

(43) International Publication Date
13 August 2015 (13.08.2015)(51) International Patent Classification:
H02M 3/28 (2006.01)(21) International Application Number:
PCT/US2015/014757(22) International Filing Date:
6 February 2015 (06.02.2015)

(25) Filing Language: English

(26) Publication Language: English

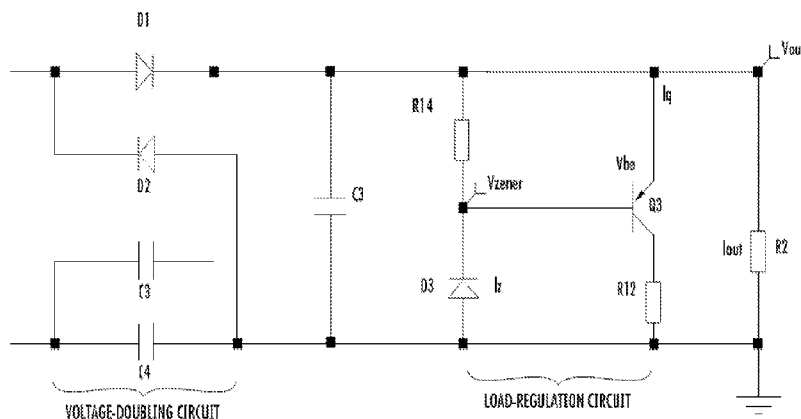
(30) Priority Data:
61/936,930 7 February 2014 (07.02.2014) US(71) Applicant: MURATA MANUFACTURING CO., LTD.
[JP/JP]; 10-1 Higashikotari 1-chome, Nagaokakyo-shi,
Kyoto 617-8555 (JP).(71) Applicant (for AG only): MURATA POWER SOLU-
TIONS [US/US]; 11 Cabot Boulevard, Mansfield, Mas-
sachusetts 02048 (US).(72) Inventor: WANG, Jing; c/o Power Solutions House, Pres-
ley Way, Crownhill, Milton Keynes, Buckinghamshire,
MK8 0ES (GB).(74) Agent: coMEDLEY, Peter; 1800 Alexander Bell Drive,
Suite 200, Reston, Virginia 20191-5465 (US).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, 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, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: VOLTAGE CONVERTER INCLUDING VOLTAGE DOUBLER AND VOLTAGE REGULATOR IN A ROYER OS-
CILLATOR

FIG. 8



(57) Abstract: A voltage converter includes a transformer with a transformer core, an input circuit with a primary winding on the transformer core, and an output circuit with a secondary winding on the transformer core. The input circuit is connected to an input voltage terminal, and the output circuit is connected to an output voltage terminal. The output circuit includes a voltage-regulation circuit, and the voltage-regulation circuit does not include a circuit component connected in series with the secondary winding and the output voltage terminal.

VOLTAGE CONVERTER INCLUDING VOLTAGE DOUBLER AND VOLTAGE REGULATOR IN A ROYER OSCILLATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to voltage conversion. More specifically, the present invention relates to DC/DC converters that include Royer oscillators and voltage regulation.

2. Description of the Related Art

[0002] A Royer oscillator is an unregulated, self-oscillating, push-pull converter. In a Royer oscillator, positive feedback from the collectors to the bases of input transistors cause the input transistors to act as switches and to provide a square-wave AC output voltage from a DC source voltage. The square-wave AC output voltage is applied to the primary winding of a transformer and then stepped either up or down by the secondary winding of the transformer. The AC voltage on the secondary winding of the transformer is then passed through a rectifier to provide a DC output voltage.

[0003] Conventional Royer-oscillator-based DC/DC converters have typically included high-power transformers to ensure that an adequate output power can be provided. However, because conventional Royer-oscillator-based DC/DC converters generally have poor efficiency, this requirement has typically been met either by including a relatively high number of turns of wire wound around the core of the transformer and/or by increasing the size of the core of the transformer. Enameled wire is typically used for the primary and secondary windings of conventional transformers, as well as for any feedback windings that may be included.

[0004] Using a high number of turns of wire for the transformer of a conventional Royer-oscillator-based DC/DC converter increases both the manufacturing difficulty of the transformer and the rate of failure of manufacturing the transformer due to damage caused to insulating layers of the wire. For example, during a conventional winding process used for winding wire around the core of a transformer, the wires are pushed through the center of the core using a needle. The needle may stick into the insulation layer of the wire and damage the wire, particularly if the core of the transformer is relatively small. For example, due to tension

on the wire during the winding process and adjacent turns of wound wire squeezing against each other, the insulation layer of the wire may break or peel, causing an electrical short that reduces the efficiency of the DC/DC converter. However, using a high number of turns of wire for the transformer of a conventional Royer-oscillator-based DC/DC converter may still be insufficient to provide adequate output power for the DC/DC converter due to the size and/or shape of the core. Further, the components of DC/DC converters can fail even at low ambient temperatures because of thermal runaway that increases the temperature of the components of DC/DC converters (particularly, switching components). Thermal runaway is a condition in which an increase in temperature causes a further increase in temperature.

[0005] Accordingly, the cores of transformers used in conventional Royer-oscillator-based DC/DC converters have typically been made relatively large. Compared to a winding on a smaller core, the wires on a larger core are squeezed to a lesser degree by each other. Thus, during the winding process, it is easier to push the wires through the center of the core, which is typically a toroid.

[0006] When only a small amount space for the winding is available on the core of a transformer, it is difficult to design and construct the transformer because the available number of turns is very limited, which restricts the ratio that may be obtained between the number of turns on the primary and secondary sides of the transformer. Since the efficiency of the DC/DC converter is related to its switching frequency and the switching frequency is directly dependent on the number of turns, using a relatively low number of turns can result in a high switching frequency. High switching frequencies cause a large amount of stress on the transistors and diodes included in the DC/DC converter, which lowers the efficiency of power conversion and makes the transistors and diodes vulnerable to thermal runaway.

[0007] Although using a larger core increases the available number of turns, which increases the available turns ratios, a DC/DC converter including a transformer with a large core may still not provide efficiency at both high and low switching frequencies. Further, at very high switching frequencies, high switching losses may occur, and the DC/DC converter may need to have its operating temperature limited to prevent thermal runaway.

[0008] Figs. 1-3 show conventional input and output circuits for a Royer-oscillator-based DC/DC converter. Fig. 1 is a circuit diagram of a conventional input circuit for a Royer-oscillator-based DC/DC converter. Fig. 2 is a circuit diagram of a conventional single-output circuit for a Royer-oscillator-based DC/DC converter. Fig. 3 is a circuit diagram of a conventional dual-output circuit for a Royer-oscillator-based DC/DC converter.

[0009] Converters using the circuits shown in Figs. 1-3 include a single, saturable transformer T1 that includes three transformer windings: a primary winding T1_p and a feedback winding T1_f on an input-side of the transformer T1 and a secondary winding T1_s on an output-side of the transformer T1. Although enameled wire has been conventionally used for the windings of transformers, the windings of the transformer T1 may alternatively use triply-insulated wire to provide an isolation barrier between the input and the output of the Royer-oscillator-based DC/DC converter. However, triply insulated wire is very thick, which causes the transformer T1 to have a relatively large size. As an example, when the conventional input circuit shown in Fig. 1 and the conventional single-output circuit shown in Fig. 2 are included in a Royer-oscillator-based DC/DC converter with transformer T1, an input voltage V_{in} of 5 V can be converted to an output voltage V_{out} of 9 V.

[0010] When the input transistor TR1 of the input circuit shown in Fig. 1 is conducting, the input voltage V_{in} is applied to the top half of the primary winding T1_p (that is, between terminals 1 and 3 of the primary winding T1_p), resulting in a constant change in flux in the transformer T1 and an induced voltage with a positive potential at the center terminal of the primary winding T1_p. A voltage with the same polarity as the primary winding T1_p is also induced in the feedback winding T1_f. The voltage induced in the feedback winding T1_f maintains input transistor TR1 in a conducting state and input transistor TR2 in a non-conducting state.

[0011] When the transformer core saturates, the change in flux of the transformer T1 falls to zero. As a result, the voltage induced in the feedback winding T1_f falls to zero and places the input transistor TR1 in a non-conducting state. With no conducting transistor TR1 and TR2 connected to the transformer TR1 to sustain the magnetizing current, the polarity of the voltage on the primary winding T1_p reverses, which also causes the polarity of voltage on the

feedback winding $T1_f$ to reverse. The new voltage induced at the feedback winding $T1_f$ places the input transistor TR2 in a conducting state and maintains the input transistor TR1 in a non-conducting state. The input transistors TR1 and TR2 continue cycling on and off as long as the input voltage V_{in} is applied.

[0012] In the input circuit shown in Fig. 1, resistor R1 is a startup resistor which provides a base current to the transistors TR1 and TR2. Capacitor C1, inductor L1, and inductor L2 help to startup the converter under noisy or low-temperature conditions. Capacitor C2 is an input capacitor that filters the input voltage V_{in} .

[0013] With respect to the single-output circuit shown in Fig. 2, diode D1, diode D2, and the bifilar of the secondary winding $T1_s$ form a full wave rectifier. When the dotted ends of the secondary winding $T1_s$ have a positive potential (that is, when a positive potential is induced between terminals 7 and 8 and between terminals 9 and 10), diode D1 provides the output voltage V_{out} to the load resistor R1 and diode D2 is reverse-biased. When the non-dotted ends of the secondary winding $T1_s$ have a positive potential, diode D2 provides the output voltage V_{out} to the load resistor R1, and diode D1 is reverse-biased.

[0014] In the single-output circuit shown in Fig. 2, capacitors C1 and C2 are output filter capacitors. Load resistor R1 is the internal load of the converter, which limits the output voltage V_{out} when there is no load at the converter output.

[0015] Fig. 3 is a dual-output version of the single-output circuit shown in Fig. 2. As shown in Fig. 3, diodes D3 and D4 are the same as diodes D1 and D2 of Fig. 2. Diodes D1 and D2 of Fig. 3 have the same function as diodes D3 and D4, but provide a negative output voltage $-V_{out}$. Capacitors C3 and C4 of Fig. 3 are output filter capacitors.

[0016] Load regulation of Royer-oscillator-based DC/DC converters has typically been adjusted by using series, shunt, or switching regulators. Fig. 4 is a circuit diagram of a conventional series regulation circuit, and Fig. 5 is a circuit diagram of a conventional shunt regulation circuit. The regulation circuits shown in Figs. 4 and 5 use the Zener voltage V_z of a Zener diode D3 and the base-emitter voltage (V_{be}) of the transistor Q3 to provide the output voltage $V_{out} = V_z + V_{be}$. In the regulation circuits shown in Figs. 4 and 5, the Zener diode D3

does not turn the transistor Q3 on and off. Instead, the Zener diode D3 directly sets the output voltage V_{out} .

[0017] In the regulation circuit shown in Fig. 4, diode D1, Zener diode D2, capacitor C3, and capacitor C4 form a voltage-doubling circuit. A pass transistor Q3 is configured as an NPN emitter-follower that keeps the output voltage V_{out} one diode drop from the base-emitter voltage V_{be} below the Zener voltage V_z ($V_{out} = V_z - V_{be}$). Resistor R12 provides the Zener current I_z , and the value of resistor R12 is set according to the difference between the voltage V_{double} of the voltage-doubling circuit and the Zener voltage V_z , divided by the current I_z in the Zener diode D2 $(V_{double} - V_{zener}) / I_z$. Capacitor C3 is an output filter capacitor, and resistor R2 is an external load of the converter.

[0018] In the regulation circuit shown in Fig. 5, diode D1, Zener diode D2, capacitor C3, and capacitor C4 form a voltage-doubling circuit. The output voltage V_{out} is equal to the Zener voltage V_z of Zener diode D2 plus the one diode drop (V_{be}) of transistor Q3. Resistor R13 is an essential component of the regulation circuit, because it limits the current I_q passing through transistor Q3. The value of resistor R13 is set according to the difference between the voltage V_{double} of the voltage-doubling circuit and the output voltage V_{out} , divided by the current I_s output by the voltage-doubling circuit through the resistor R13 $(V_{double} - V_{out}) / I_s$. Capacitor C3 is an output filter capacitor, and resistor R2 is an external load of the converter. The output current I_{out} through resistor R2 is approximately equal to the difference between the current I_s output by the voltage-doubling circuit through the resistor R13 and the current I_q passing through the transistor Q3 ($I_{out} = I_s - I_q$).

[0019] However, the series regulation circuit shown in Fig. 4 always has the transistor Q3 in series with the load at the output voltage V_{out} , and the shunt regulation circuit shown in Fig. 5 always has the resistor R13 in series with the load at the output voltage V_{out} . As a result of the transistor Q3 and resistor R13 being in series with the load, the efficiencies of the regulation circuits shown in Figs. 4 and 5 are very low across the entire load range (0% - 100%). A voltage converter is typically specified for its nominal output voltage and power. The output voltage and power can be used to determine an equivalent nominal resistance load, which is generally

regarded as the 100% load. Other load percentages can be determined by comparing the equivalent resistance with the equivalent nominal resistance load.

[0020] Thus, conventional series and shunt regulators lose a significant portion of power in the passing elements (e.g., transistor Q3 and resistor R13) that lower the efficiency of the regulators over the entire load range. Furthermore, although switching regulators can provide a higher efficiency than series and shunt regulators, switching regulators require many components and are generally very expensive. In addition, Zener diodes are susceptible to thermal runaway, especially at high switching frequencies.

SUMMARY OF THE INVENTION

[0021] To overcome the problems described above, preferred embodiments of the present invention provide a Royer-oscillator-based converter with an output circuit that reduces the overall size of the converter while maintaining high efficiency, output regulation, and low cost.

[0022] A voltage converter according to a preferred embodiment of the present invention includes a transformer with a transformer core, an input circuit with a primary winding on the transformer core, and an output circuit with a secondary winding on the transformer core. The input circuit is connected to an input voltage terminal, and the output circuit is connected to an output voltage terminal. The output circuit includes a voltage-regulation circuit, and the voltage-regulation circuit does not include a circuit component connected in series with the secondary winding and the output voltage terminal.

[0023] The voltage-regulation circuit preferably includes a first resistor and a switching element connected between the output voltage terminal and ground and includes a Zener diode and a second resistor connected in parallel with the first resistor and the switching element.

[0024] Preferably, the switching element is a transistor. The transistor is preferably a PNP bipolar transistor or an NPN bipolar transistor. Preferably, a base terminal of the transistor is connected to a point between the Zener diode and the second resistor.

[0025] Preferably, when a voltage at the output voltage terminal is greater than a combined voltage of a Zener voltage of the Zener diode and a base-emitter voltage of the transistor, the transistor turns on and current flows through the second resistor to regulate the

voltage at the output voltage terminal. Preferably, when a voltage at the output voltage terminal is less than a combined voltage of a Zener voltage of the Zener diode and a base-emitter voltage of the transistor, the transistor turns off so that no current flows through the second resistor and the voltage at the output voltage terminal is unregulated.

[0026] The first resistor is preferably a variable resistor.

[0027] The output circuit preferably includes a voltage-doubling circuit arranged between the secondary winding and the voltage-regulation circuit. Preferably, the voltage-doubling circuit includes a first diode, a second diode, a first capacitor, and a second capacitor.

Preferably, an anode of the first diode is connected to a first end of the secondary winding and a cathode of the first diode is connected to the output voltage terminal, an anode of the second diode is connected to ground and a cathode of the second diode is connected to the first end of the secondary winding, the first capacitor is connected between the output voltage terminal and a second end of the secondary winding, and the second capacitor is connected between the second end of the secondary winding and ground.

[0028] The input circuit preferably includes a feedback winding on the transformer core. Preferably, the input circuit and the secondary winding are configured as a Royer oscillator.

[0029] Preferably, at least one of the primary winding and the secondary winding is defined by triply insulated wire. Preferably, at least one of the primary winding and the secondary winding includes a single-wire coil arrangement.

[0030] Preferably, the transformer, the input circuit, and the output circuit are included within a single housing. The input and output circuits are preferably arranged on separate input and output printed circuit boards. The input and output printed circuit boards are preferably arranged on opposing sides of the housing. The transformer is preferably arranged to sit against the input printed circuit board.

[0031] The above and other features, elements, steps, configurations, characteristics and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments of the present invention with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] Fig. 1 is a circuit diagram a conventional input circuit for a Royer-oscillator-based DC/DC converter.

[0033] Fig. 2 is a circuit diagram of a conventional single-output circuit for a Royer-oscillator-based DC/DC converter.

[0034] Fig. 3 is a circuit diagram of a conventional dual-output circuit for a Royer-oscillator-based DC/DC converter.

[0035] Fig. 4 is a circuit diagram of a conventional series regulation circuit.

[0036] Fig. 5 is a circuit diagram of a conventional shunt regulation circuit.

[0037] Fig. 6 is a circuit diagram of a single-output voltage-doubling output circuit according to a preferred embodiment of the present invention.

[0038] Fig. 7 is a circuit diagram of a dual-output circuit according to a preferred embodiment of the present invention.

[0039] Fig. 8 is a circuit diagram of a single-output voltage-doubling output circuit with a load-regulation circuit according to a preferred embodiment of the present invention.

[0040] Fig. 9 is a graph showing test results of the output voltage and efficiency of regulated and non-regulated converters.

[0041] Fig. 10 is a circuit diagram of a single-output voltage-doubling output circuit with a load-regulation circuit according to another preferred embodiment of the present invention.

[0042] Fig. 11 is a perspective view of a housing in accordance with preferred embodiments of the present invention.

[0043] Figs. 12A to 12C are perspective, rear, and front views of the arrangement of a transformer in the housing shown in Fig. 11.

[0044] Fig. 13 is a layout view of an example of an input PCB included in the housing shown in Fig. 11.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0045] Preferred embodiments of the present invention will now be described in detail with reference to Figs. 6 to 13. Note that the following description is in all aspects illustrative

and not restrictive and should not be construed to restrict the applications or uses of the various preferred embodiments of the present invention in any manner.

[0046] The input circuit of a Royer-oscillator-based DC/DC converter according to the preferred embodiments of the present invention is preferably the conventional input circuit for a Royer-oscillator-based DC/DC converter shown in Fig. 1. Preferably, the input circuit is included on an input printed circuit board (PCB) that is separated, in a housing, from an output PCB that includes an output circuit of the converter to provide an isolation barrier between the input and the output of the converter. The housing is preferably a multifunctional housing defining a carriage for the transformer T1 of the converter, while also providing a central header or body portion to structurally support the components of the converter. One example of a housing that may be used in accordance with the preferred embodiments of the present invention is shown in Fig. 11. The input PCB and the output PCB are preferably mounted on either side of the housing, and the housing is preferably formed to have a cube-shaped configuration or similar structure. Preferably, the transformer T1 is located in a cavity of the housing and links the input PCB and output PCB. Specifically, the transformer core of the transformer T1 electromagnetically links the input and output PCBs, while the windings of the transformer T1 provide a physical and electrical connections to the input and output PCBs. Figs. 12A to 12C are perspective, rear, and front views of the arrangement of transformer T1 in the housing shown in Fig. 11. Fig. 13 is a layout view of an example of an input PCB included in the housing shown in Fig. 11. As shown in Figs. 1, 11, 12A, 12C, and 13, terminals 1-6 of the primary winding T1_p are preferably connected to corresponding terminals 1-6 of the housing and terminals 1-6 of the input PCB. As shown in Fig. 12B, similar terminals are preferably provided on the opposing side of the housing to connect to the secondary winding T1_s and the output PCB. Preferably, the housing also includes terminals connected to ground (GND), the input voltage V_{in} and the output voltage V_{out} (not shown). Electronic components mounted on the input PCB and the output PCB preferably face the interior of the housing to protect the components and to provide a flat surface for packaging.

[0047] Three groups of windings are provided on the transformer T1: a primary winding T1_p, a feedback winding T1_f, and a secondary winding T1_s. The primary winding T1_p and the

feedback winding $T1_f$ are at the input side of the transformer $T1$, and the secondary winding $T1_s$ is at the output side of the transformer $T1$. Accordingly, a converter that includes the transformer $T1$ requires a certain level of isolation to separate components at the input side of the transformer $T1$ from components at the output side of the transformer $T1$. Thus, although the input and output PCBs are physically separated at opposing sides of the housing, the windings of the transformer $T1$ also need to be separated to electrically isolate the input and output components. The windings can either be physically separated, which requires a large transformer core to provide adequate spacing between the windings, or triply insulated wire can be used for the windings. However, triply insulated wire is expensive and reduces the efficiency of manufacturing the transformer $T1$. Accordingly, to reduce the use of the thick triply insulated wire for the windings of the transformer $T1$, while still providing a sufficient isolation barrier and a relatively small transformer core size, the input PCB faces inward so that the transformer $T1$ is arranged to sit against the input PCB, and triply insulated wire is preferably only used in the secondary windings $T1_s$, which reduces the amount of triply insulated wire required to provide a sufficient isolation barrier.

[0048] Fig. 6 is a circuit diagram of a single-output voltage-doubling output circuit according to a preferred embodiment of the present invention. This circuit is preferably provided on the output PCB. As indicated by the name “voltage-doubling,” the secondary winding $T1_s$ only needs to provide half of the desired output voltage V_{out} , since the voltage at the secondary winding $T1_s$ is doubled by the output circuit to provide the final output. Therefore, the number of turns can be halved in the secondary winding $T1_s$, or, if the number of the secondary winding is kept the same, the number of the primary winding $T1_p$ can be doubled. These arrangements allow for the switching frequency of the preferred embodiments of the present invention to be halved as compared with conventional Royer-oscillator-based DC/DC converters, which lowers switching losses and reduces the chance of thermal runaway.

[0049] Preferably, the single-output voltage-doubling circuit shown in Fig. 6 is used when only a single output voltage V_{out} is required. Preferably, for highest efficiency, the input voltage V_{in} is about 5 V and the output voltage V_{out} is between about 9 V and about 15 V, for example.

[0050] Moreover, unlike the conventional single-output circuit shown in Fig. 2, which uses a bifilar coil arrangement, the single-output voltage-doubling circuit in Fig. 6 uses only a single-wire coil arrangement in the output circuit to tap the secondary winding $T1_s$. This allows the number of turns of the primary winding $T1_p$ to be doubled and the number of turns of the secondary winding $T1_s$ to be halved, while keeping the input voltage V_{in} and the output voltage V_{out} the same as that of a conventional converter. For example, in a Royer-oscillator-based DC/DC converter that uses the conventional circuit shown in Fig. 2, the total number of turns in the primary winding $T1_p$ is $11+11=22$, and the total number of turns in the secondary winding $T1_s$ is $25+25=50$. However, in a Royer-oscillator-based DC/DC converter that uses the single-output voltage-doubling circuit shown in Fig. 6, the total number of turns in the primary winding $T1_p$ can be increased to $22+22=44$, and the total number of turns in the secondary winding $T1_s$ can be decreased to 25, for example.

[0051] More specifically, the number of turns used to provide a winding refers to the number of turns on each of the filar, regardless of whether the winding is bifilar or single filar. In Fig. 2, both the primary winding $T1_p$ and the secondary winding $T1_s$ preferably are bifilar, for example. However, in Fig. 6, only the primary winding $T1_p$ is bifilar, while the secondary winding $T1_s$ is single filar, for example. Accordingly, when the voltage-doubling circuit is included, the number of turns on the secondary winding $T1_s$ can be halved, or, if the number of turns on the secondary winding $T1_s$ is kept the same, the number of turns on the primary winding $T1_p$ can be doubled. Preferably, according to the preferred embodiments of the present invention, the transformer T1 has a turns ratio (the number of turns in one filar of the secondary winding $T1_s$ over the number of turns in one filar of the primary winding $T1_p$) that is between one-half and two-thirds of the turns ratio of a conventional transformer for the same input voltage V_{in} and output voltage V_{out} .

[0052] Halving the number of turns in the secondary winding $T1_s$ makes it much easier to wind the wire onto a small transformer core, especially for a thick wire such as a triply insulated wire. Doubling the number of turns in the primary winding $T1_p$ provides a lower switching frequency for the Royer oscillator, which lowers switching losses and increases the range of acceptable operating temperatures for the Royer-oscillator-based DC/DC converter.

Accordingly, using the single-output voltage-doubling circuit shown in Fig. 6 with a Royer oscillator allows a high-isolation DC-DC converter to be provided in a relatively small housing.

[0053] Fig. 7 is a circuit diagram of a dual-output circuit according to a preferred embodiment of the present invention. Compared to the conventional dual-output circuit shown in Fig. 3, the total number of turns in the secondary winding $T1_s$ of a doubler circuit of the dual-output circuit shown in Fig. 7 is the same, since the dual-output circuit shown in Fig. 7 requires two separate secondary winding sections $T1_{s1}$ and $T1_{s2}$ to provide two output voltages $+V_{out}$ and $-V_{out}$. However, the number of turns in the primary winding $T1_p$ is doubled in the dual-output circuit shown in Fig. 7 to achieve half of the switching frequency as compared with the dual-output circuit shown in Fig. 3. The dual-output circuit shown in Fig. 7 is preferably configured by joining together two of the single-output voltage-doubling circuits shown in Fig. 6, such that a $-V_{out}$ terminal of one of the single-output voltage-doubling circuits is connected to a $+V_{out}$ terminal of the other single-output voltage-doubling circuit. That is, each of the separate secondary winding sections $T1_{s1}$ and $T1_{s2}$ of Fig. 7 preferably has the same number of turns as the secondary winding $T1_s$ shown in Fig. 6. Further, diode D3, diode D4, capacitor C2, capacitor C5, capacitor C6, and resistor R2 of Fig. 7 are preferably the same as diode D1, diode D2, capacitor C1, capacitor C3, capacitor C4, and resistor R1 of Figs. 6 and 7. As shown in Figs. 6 and 7, capacitors C1 and C2 are output filter capacitors, and resistors R1 and R2 are the internal load of the converters. The values of the capacitors C1 and C2 are preferably set according to predetermined requirements for a ripple in the output voltage V_{out} , and the values of the internal load resistors R1 and R2 are preferably set to limit the output voltage V_{out} during low load conditions.

[0054] However, load regulation can become difficult under conditions such as a heavy-load, particularly when a voltage-doubling circuit is used in a Royer-oscillator-based DC/DC converter. Test results of a Royer-oscillator-based DC/DC converter using the single-output voltage-doubling circuit shown in Fig. 6, with an input voltage V_{in} of 5 V and an output voltage V_{out} having a nominal voltage $V_{nominal}$ of 9 V, are shown in Table 1.

Table 1: Test results of the single-output voltage-doubling circuit shown in Fig. 6

Output @ 10% Load	Output @ 100% Load	Accuracy @ 10% Load	Accuracy @ 100% Load	Efficiency @ 100% Load	Load Regulation	Line Regulation
10.02 V	8.49 V	11.32 %	-5.71 %	72.38 %	17.03 %	1.37

[0055] The load regulation and line regulation values shown in Table 1 are calculated as follows:

$$\text{Accuracy @ 10\% Load} = 100\% * (V_{\text{out}@10\%} - V_{\text{nominal}})/V_{\text{nominal}}$$

$$\text{Accuracy @ 100\% Load} = 100\% * (V_{\text{out}@100\%} - V_{\text{nominal}})/V_{\text{nominal}}$$

$$\text{Efficiency @ 100\% Load} = 100\% * (V_{\text{out}@100\%} * I_{\text{out}@100\%}) / (V_{\text{in}@100\%} * I_{\text{in}@100\%})$$

$$\text{Load regulation} = 100\% * (V_{\text{out}@10\%} - V_{\text{out}@100\%}) / V_{\text{nominal}}$$

$$\text{Line Regulation} = (V_{\text{out}@V_{\text{in}110\%}} - V_{\text{out}@V_{\text{in}90\%}}) / (V_{\text{in}110\%} - V_{\text{in}90\%}).$$

[0056] Table 1 shows that the load regulation can be as high as 17.03%. Load regulation can be improved by increasing the output voltage V_{out} , which causes a corresponding reduction in the lower output current. As shown in Fig. 6, a lower output current results in lower losses in the wire of the secondary winding T1_s and the diodes D1 and D2, such that the voltage drop from the secondary side of the transformer T1 to the output voltage terminal V_{out} is reduced.

[0057] Fig. 8 is a circuit diagram of a single-output voltage-doubling output circuit with a load-regulation circuit. As shown in Fig. 8, the load-regulation circuit is preferably provided between the voltage-doubling circuit and the output voltage V_{out} at a load resistor R2.

Preferably, the voltage-doubling circuit is similar to the voltage-doubling circuit shown in Fig. 6.

[0058] As shown in Fig. 8, the load-regulation circuit includes resistors R12 and R14, a Zener diode D3, and a transistor Q3. The transistor Q3 is preferably a PNP-type bipolar transistor, although other types of transistors may be used. In addition, other transistor configurations may be used, such as a Darlington pair or Darlington combination. The resistor R14 is a current-limiting resistor for the base current applied to the transistor Q3 and the Zener current through the Zener diode D3. Capacitor C3 is a filter capacitor arranged between the voltage-doubling circuit and the load-regulation circuit. Preferably, as explained below, the load-regulation circuit is only activated during light-load conditions and is not in-circuit with the load resistor R2 during high-load conditions. More specifically, the load-regulation circuit is

preferably activated when a power converter that includes the circuit shown in Fig. 8 is operated at around 75% of its load or power rating (i.e., full load or full power). A margin of about 25% is generally provided for most common load conditions of a converter. The operation of the voltage-doubling circuit shown in Fig. 8 is described below.

[0059] During light-load conditions of the converter (e.g., 10% of full load), the output voltage V_{out} is greater than or equal to the Zener voltage V_z of the Zener diode D3 and the base-emitter voltage V_{be} of the transistor Q3 (that is, $V_{out} \geq V_{be} + V_z$). Accordingly, the transistor Q3 is turned on, and the resistor R12 is connected in parallel with the load resistor R2. Resistor R12 is preferably chosen so that the overall load of the converter is set to a predetermined level of full load condition (e.g., 75%). Therefore, the output voltage V_{out} is limited to be at the nominal voltage $V_{nominal}$ of 9 V during a full load condition.

[0060] If the output voltage V_{out} drops and the condition $V_{out} \geq V_{be} + V_z$ is no longer satisfied, the transistor Q3 is switched off, and the output voltage V_{out} rises again. When the output voltage V_{out} again rises to a level that satisfies $V_{out} \geq V_{be} + V_z$, the transistor Q3 is switched on again to connect the resistor R12 in parallel with the load resistor R2 to limit the output voltage V_{out} . That is, the transistor Q3 is continuously switched on and off to regulate the output voltage V_{out} during light-load conditions.

[0061] When the converter is under a full load condition (e.g., 75% of full load), which has a lower output voltage V_{out} than light-load conditions described above, the output voltage V_{out} is lower than the Zener voltage V_z and the base-emitter voltage V_{be} ($V_{out} < V_{be} + V_z$).

Accordingly, the transistor Q3 is maintained in an off state so that the resistor R12 is not connected in parallel with the load resistor R2. Also, when $V_{out} < V_{be} + V_z$, no current flows through the Zener diode D3 and the resistor R14. Therefore, the load-regulation circuit is not activated, and is thus out of circuit with the load resistor R2, under heavy-load conditions. That is, no circuit component is arranged between the voltage-doubling circuit and the load resistor R2 when the converter is under a heavy-load condition, and the voltage-doubling circuit and the load resistor R2 are directly connected by a wire, trace, or other connective element.

[0062] The values for the parallel resistor R12 and the current-limiting resistor R14 are preferably determined according to the following equations, where $(P * 0.75)$ represents the power output by the converter at full load:

$$R14 = (V_{out} - V_{zener}) / I_z$$

$$V_{out}^2 / (P * 0.75) = (R12 * R2) / (R12 + R2)$$

$$R2 = V_{out} / I_{out}$$

[0063] If a Darlington pair or Darlington combination is used in place of the transistor Q3, the condition for connecting the resistor R12 in parallel with the load resistor R2 changes to $V_{out} \geq n * V_{be} + V_z$, where n is the number of transistors in the Darlington pair or Darlington combination. Similarly, the condition for disconnecting the resistor R12 from the load resistor R2 changes to $V_{out} < n * V_{be} + V_z$.

[0064] Test results of a Royer-oscillator-based DC/DC converter using the single-output voltage-doubling output circuit shown in Fig. 6 with the load-regulation circuit shown in Fig. 8 are provided below in Table 2.

Table 2: Test results of the regulated single-output voltage-doubling output circuit shown in Fig. 6 with the load-regulation circuit shown in Fig. 8

Output @ 10% Load	Output @ 100% Load	Accuracy @ 10% Load	Accuracy @ 100% Load	Efficiency @ 100% Load	Load Regulation	Line Regulation
9.41 V	8.49 V	4.57 %	-5.64 %	72.13 %	10.21 %	1.16

[0065] When compared to the test results shown in Table 1 for a single-output voltage-doubling circuit without a load-regulation circuit, the load accuracy has been decreased from 11.32% to 4.57% under a light-load condition (10% load) and the load-regulation has been reduced by 6.82% for a single-output voltage-doubling output circuit with the load-regulation circuit shown in Fig. 8. However, the additional load-regulation circuit does not affect performance during a heavy-load condition (100% load). That is, the efficiency and accuracy during the heavy-load condition are substantially the same. Furthermore, the line regulation improved from 1.37 to 1.16.

[0066] Fig. 9 is a graph showing test results of the output voltage and efficiency of regulated and non-regulated converters. More specifically, Fig. 9 compares the output voltage

V_{out} and the efficiency of the unregulated single-output voltage-doubling output circuit shown in Fig. 6 with the regulated single-output voltage-doubling output circuit shown in Fig. 8. The regulated circuit shown in Fig. 8 limits the output voltage V_{out} at low load to improve load regulation (Load regulation = $100\% * (V_{out@10\%} - V_{out@100\%})/V_{nominal}$). If the output voltage V_{out} is too high, devices connected to the converter can be damaged. However, because the unregulated circuit shown in Fig. 6 and the regulated circuit shown in Fig. 8 have similar efficiency at high load, the load-regulation circuit is able to increase load regulation without affecting full load operation. In addition, the load-regulation circuit of Fig. 8 may replace the internal load resistor R1 shown in Fig. 6.

[0067] To summarize, the load-regulation circuit shown in Fig. 8 has a low component count, as it only requires two resistors (resistors R12 and R14), one transistor (transistor Q3), and one Zener diode (Zener diode D3). Because all of these components are available in small packages, the load regulation circuit shown in Fig. 8 can be easily integrated into new or existing converters. Preferably, the load-regulation circuit shown in Fig. 8 can be added to the output stage of a previously-constructed converter as an additional circuit with no modification made to the existing circuitry of the previously-constructed converter. In addition, because the load-regulation circuit shown in Fig. 8 is not connected to the load of a converter under heavy-load conditions, the load-regulation circuit does not affect the overall performance for the routine use (above 75%) of the converter. However, because the resistor R12 of the load-regulation circuit shown in Fig. 8 is connected to the load of a converter under light-load conditions, the converter can be specified to be operable even at 0% or nearly 0% load.

[0068] Moreover, in addition to improving load-regulation, the load-regulation circuit shown in Fig. 8 also improves line regulation. The voltage-regulation level of the load-regulation circuit shown in Fig. 8 can be easily changed by simply adjusting the value of the resistor R12. According to a preferred embodiment of the present invention, the resistor R12 is a variable resistor that is adjustable after a converter including the load-regulation circuit shown in Fig. 8 has been manufactured. According to another preferred embodiment, the resistor R12 is a temperature-dependent resistor (thermistor).

[0069] The load-regulation circuit shown in Fig. 8 uses the Zener diode D3 to control the on and off switching of the transistor Q3. As the transistor Q3 is controlled to turn on and off, the resistor R12 is respectively connected and disconnected from a parallel configuration with the load resistor R2 to limit the output voltage V_{out} . However, the preferred embodiments of the present invention are not limited thereto, and other arrangements can also be used for load regulation, including the arrangement shown in Fig. 10. Fig. 10 is a circuit diagram of a single-output voltage-doubling output circuit with a load-regulation circuit according to another preferred embodiment of the present invention. As shown in Fig. 10, the load-regulation circuit can be “reversed” to use NPN-type bipolar transistor as shown in Fig. 10. In addition, other transistor configurations may be used, such as a Darlington pair or Darlington combination.

[0070] The voltage-doubling circuit shown in Figs. 6, 8, and 10 is preferably a general output circuit that can be applied to many types of converters. However, the preferred embodiments of the present invention are preferably applied to Royer-oscillator-based converters, which provide the advantages of low component count, low cost to manufacture, and outstanding performance, including quick start up, high efficiency, low ripple, and excellent load and line regulations. The voltage-doubling circuit shown in Figs. 6, 8, and 10 also includes a low component count. With the configuration of the voltage-doubling circuit shown in Figs. 6, 8, and 10 including the circuitry of a Royer oscillator (specifically, the input circuit of a Royer-oscillator-based converter shown in Fig. 1), the capability of the Royer circuitry is expanded to be able to provide a high-isolation converter in a very small package or housing.

[0071] Accordingly, the preferred embodiments of the present invention provide a converter with high isolation in a small package or housing and a transformer that is easily wound and assembled. The converter achieves high efficiency because it relies on a relatively low switching frequency due to an increased number of primary turns being used for the transformer. The converter also achieves a high operating temperature due to relatively low switching losses. Lower switching losses reduce the stress on the transistors and diodes of the converter. The junction temperature of the transistors and diodes of the converter can be calculated by the equation $T_j = P_{loss} * R_{\theta} + T_a$, where T_j is the junction temperature (which is preferably limited to about 150 °C), T_a is the ambient temperature (i.e., the operating

temperature of the converter), R_{θ} is thermal resistance (a constant), and P_{loss} is power loss. When the power loss is reduced, according to the above equation, the ambient temperature increases until the junction temperature limit is reached.

[0072] Other voltage multiplier circuits, such as a tripler, a quadrupler, etc. may be used in place of the voltage-doubling circuit shown in Figs. 6, 8, and 10. However, the voltage-doubling circuit shown in Figs. 6, 8, and 10 is preferably used, because higher-order voltage multiplier circuits result in low efficiency, poor load regulation, high ripple, etc. when used with a Royer oscillator (specifically, the input circuit of a Royer-oscillator-based converter shown in Fig. 1). Further, higher-level voltage multiplier circuits are typically not used with Royer oscillators unless a suitable companion circuit is included to address these problems, which increases the overall size, cost, and design complexity of the converter. That is, even if a companion circuit is designed to allow for a higher-level voltage multiplier circuit to be used, the converter will lose the primary benefits of using a Royer-oscillator-based converter, namely, low component count and low cost to manufacture.

[0073] Preferred embodiments of the present invention can be applied to all Royer-oscillator-based converters in any mechanical format that may include or require a voltage-doubling circuit. It is noted that the statements herein regarding doubling and halving above are only for comparison purposes with respect to the conventional circuits shown in Figs. 2 and 3. The actual number of turns of the primary and secondary windings may not be necessarily doubled or halved from the original topology. The chosen number of turns depends on the assembling ability during manufacturing and the performance required. In general, the voltage-doubling circuit allows for more turns in the primary winding and less turns in the secondary winding, which allows Royer converters to be manufactured in small packages or housings. Together with the regulation circuit, the voltage-doubling circuit allows the converter to achieve excellent output performance.

[0074] A Royer-oscillator-based DC/DC converter according to the preferred embodiments of the present invention preferably includes a housing and components similar to those shown and described in U.S. Patent Pre-Grant Publication No. 2012/0099288, incorporated herein by reference in its entirety. One example of a housing that may be used in accordance with the

preferred embodiments of the present invention is shown in Fig. 11. However, the preferred embodiments of the present invention can be applied to other converters that use Royer topology and in any mechanical format.

[0075] The preferred embodiments of the present invention are preferably implemented as 1 W, 3-kV-isolated, surface-mount DC/DC converters with a 3.3 V or 5 V input and a 3.3 V, 5 V, or 9 V (nominal) single output or a 12 V or 15 V (nominal) dual output, for example. The preferred embodiments of the present invention preferably have an industrial operating temperature range from about -40° C to about 85° C, for example. The preferred embodiments of the present invention preferably have approximately half the footprint area (i.e., the area needed on a printed circuit board (PCB) to be mounted) of any existing surface-mount 1W, 3kV isolated DC/DC converter. For example, the TES1V converter of TRACO has a footprint of 179.3 cm² while a converter according to the preferred embodiments of the present invention has footprint of about 69 cm².

[0076] Because the preferred embodiments of the present invention have a small housing size, there is little room to accommodate the transformer core. Further, the preferred embodiments of the present invention preferably use triply-insulated wire, which is much thicker than conventional enameled wire, to form the windings on the transformer in order to achieve 3 kV reinforced isolation. For example, whereas a known converter with a 5 V input voltage V_{in} and a 9 V output voltage V_{out} may use 0.08 mm Japanese Industrial Standard (JIS) wire, the preferred embodiments of the present invention preferably use 0.3175 mm triply-insulated wire.

[0077] Because of the size of the core and the thickness of the wire that are preferably used in the preferred embodiments of the present invention, the possible number of transformer turns is very limited. Accordingly, if the voltage-doubling circuit shown in Figs. 6, 8 and 10 is not used, the switching frequency of the converter would need to be very high, especially to provide a high output voltage V_{out} . For example, a conventional converter with a 5 V input voltage V_{in} and a 9 V output voltage V_{out} might require a switching frequency of about 172 kHz if the conventional output circuit shown in Fig. 2 were used, which is too high for a Royer converter and would cause issues such as low efficiency and thermal runaway for diodes

and transistor(s). The switching frequency would need to further increase for higher output voltages, for example, a converter with a 15 V output voltage V_{out} might require a switching frequency of about 415 kHz, exacerbating the issues of low efficiency and thermal runaway.

[0078] The same problems described above arise with the conventional dual-output circuit shown in Fig. 3. A sample was constructed with a 24 V input voltage V_{in} and a ± 15 V output voltage V_{out} (dual-output), using the dual-output circuit shown in Fig. 3. However, this sample failed at an ambient temperature of 65 °C, which is too low of a temperature for a practical converter, since converters are typically required to operate at temperatures up to 85 °C. Thus, conventional output circuits, such as those shown in Figs. 2 and 3, are unable to achieve a practical converter having a small package size as described above with respect to the preferred embodiments of the present invention.

[0079] While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

WHAT IS CLAIMED IS:

1. A voltage converter, comprising:
a transformer including a transformer core;
an input circuit including a primary winding on the transformer core; and
an output circuit including a secondary winding on the transformer core; wherein
the input circuit is connected to an input voltage terminal and the output circuit is
connected to an output voltage terminal;
the output circuit includes a voltage-regulation circuit; and
the voltage-regulation circuit does not include a circuit component connected in series
with the secondary winding and the output voltage terminal.
2. The voltage converter according to claim 1, wherein the voltage-regulation circuit
includes:
a first resistor and a switching element connected between the output voltage terminal
and ground; and
a Zener diode and a second resistor connected in parallel with the first resistor and the
switching element.
3. The voltage converter according to claim 2, wherein the switching element is a
transistor.
4. The voltage converter according to claim 3, wherein the transistor is a PNP bipolar
transistor or an NPN bipolar transistor.
5. The voltage converter according to claim 3, wherein a base terminal of the transistor
is connected to a point between the Zener diode and the second resistor.
6. The voltage converter according to claim 5, wherein, when a voltage at the output
voltage terminal is greater than a combined voltage of a Zener voltage of the Zener diode and a

base-emitter voltage of the transistor, the transistor turns on and current flows through the second resistor to regulate the voltage at the output voltage terminal.

7. The voltage converter according to claim 5, wherein, when a voltage at the output voltage terminal is less than a combined voltage of a Zener voltage of the Zener diode and a base-emitter voltage of the transistor, the transistor turns off so that no current flows through the second resistor and the voltage at the output voltage terminal is unregulated.

8. The voltage converter according to claim 2, wherein the first resistor is a variable resistor.

9. The voltage converter according to claim 1, wherein the output circuit includes a voltage-doubling circuit arranged between the secondary winding and the voltage-regulation circuit.

10. The voltage converter according to claim 9, wherein the voltage-doubling circuit includes a first diode, a second diode, a first capacitor, and a second capacitor.

11. The voltage converter according to claim 10, wherein:
an anode of the first diode is connected to a first end of the secondary winding and a cathode of the first diode is connected to the output voltage terminal;
an anode of the second diode is connected to a ground and a cathode of the second diode is connected to the first end of the secondary winding;
the first capacitor is connected between the output voltage terminal and a second end of the secondary winding; and
the second capacitor is connected between the second end of the secondary winding and ground.

12. The voltage converter according to claim 1, wherein the input circuit includes a feedback winding on the transformer core.

13. The voltage converter according to claim 12, wherein the input circuit and the secondary winding are configured to define a Royer oscillator.

14. The voltage converter according to claim 1, wherein at least one of the primary winding and the secondary winding comprises triply insulated wire.

15. The voltage converter according to claim 1, wherein at least one of the primary winding and the secondary winding includes a single-wire coil arrangement.

16. The voltage converter according to claim 1, wherein the transformer, the input circuit, and the output circuit are included within a single housing.

17. The voltage converter according to claim 16, wherein the input and output circuits are arranged on separate input and output printed circuit boards.

18. The voltage converter according to claim 17, wherein the input and output printed circuit boards are arranged on opposing sides of the housing.

19. The voltage converter according to claim 17, wherein the transformer is arranged to sit against the input printed circuit board.

FIG. 1
PRIOR ART

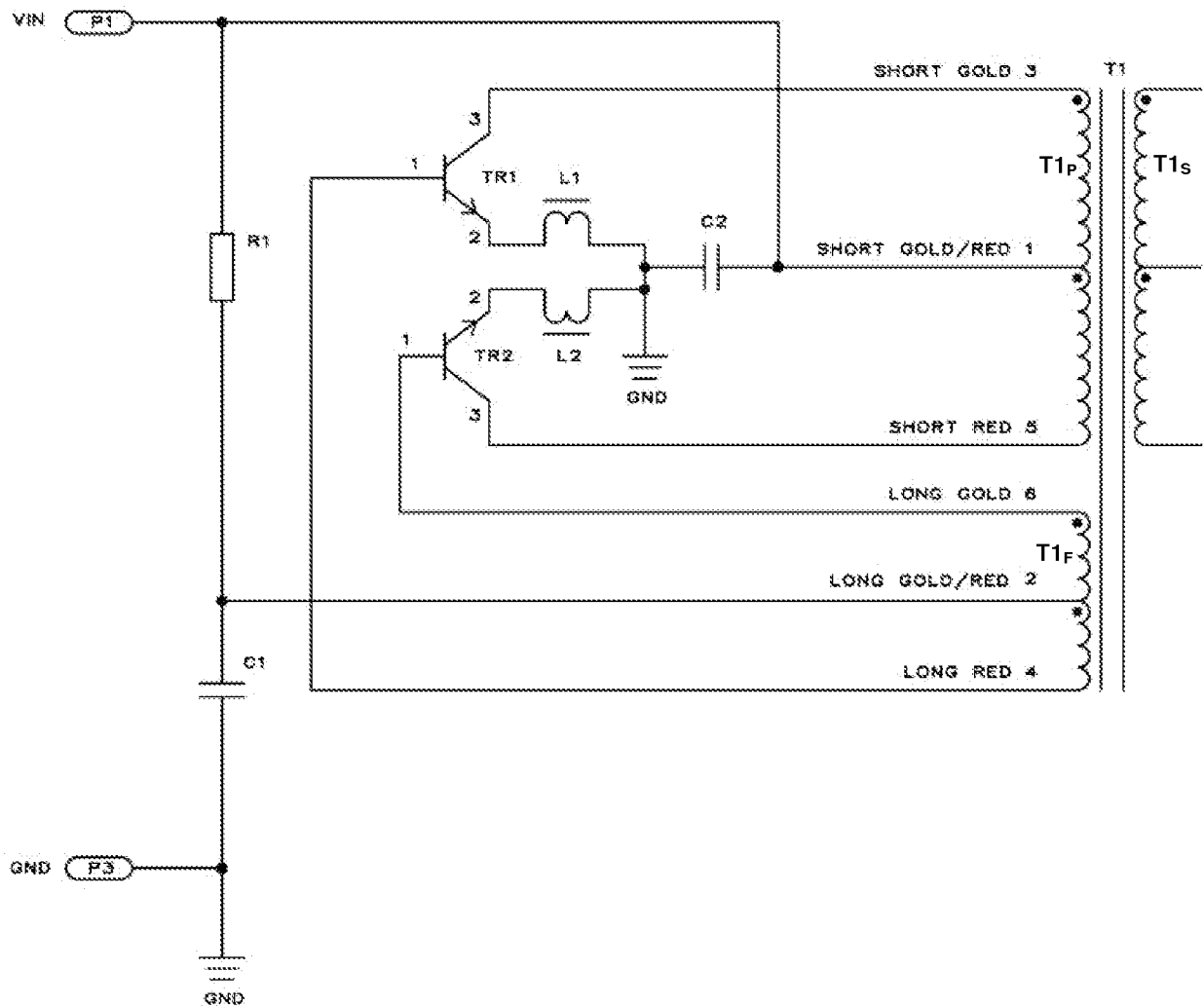


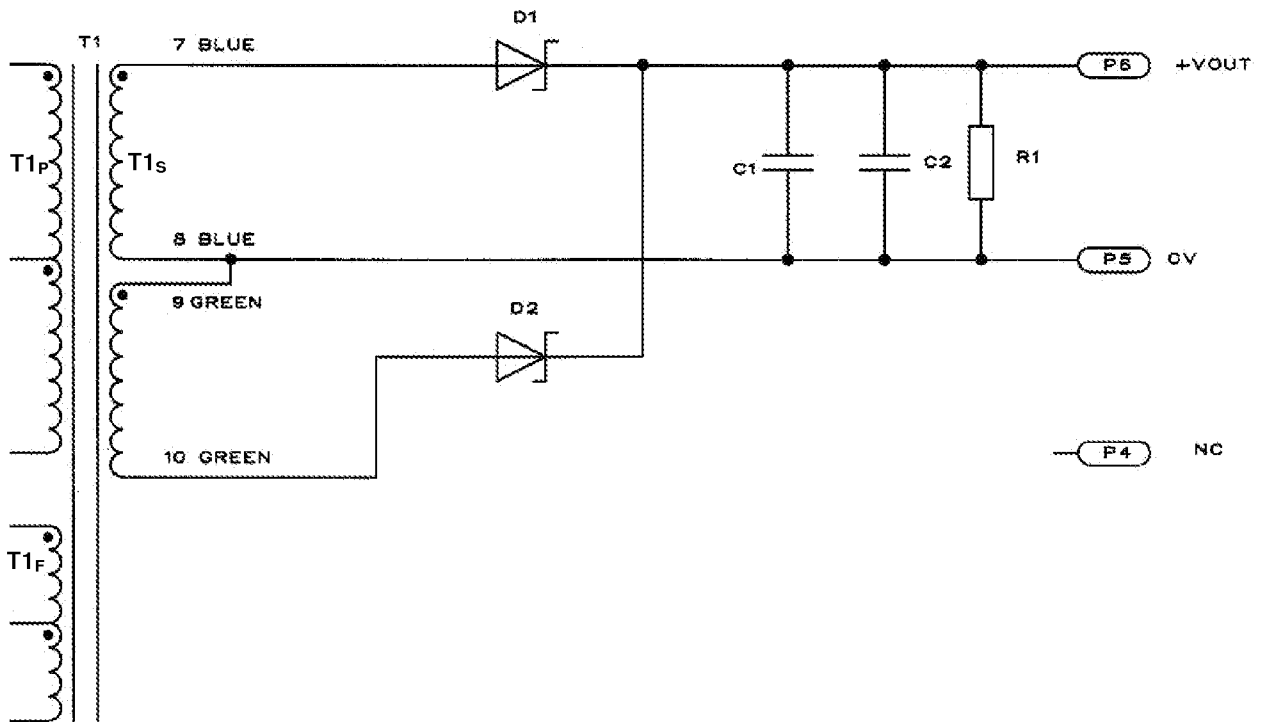
FIG. 2
PRIOR ART

FIG. 3
PRIOR ART

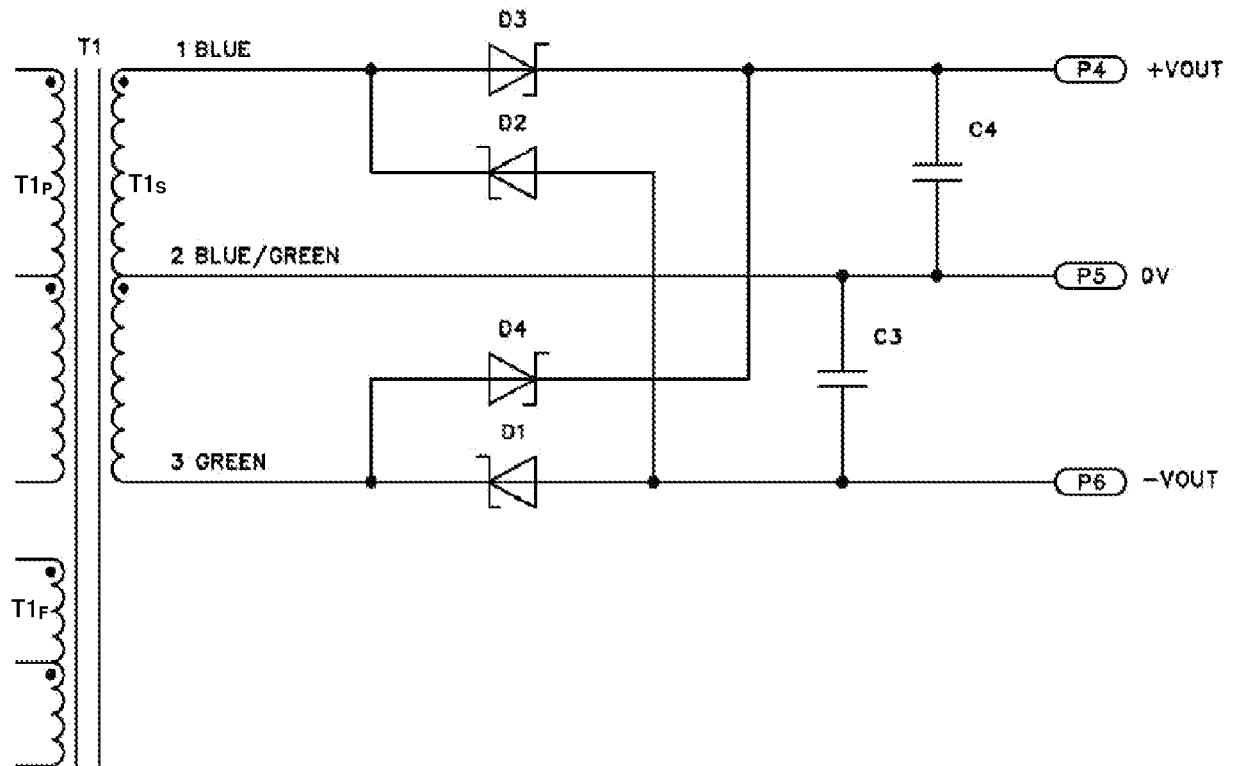


FIG. 4
PRIOR ART

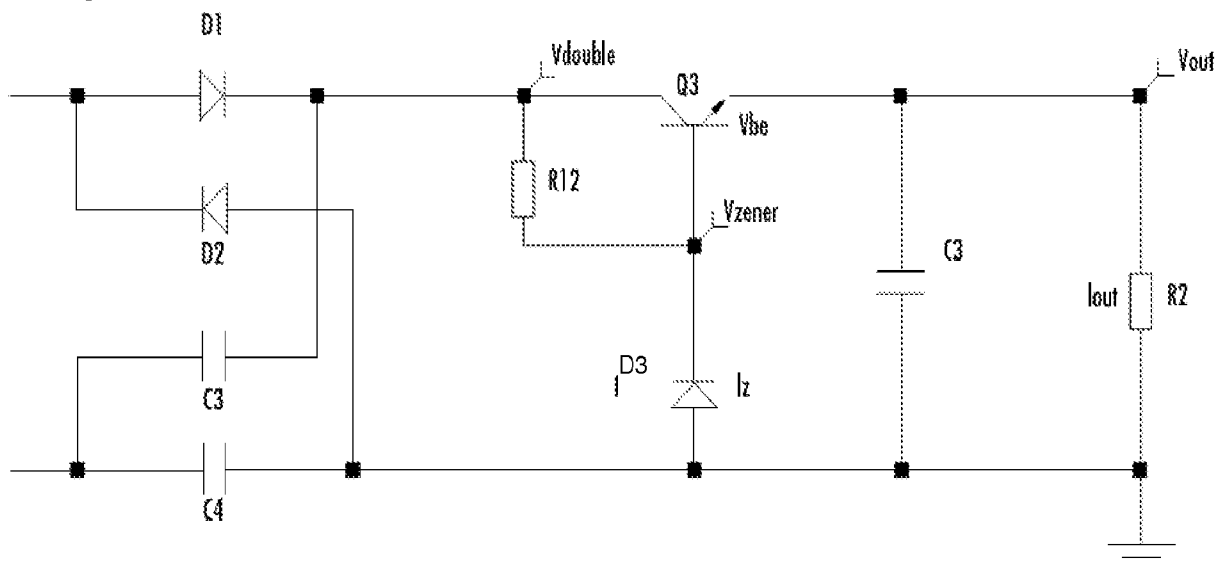


FIG. 5
PRIOR ART

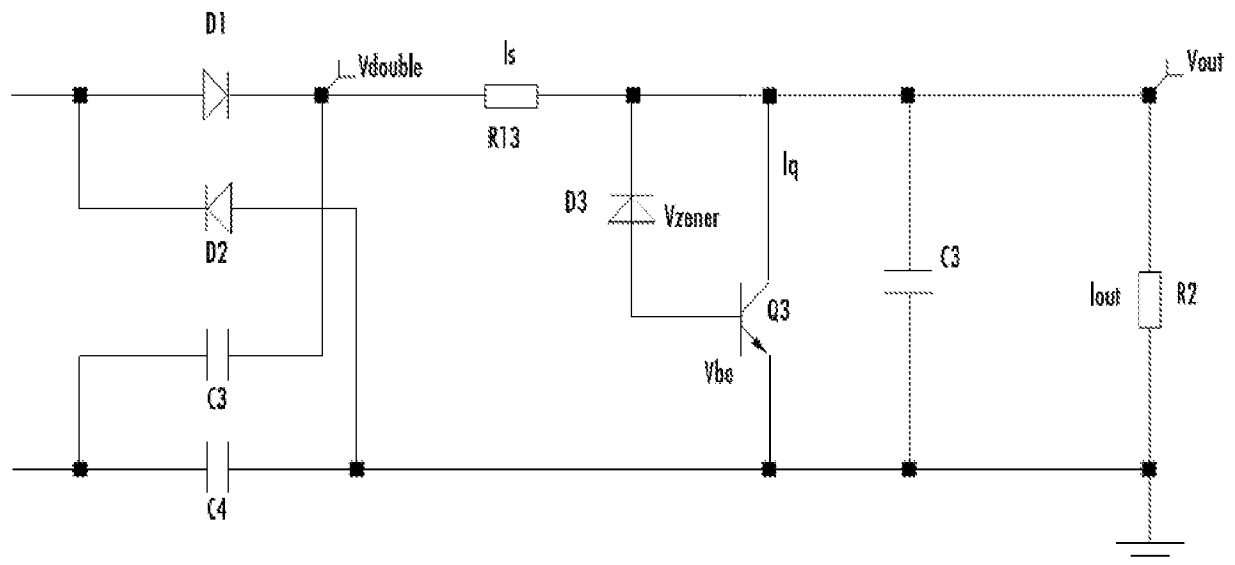


FIG. 6

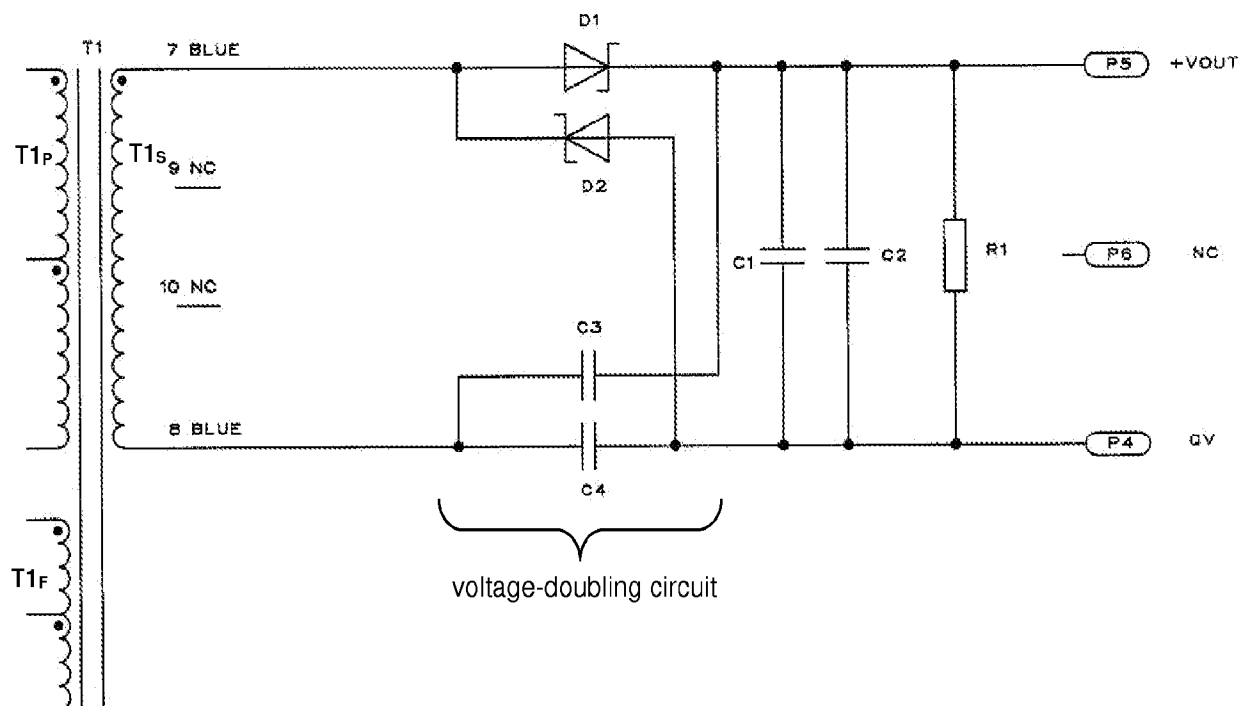


FIG. 7

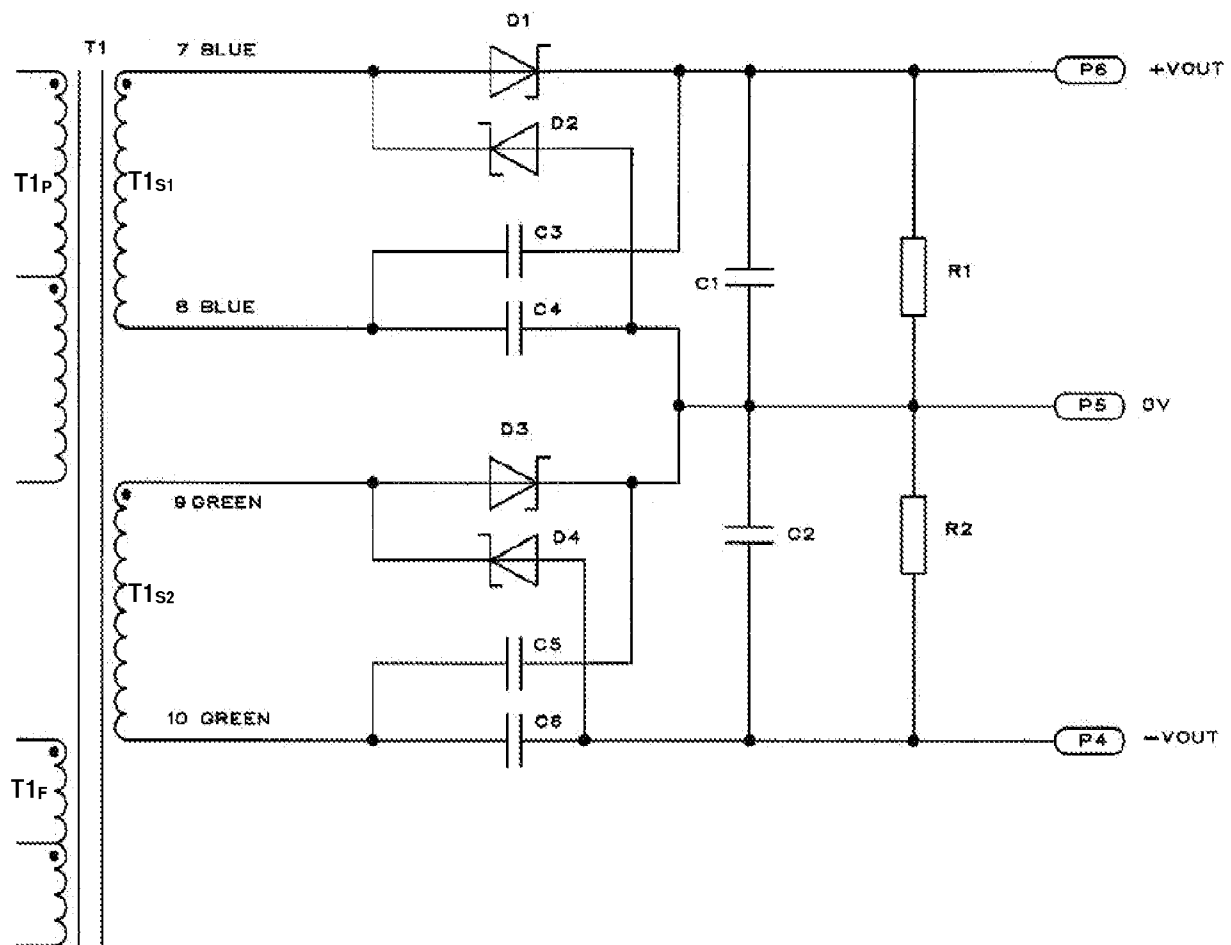


FIG. 8

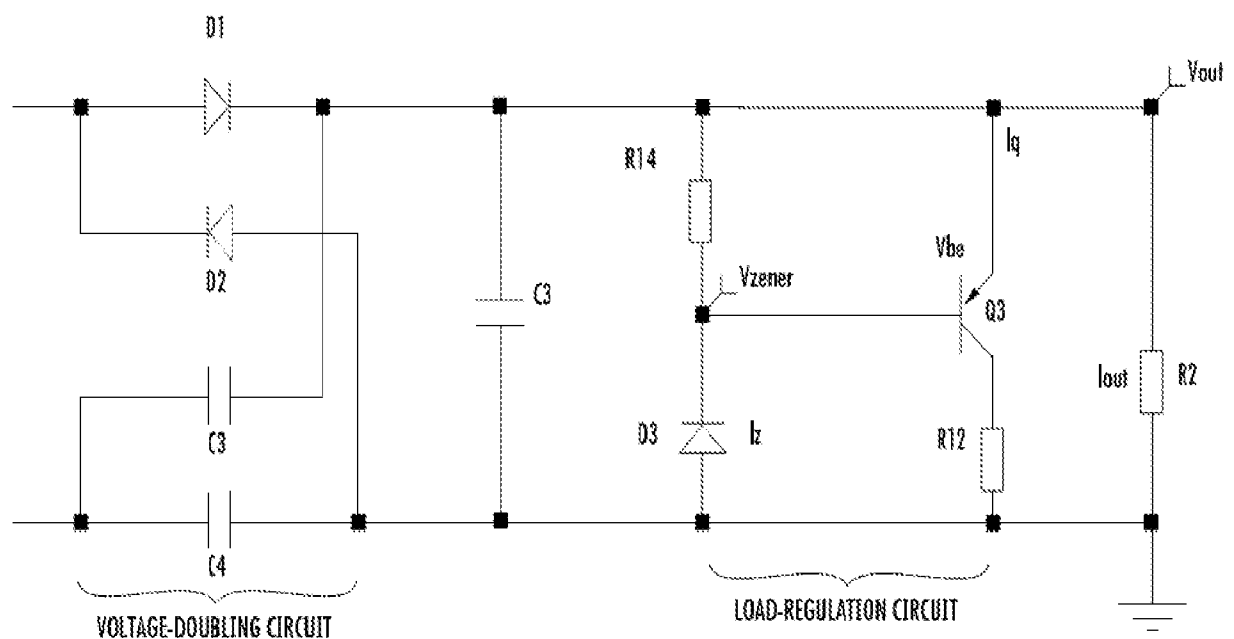


FIG. 9

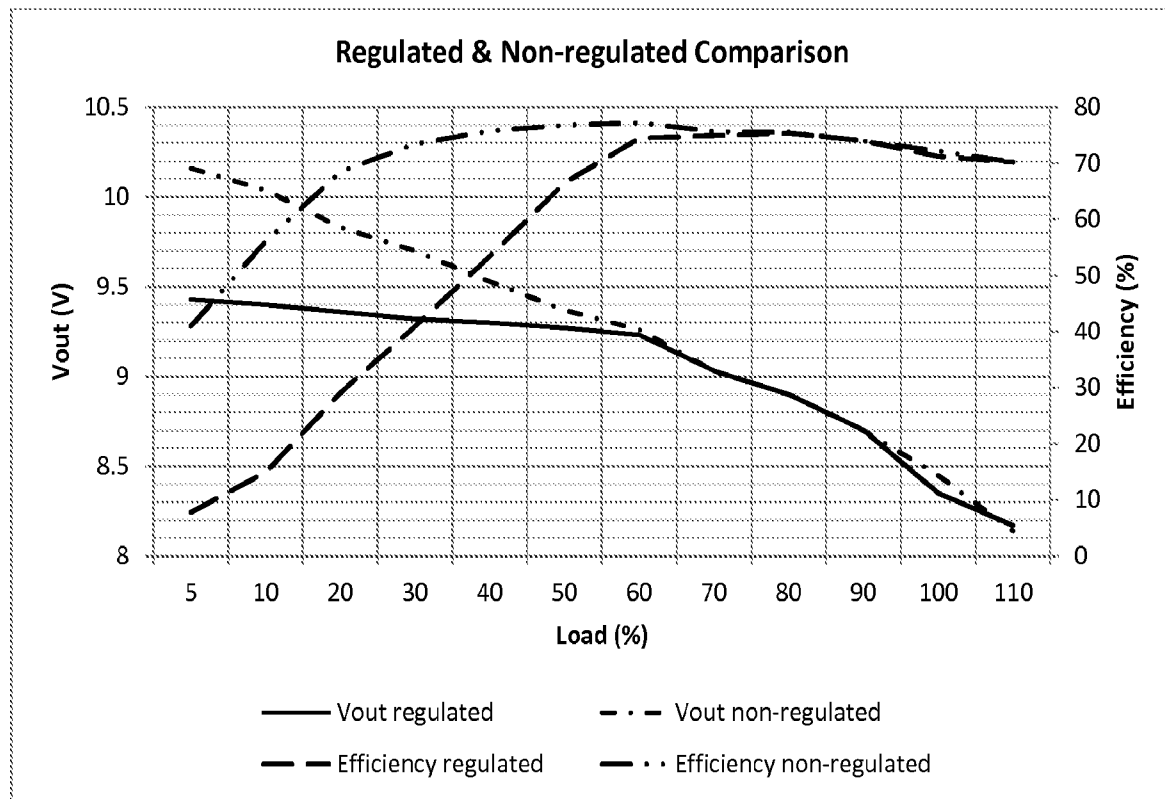


FIG. 10

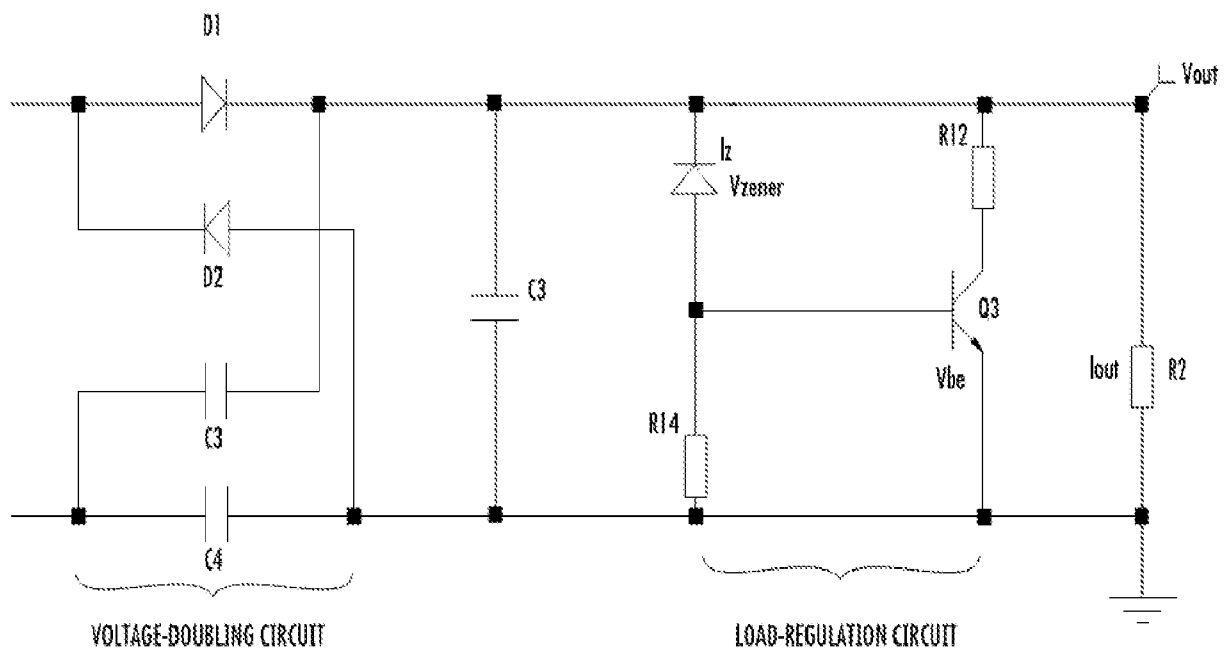


FIG. 11

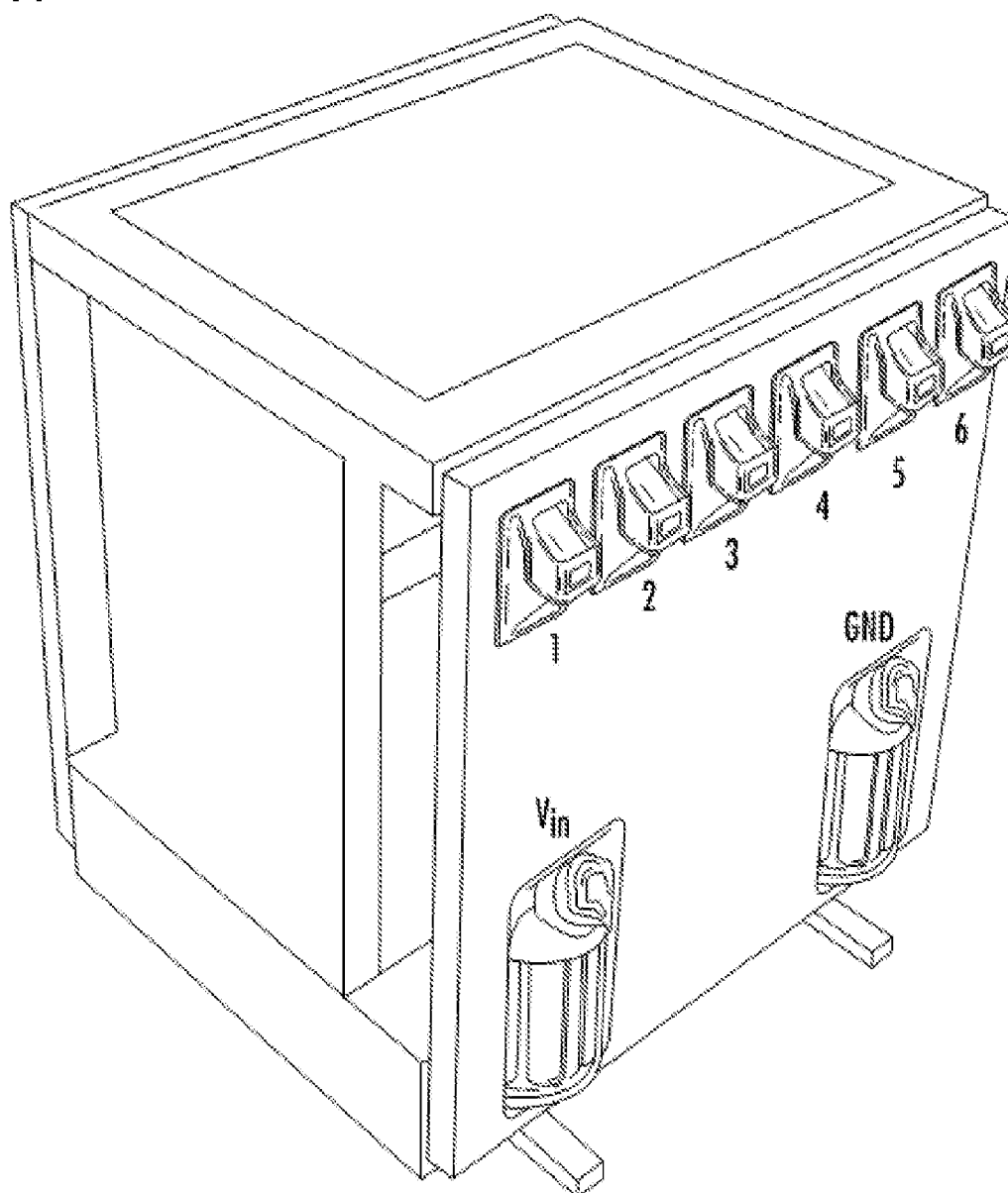


FIG. 12A

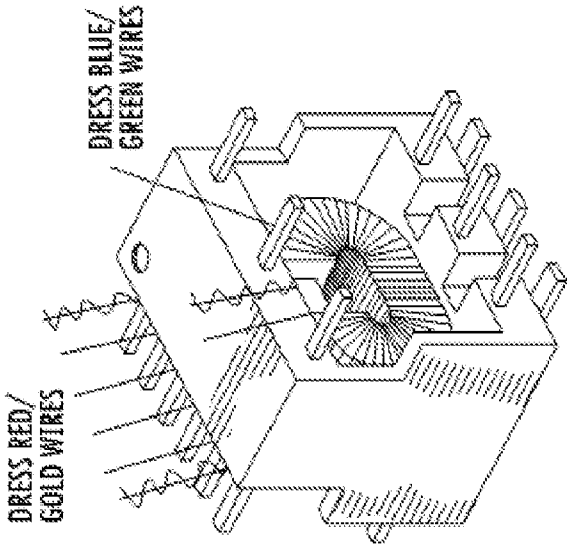


FIG. 12B

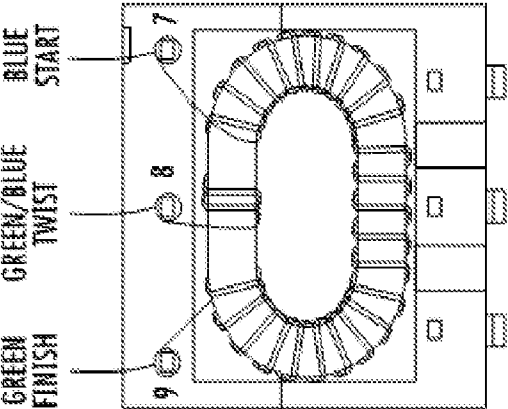


FIG. 12C

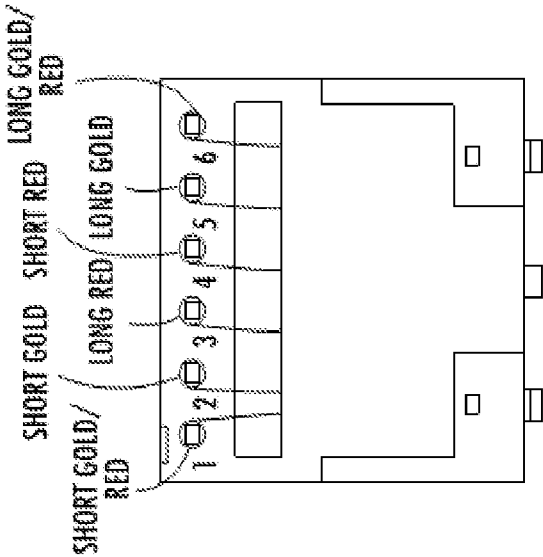
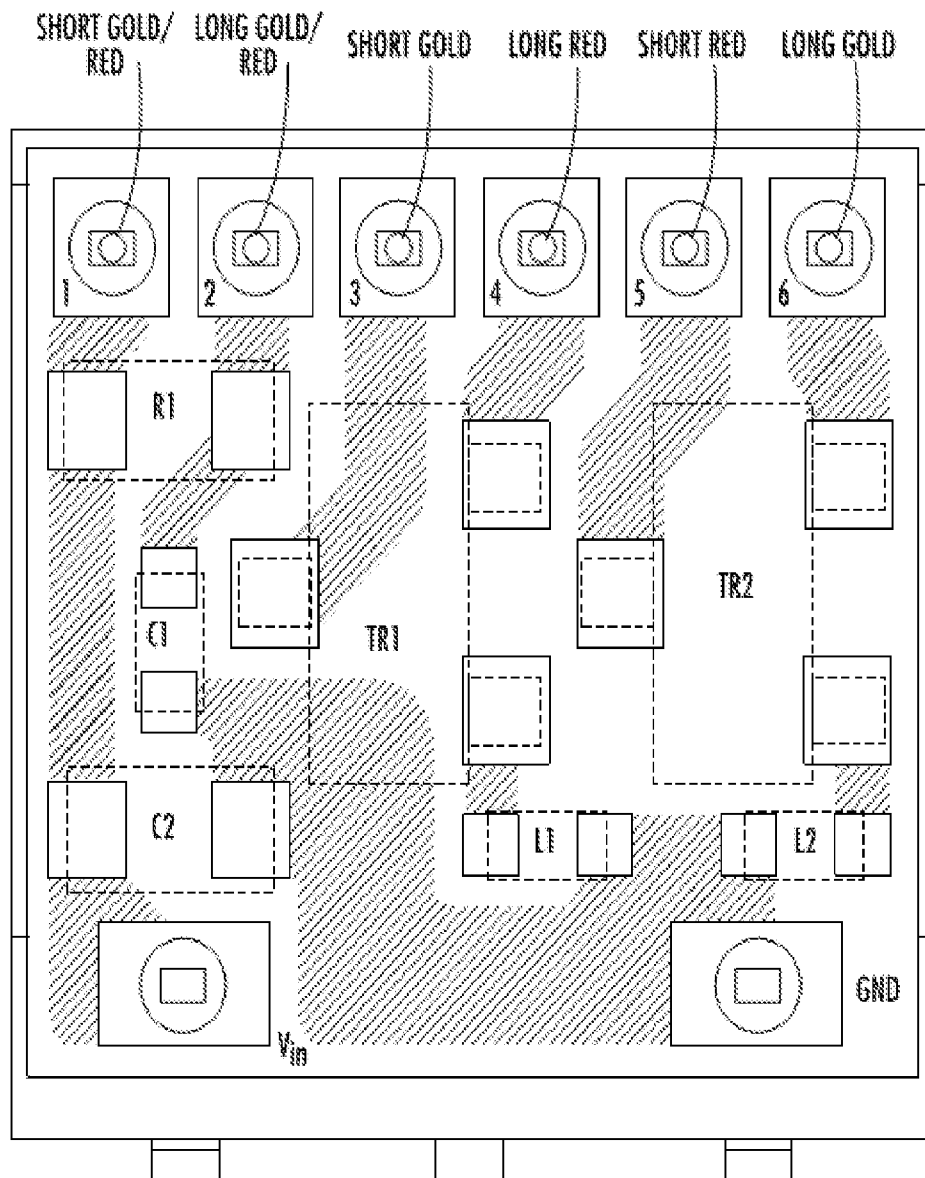


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/014757**A. CLASSIFICATION OF SUBJECT MATTER****H02M 3/28(2006.01)i**

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 3/28; H02M 3/335; H05B 41/24; H02M 7/538; H02M 7/48

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: converter, Royer oscillator, power, regulation circuit, zener diode, resistor, capacitor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6215680 B1 (WALTER ROLSTON) 10 April 2001 See abstract, column 2, line 49-column 5, line 35 and figures 1-5.	1-19
A	JP 05-316740 A (MINEBEA CO., LTD.) 26 November 1993 See abstract, paragraphs [0007]-[0011] and figures 1-3.	1-19
A	US 5412555 A (HIROSHI URAMOTO) 02 May 1995 See abstract, column 3, line 43-column 6, line 23 and figures 1-5.	1-19
A	US 2006-0250822 A1 (SHIN NAKAGAWA) 09 November 2006 See abstract, paragraphs [0040]-[0047] and figures 2-3.	1-19
A	KR 10-2006-0027421 A (SAMSUNG ELECTRONICS CO., LTD. et al.) 28 March 2006 See abstract, claims 1-10 and figures 1-6.	1-19



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 application or patent 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

29 April 2015 (29.04.2015)

Date of mailing of the international search report

30 April 2015 (30.04.2015)

Name and mailing address of the ISA/KR

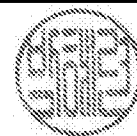
International Application Division
Korean Intellectual Property Office
189 Cheongsu-ro, Seo-gu, Daejeon Metropolitan City, 302-701,
Republic of Korea

Facsimile No. ++82 42 472 7140

Authorized officer

PARK, Hye Lyun

Telephone No. +82-42-481-3463



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/014757

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6215680 B1	10/04/2001	None	
JP 05-316740 A	26/11/1993	None	
US 5412555 A	02/05/1995	JP 04-299069 A	22/10/1992
US 2006-0250822 A1	09/11/2006	EP 1748541 A1	31/01/2007
		JP 4769714 B2	07/09/2011
		US 7272019 B2	18/09/2007
		WO 2005-112243 A1	24/11/2005
KR 10-2006-0027421 A	28/03/2006	CN 1780518 A	31/05/2006
		KR 10-0627704 B1	25/09/2006
		US 2006-0061304 A1	23/03/2006
		US 2007-0229002 A1	04/10/2007
		US 2007-0229084 A1	04/10/2007
		US 7242155 B2	10/07/2007
		US 7388336 B2	17/06/2008
		US 7414373 B2	19/08/2008