, and the mains-to-DC converter is advantageously rated based on an average output power of the amplifier.

[0014] In some examples, a plurality of series arrangements of the switched DC/DC converter and the amplifier are provided. Each amplifier receives a supply voltage from the respective switched DC/DC converter. The series arrangements of switched DC/DC converter and amplifier can be connected in parallel at the output of the amplifier, e.g. through a power combiner and/or at the input of the switched DC/DC converter, e.g. at the DC link. This way, a RF pulse amplifying device with higher output power can be provided.

[0015] According to a second aspect of the present disclosure, there is provided an apparatus for generating a RF electromagnetic field, such as a magnetic resonance imaging apparatus, a plasma generating apparatus, a particle accelerator, or a laser apparatus, comprising the device as described herein.

[0016] According to a third aspect of the present disclosure, there is provided a method of amplifying a RF pulse. A method according to the present disclosure comprises storing energy in an energy storage device at a DC bus voltage and stepping down the DC bus voltage to a supply voltage utilizing a switched DC/DC converter. The supply voltage is applied to an amplifier, which amplifies the RF pulse. The switched DC/DC converter is operated while amplifying the RF pulse. Advantageously, the amplifier outputs RF pulses at a pulse repetition frequency and the switched DC/DC converter is operated at a switching frequency, wherein a ratio of the switching frequency to the pulse repetition frequency is at least 10, preferably at least 20, preferably between 50 and 10000.

[0017] Advantageously, a ratio of the DC bus voltage to the supply voltage is at least 1.5, preferably at least 2. A larger ratio of DC bus voltage to supply voltage allows for a larger voltage variation of the DC bus voltage during pulse generation (e.g. due to voltage droop). The DC bus voltage can be between 20 V and 500 V, particularly between 70 V and 300 V. The supply voltage is advantageously between 5 V and 200 V, preferably between 12 V and 150 V, or between 28 V and 100 V.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Aspects of the present disclosure will now be described in more detail with reference to the appended drawings, wherein same reference numerals illustrate same features and wherein:

[0019] FIG. **1** represents a schematic diagram of a device for amplifying RF pulses according to aspects of the present disclosure;

[0020] FIG. **2** represents a diagram of a non-isolated DC/DC converter that can be utilized in the device for amplifying RF pulses according to aspects of the present disclosure;

[0021] FIG. **3** represents a schematic diagram of an isolated DC/DC converter that can be utilized in the device for amplifying RF pulses according to aspects of the present disclosure;

[0022] FIG. **4** represents a schematic diagram of a device for amplifying RF pulses according to aspects of the present disclosure comprising a plurality of amplifiers and a RF power combiner.

DETAILED DESCRIPTION

[0023] Referring to FIG. **1**, a device **10** for amplifying RF pulses according to the present disclosure is configured to provide an amplified RF pulsed signal, which can comprise one or more pulses, at an output **16**. The RF pulsed signal is generated by a signal generator **153** and supplied to RF amplifier **15** at a signal input **152**. RF amplifier **15**, which can be any suitable power amplifier as known in the art capable of amplifying a pulsed RF signal, preferably a class B or class E amplifier, is configured to amplify the pulsed RF signal received at signal input **152** and provide the amplified signal at output **16**. The RF pulses, which advantageously are AC pulses, can have a pulse duration of the order of a few milliseconds, such as between 1 ms and 100 ms, preferably between 1 ms and 50 ms, even though shorter pulses, e.g. of the order between 50 μs and 1 ms are possible. The pulse duty-cycle can range between 0.5% and 25%, and is typically between 1% and 10%. The power delivered by a pulse can range between 1 kW and 100 kW, possibly between 2 kW and 60 kW, such as between 5 kW and 50 kW, for example about 20 kW, which is typical for MRI applications.

[0024] RF amplifier **15** comprises an input **151** for receiving a supply voltage V.sub.DD. For RF amplifiers based on LDMOS or GaN transistors, the supply voltage V.sub.DD may range between 12 V and 100 V, and is typically V.sub.DD=50 V. The power delivered by the RF amplifier **15** at the output **16** is typically directly related to the supply voltage.

[0025] The input **151** of RF amplifier **15** is connected to the DC link **13** through a DC/DC buck converter **14**. The DC link is at a bus voltage V.sub.BUS which is higher than the supply voltage V.sub.DD and the DC/DC converter is configured to step down the bus voltage V.sub.BUS to the supply voltage V.sub.DD.

[0026] An energy storage device **12**, which acts as an energy buffer, is connected to DC link **13**. Energy storage device **12** can comprise a capacitor bank, or one or more ultracapacitors, or any other energy buffering system as known in the art. Energy storage device buffers electrical energy typically at the bus voltage V.sub.BUS of DC link **13**. Energy storage device is charged via a mains supply **9**, typically providing AC power. An AC/DC converter **11** is connected between the mains supply **9** and the energy storage device **12**. Particularly, the AC/DC converter **11** comprises a DC output connected to the DC link **13** and the energy storage device **12** is connected to the DC link **13**. The AC/DC converter **11** can be an active or a passive rectifier as is known in the art.

[0027] Advantageously, the AC/DC converter **11** is rated based on the average power requested by RF amplifier **15**. The output power provided by AC/DC converter **11** can be limited to the average power requested by, or rated for RF amplifier **15**. While the peak power required by RF amplifier **15** during generation of a pulse is typically 5 to 40 times higher, the energy storage device **12** and DC/DC converter **14** are sized to be capable of delivering the demanded peak power.

[0028] Voltage droop of the bus voltage V.sub.BUS inevitably occurs during pulse amplification due to a discharging energy storage device. To prevent the voltage droop of V.sub.BUS diffusing to the RF amplifier supply voltage V.sub.DD, the bus voltage is chosen to be higher than the RF amplifier supply voltage V.sub.DD, and a switched (or switched-mode) DC/DC buck converter **14** is configured to step-down the bus voltage V.sub.BUS to the supply voltage V.sub.DD. DC/DC converter **14** is hence configured to operate, i.e., switch, during pulse amplification, and advantageously to operate, i.e., switch, continuously, to provide a controlled and substantially stable supply voltage V.sub.DD. Hence, while the bus voltage V.sub.BUS may vary when power is drawn from the RF amplifier, in particular during amplification of a pulse, the DC/DC converter is controlled to maintain the supply voltage V.sub.DD substantially constant irrespective of a change of V.sub.BUS. As a result, the device according to the present disclosure avoids RF power droop resulting from voltage droop at the bus voltage of the energy buffer.

[0029] The specifications of the energy storage device **12** with respect to voltage droop can hence be relaxed, since the voltage variation will be absorbed by controlling operation of the switched DC/DC converter **14**. Hence, energy storage device **12** can be designed as a much smaller energy buffer compared to prior art solutions, allowing to reduce volume and cost of the device according to the present disclosure compared to existing RF pulse amplifying devices. In addition, the specifications of the AC/DC converter **11** can be relaxed as well, since the converter **11** needs to be designed for the average output power of the device **10**. The AC/DC converter **11** can operate continuously, irrespective of the amplification of a pulse by RF amplifier **15**, to charge the energy storage device **12** and compensate any idle losses (e.g. of DC/DC converter **14**) for maintaining a predetermined voltage V.sub.BUS on the DC link **13**. A suitable control logic can be provided which operates AC/DC converter **11** on the basis of the sensed voltage level of the bus voltage V.sub.BUS.

[0030] The ratio V.sub.BUS/V.sub.DD (rated values) is advantageously at least 1.3, advantageously between 1.5 and 20, possibly between 1.7 and 10, such as 2, 2.5 or 3. The larger the ratio V.sub.BUS/V.sub.DD, the larger the allowable voltage variation on V.sub.BUS. A voltage variation of at least 20% on V.sub.BUS during generation of a pulse can be allowed. In some examples a voltage variation of at least 30%, or at least 50% on V.sub.BUS can be allowed.

[0031] Referring to FIG. **2**, a specific example of a switched DC/DC converter **14** is provided as a non-isolated half bridge converter. Half bridge **143** comprises controllable high-side switch T.sub.1, which can be a MOSFET (metal oxide semiconductor field effect transistor) or IGBT (insulated gate bipolar transistor) switch device having unidirectional or bidirectional current blocking capability and a low-side switch T.sub.2, which can be a controllable switch (e.g. MOSFET or IGBT as with T.sub.1) or a passive device with current blocking capability, such as a diode. The upper node of half bridge **143** is connected to the input terminal **141** of DC/DC converter **14**. Input terminal **141** can be connected to the positive rail of the DC link **13**. The lower node of half bridge **143** can be connected to the negative rail of the DC link **13**, or as shown in FIG. **2**, to a common ground. The middle node **144** of half bridge **143**, between the switches T.sub.1 and T.sub.2, is connected to the output terminal **142** of DC/DC converter **14** through an inductor L.

[0032] A local input capacitor C.sub.1 can be connected with its positive terminal to the input terminal **141**. The negative terminal of C.sub.1 can be connected to the common ground, or, as the case may be, to the negative rail of DC link **13**. The bus voltage V.sub.BUS hence is provided across local input capacitor C.sub.1. Local input capacitor C.sub.1 is utilized to provide local decoupling. It is not, in principle, configured for buffering energy. A local output capacitor C.sub.2 can be connected with its positive terminal to the output terminal **142**. The negative terminal of C.sub.2 can be connected to the common ground, or as the case may be, to a negative input terminal of RF amplifier **15**. The supply voltage V.sub.DD is provided across local output capacitor C.sub.2. As with C.sub.1, local output capacitor C.sub.2 is merely provided for local decoupling. It is not, in principle, configured for buffering energy.

[0033] Control unit **17** controls operation of switch T.sub.1 and possibly T.sub.2 (in case T.sub.2 is controllable) of half bridge **143**, e.g. through pulse width modulation (PWM). A voltage sensor **145** measures the supply voltage V.sub.DD, e.g. at output terminal **142**, and provides a feedback signal **171** to the control unit **17**. This way, control unit **17** can control the supply voltage V.sub.DD to be substantially at a predetermined value irrespective of changes in the bus voltage V.sub.BUS through appropriately adapting the duty cycle of T.sub.1 (and possibly T.sub.2). Control unit **17** can comprise an input **172** for receiving a set value of the supply voltage V.sub.DD. Such a half bridge converter provides high performance at minimal cost and volume.

[0034] Referring again to FIG. **1**, control unit **17** can additionally control operation of the RF amplifier **15**, in particular controlling the generation of the RF pulsed signal. Additionally, or in the alternative, control unit **17** can control operation of AC/DC converter **11**.

[0035] Other converter topologies can be utilized for DC/DC converter **14**. By way of example, referring to FIG. **3**, it may be convenient to provide an isolating DC/DC converter **24**, such as including a transformer **248** providing galvanic isolation between the input terminal **141** and the output terminal **142** of DC/DC converter **24**. DC/DC converter **24** comprises a first full bridge converter circuit **246** connected to the input terminal **141** and a first ground node G**1**, and a second full bridge converter circuit **247** connected to the output terminal **142** and second ground node G**2**. The first and second full bridge converter circuits **246**, **247** are coupled through a transformer **248** providing galvanic isolation, e.g. having 1:1 winding ratio, even though any other suitable winding ratio can be used. The switches in the bridge legs of the first full bridge converter circuit **246** can be active semiconductor switching devices, in which case they are operated through control unit **17**. The switches in the bridge legs of the second full bridge converter circuit **247** can be active or passive semiconductor switching devices. It will be convenient to note that ground nodes G**1** and G**2** should be galvanically isolated. Plenty of isolated DC/DC converter topologies can be utilized, such as a dual active bridge, a flyback converter, a series or parallel resonant converter, and a half bridge or full bridge converter.

[0036] Referring to FIG. **4**, a RF pulse generator **20** can comprise a power combiner **18** for combining the outputs **16** of a multiplicity of RF power amplifiers **15**.sub.1-**15**.sub.N into a combined output **26**. Each RF amplifier **15**.sub.1-**15**.sub.N is connected to a respective DC/DC converter **14**.sub.1-**14**.sub.N which provides the supply voltage to the respective RF amplifier. The RF pulse generator (such as block **153** in FIG. **1**) is not shown in FIG. **4** for clarity purposes. All the DC/DC converters **14**.sub.1-**14**.sub.N have their input terminals connected to the DC link **13**. Hence, all DC/DC converters **14**.sub.1-**14**.sub.N are supplied with the same bus voltage V.sub.BUS and each of the N DC/DC converters can be independently controlled to provide a predetermined supply voltage V.sub.DD,1-V.sub.DD,N, which can be same or different. A suitable combiner is disclosed in WO 2020/058361.

COMPARATIVE EXAMPLE

[0037] In this comparative example, the diagram of FIG. **1** was considered, which was further adapted in that no DC/DC converter **14** was utilized and the bus voltage V.sub.BUS was directly supplied as supply voltage (V.sub.DD) of the RF amplifier **15**, i.e. V.sub.BUS=V.sub.DD. The allowable voltage droop (dV.sub.BUS) was limited to 0.1 V and V.sub.DD=50 V. The case in which the peak power output by the RF amplifier P.sub.RF_SUP=10 kW and the pulse duration T.sub.RF=5 ms was considered. The required capacitance of capacitor bank C.sub.BUS for energy storage device **12** was calculated as:

[00001] $C_{\mathrm{BUS}} = [(P_{\mathrm{RF\_SUP}} / V_{\mathrm{BUS}}) \times T_{RF}] / = \mathrm{dV}_{\mathrm{BUS}} = [(10\mathrm{kW} / 50V) \times 5\mathrm{ms}] / 0.1 = 10F$.

EXAMPLE

[0038] In this example, the diagram of FIG. **1** was considered, including the DC/DC converter **14**. A bus voltage V.sub.BUS=100 V was considered with allowable voltage droop dV.sub.BUS=25 V (resulting in V.sub.BUS varying between 100 V and 75 V which was input to the DC/DC converter **14**). The RF amplifier supply voltage V.sub.DD=50 V needs to be provided by the output of the DC/DC converter **14**. As in the comparative example, peak power output by the RF amplifier P.sub.RF_SUP=10 kW and the pulse duration T.sub.RF=5 ms. The required capacitance of capacitor bank C.sub.BUS for energy storage device **12** was calculated as: [0039] C.sub.BUS=[(P.sub.RF_SUP/V.sub.BUS)×T.sub.RF]/dV.sub.BUS=[(10 kW/50V)×5 ms]/25=40 mF, meaning that the energy storage device can be designed with a 250 times smaller capacitance compared to the comparative example.

[0040] Advantageously, the ratio of capacitance of the energy storage device **12** to the peak power output of the RF amplifier **15** in pulse generators according to aspects of the present disclosure (C.sub.BUS/P.sub.RF_SUP) is 0.100 mF/W or less, advantageously 0.050 mF/W or less, advantageously 0.025 mF/W or less, advantageously between 0.5.Math.10.sup.−3 mF/W and 0.020 mF/W, advantageously between 1.Math.10.sup.−3 mF/W and 0.010 mF/W. The (rated) bus voltage V.sub.BUS in pulse generators according to aspects of the present disclosure is advantageously at least 50 V, at least 70 V, at least 75 V, at least 100 V, or at least 120 V. The (rated) bus voltage V.sub.BUS is advantageously 1000 V or less, advantageously between 500 V or less, 300 V or less, or 200 V or less.

[0041] The RF pulse generators as described in the present disclosure can be utilized for generating an RF electromagnetic field. They may find application as amplifiers in MRI apparatuses, as plasma generator, CO.sub.2 lasers or particle accelerators. To this end, the output **16** or **26** of the pulse generators **10**, **20** respectively, can be coupled to a tank circuit **30** which can include an RF coil for generating a magnetic field.

Claims

1. A device (**10**, **20**) for amplifying a radio frequency (RF) pulse, the device comprising: an amplifier (**15**) configured to amplify an RF pulsed signal, the amplifier comprising an input (**151**) configured to receive a supply voltage (V.sub.DD), a DC link (**13**) configured to supply a DC bus voltage (V.sub.BUS), an energy storage device (**12**) connected to the DC link, a switched DC/DC converter (**14**, **24**) comprising a converter input (**141**) connected to the DC link and a converter output (**142**) connected to the input (**151**) of the amplifier, and a control unit (**17**) configured to operate the switched DC/DC converter, wherein the switched DC/DC converter (**14**, **24**) is configured to step down the DC bus voltage (V.sub.BUS) at the converter input to the supply voltage (V.sub.DD) at the converter output, and wherein the control unit (**17**) is configured to operate the switched DC/DC converter (**14**, **24**) continuously to control the supply voltage at a predetermined value during generation of the RF pulsed signal.
2. The device of claim 1, wherein the switched DC/DC converter (**14**) is configured to be operated at a switching frequency, wherein a ratio of the switching frequency to a repetition frequency of the RF pulse is at least 10.
3. The device of claim 1, wherein a ratio of a rated value of the DC bus voltage (V.sub.BUS) to the supply voltage (V.sub.DD) is at least 1.5.
4. The device of claim 1, wherein the control unit (**17**) is configured to switch the switched DC/DC converter (**14**) during amplification of a pulse of the RF pulsed signal.
5. The device of claim 1, further comprising a mains-to-DC converter (**11**) having an output connected to the DC link (**13**), the mains-to-DC converter being configured to supply energy to the energy storage device (**12**).
6. The device of claim 5, wherein the mains-to-DC converter (**11**) is an AC-to-DC converter.
7. The device of claim 1, wherein the energy storage device (**12**) comprises one or more storage capacitors.
8. The device of claim 7, wherein a ratio of capacitance of the energy storage device (**12**) to peak output power of the amplifier is between 0.5 mF/W and 100 mF/W.
9. The device (**20**) of claim 1, comprising a plurality of the switched DC/DC converter (**14**.sub.1, **14**.sub.N) and a plurality of the amplifier (**15**.sub.1, **15**.sub.N), wherein each of the plurality of amplifiers is series connected to a respective one of the plurality of switched DC/DC converters for receiving the supply voltage therefrom, wherein the plurality of amplifiers are parallel connected to an output (**26**) of the device.
10. The device of claim 9, wherein the output of the device (**26**) comprises a power combiner (**18**) connected to outputs of the plurality of amplifiers.
11. The device of claim 9, wherein the plurality of switched DC/DC converters are parallel connected to the DC link (**13**).
12. The device of claim 1, wherein the switched DC/DC converter (**14**) is a non-isolated converter.
13. The device of claim 1, wherein the switched DC/DC converter is an isolated converter.
14. An apparatus for generating an RF electromagnetic field, the apparatus comprising the device of claim 1.
15. The apparatus of claim 14, further comprising a coil configured to generate the RF electromagnetic field, wherein the coil is coupled to the device (**10**, **20**).
16. A method of amplifying a RF pulse, the method comprising: storing energy in an energy storage device (**12**) at a DC bus voltage (V.sub.BUS), stepping down the DC bus voltage to a supply voltage (V.sub.DD) utilizing a switched DC/DC converter (**14**), applying the supply voltage to an amplifier (**15**), the amplifier amplifying the RF pulse, wherein the supply voltage is controlled to be at a predetermined value by switching the switched DC/DC converter (**14**) continuously while amplifying the RF pulse.

17. The method of claim 16, wherein a plurality of the RF pulses are amplified, the plurality of RF pulses having a pulse repetition frequency and wherein the switched DC/DC converter (**14**) is operated at a switching frequency, wherein a ratio of the switching frequency to the pulse repetition frequency is at least 10.
18. The method of claim 16, wherein a ratio of the DC bus voltage (V.sub.BUS) to the supply voltage (V.sub.DD) is at least 1.5.
19. The method of claim 16, further comprising generating the RF pulse and applying the RF pulse to the amplifier.
20. The method of claim 16 wherein the energy in the energy storage device is stored in one or more capacitors.