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(54) Title: THREE-QUARTER BRIDGE POWER CONVERTERS FOR WIRELESS POWER TRANSFER APPLICATIONS AND OTHER APPLICATIONS

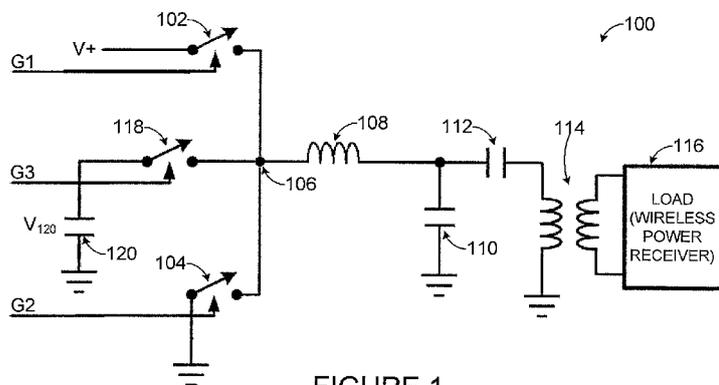


FIGURE 1

(57) Abstract: A three-quarter bridge power converter (100, 300, 400, 500, 600, 800, 900) includes a first switch (102, 302, 402, 502, 602, 802, 902) configured to selectively couple a switch node (106, 306, 406, 506, 606, 806, 906) to a higher voltage. The power converter also includes a second switch (104, 304, 404, 504, 604, 804, 904) configured to selectively couple the switch node to a lower voltage. The power converter further includes a third switch (118, 318, 418, 518, 618, 818, 918) configured to selectively cause a third voltage to be provided to the switch node when the first and second switches are not coupling the switch node to the higher and lower voltages. The third switch may be configured to selectively couple the switch node to an energy storage or energy source, such as a capacitor (120, 320, 420, 820, 920). The third switch may also be configured to selectively couple an energy storage or energy source (512, 612) to ground, where the energy storage or energy source is coupled to the switch node.

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THREE-QUARTER BRIDGE POWER CONVERTERS FOR WIRELESS POWER
TRANSFER APPLICATIONS AND OTHER APPLICATIONS

TECHNICAL FIELD

5 [0001] This disclosure relates generally to power converters.
More specifically, this disclosure relates to three-quarter
bridge power converters for wireless power transfer applications
and other applications.

BACKGROUND

[0003] Various power conversion architectures have been developed and used in a wide range of applications. Two common power conversion architectures are half bridge architectures and full bridge architectures.

[0004] In half bridge architectures using symmetrical drive, a disadvantage is that, at anything less than a maximum drive duty factor, there are "dead times" during which switches in the half bridge are not active (conducting). This can cause currents to flow through the body diodes of the switches, resulting in significant losses (often on an order of equal to or greater than I^2R losses). Placing Schottky diodes in parallel with the switches can help but can still result in significant Schottky losses during some operating conditions. While asymmetrical drive can solve the dead time problem, a disadvantage is that it typically results in poor waveform quality, which can require much lower impedance in a matching network. This increases half bridge circulating RMS current, which again increases losses.

[0005] Full bridge architectures with phase modulation can solve the dead time problem since current always flows through two actuated switches. However, full bridge architectures force a load to be driven differentially at a high common mode voltage, which can be a significant drawback in certain applications.

BRIEF DESCRIPTION OF DRAWINGS

[0006] For a more complete understanding of this disclosure and its features, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

[0007] FIGURES 1 through 6 illustrate example three-quarter bridge power converters and related details according to this disclosure;

[0008] FIGURE 7 illustrates an example control circuit for a three-quarter bridge power converter according to this

disclosure;

[0009] FIGURE 8 illustrates an example three-quarter bridge power converter with multiple transmit coils according to this disclosure;

5 [0010] FIGURE 9 illustrates an example three-quarter bridge power converter with current and voltage sensing instrumentation according to this disclosure; and

[0011] FIGURE 10 illustrates an example method for power conversion using a three-quarter bridge power converter according
10 to this disclosure.

DETAILED DESCRIPTION

[0012] FIGURES 1 through 10, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the invention may be implemented in any type of suitably arranged device or system.

[0013] FIGURES 1 through 6 illustrate example three-quarter bridge power converters and related details according to this disclosure. These new three-quarter bridge power converter topologies can be used in a wide range of applications. A three-quarter bridge power converter can significantly reduce or substantially eliminate commutating diode conduction losses associated with symmetrical pulse width modulated (PWM) half bridge power converters, while maintaining many of the advantages of a basic half bridge architecture.

[0014] An example of where this approach may be useful is in magnetically-coupled wireless power transfer environments. In these types of environments, a power "transmitter" (the primary side of a transformer) is physically separate from a power "receiver" (the secondary side of the transformer). The power transmitter represents any suitable structure for transmitting power, and the power receiver represents any suitable structure for receiving power. Effectively, the primary side of the transformer resides in one physical device, and the secondary side of the transformer resides in a completely separate device.

Additionally, the receiver (secondary) coils may be of various shapes and sizes, and the transmitter and receiver may be manufactured by different companies. Altogether, this environment presents several challenges that are unique compared to other isolated power transfer schemes:

- The exact coupling coefficient k is unknown and lower than

typical in an isolated power converter, so the transformation ratio may not be easily predicted;

- To minimize electro-magnetic interference (EMI) and enable the use of reactive impedance matching, waveforms should be as sinusoidal as possible;

- The primary and secondary sides are not on the same core and the transmitter coil may be much larger than the receiver coil, so magnetic flux lines may exist that are not contained in the core; and

- For simplifying instrumentation and facilitate switching between a matrix of multiple transmit coils, it may be desirable to couple one side of the transmit (primary) coil to ground. The three-quarter bridge power converters shown and described below can be used in these or other environments to reduce power losses during operation.

[0015] FIGURE 1 illustrates a first example three-quarter bridge power converter 100. As shown in FIGURE 1, the power converter 100 includes switches 102-104, which may represent the typical switches used in a half bridge power converter architecture. The switch 102 is coupled to receive a supply voltage $V+$, and the switch 104 is coupled to ground. The $V+$ and ground voltages represent rail voltages. The switch 102 can selectively couple the supply voltage $V+$ to a switch node 106 under the control of a control signal $G1$. The switch 104 can selectively couple the switch node 106 to ground under the control of a control signal $G2$. Each of the switches 102-104 includes any suitable switching structure, such as a MOSFET or other transistor device.

[0016] The switch node 106 is coupled to an inductor 108, which in this example is coupled to an output capacitor 110 and a direct current (DC) blocking capacitor 112. The inductor 108 represents any suitable inductive structure having any suitable inductance. Each of the capacitors 110-112 represents any

suitable capacitive structure having any suitable capacitance.

[0017] The capacitor 112 is also coupled to a coil, which in this example represents the primary side of a transformer 114. The secondary side of the transformer 114 is coupled to a load 5 116. The transformer 114 includes any suitable structure for transferring power in an isolated manner. Each side of the transformer 114 could have any suitable structure, such as a coil with any number of turns. As noted above, the primary side of the transformer 114 could include a matrix of different transmit 10 coils that can be switched into and out of the power converter 100.

[0018] A third switch 118 is added in the power converter 100 to form the three-quarter bridge architecture. The third switch 118 selectively couples the switch node 106 to an energy storage 15 or energy source. In this case, the energy storage or source is a power storage component formed by a capacitor 120, although any other suitable energy source or storage component(s) could be used. The capacitor 120 includes any suitable capacitive structure having any suitable capacitance. In some embodiments, 20 ripple can be a strict function of current flow during the on-time of the switch 118. In practice, it may be beneficial to limit the ripple in the capacitor 120 to a few hundred millivolts in order to reduce or minimize dielectric losses in the capacitor 120. This can be accomplished by increasing the size of the 25 capacitor 120.

[0019] The switch 118 can selectively couple the switch node 106 to the energy storage or source under the control of a control signal G3. The switch 118 includes any suitable structure for coupling an energy storage or source to a specified 30 node. For example, the switch 118 may represent a structure providing bi-directional blocking capability. In some embodiments, the switch 118 can be implemented using MOSFET transistors (or other types of transistors) coupled in series.

For instance, the switch 118 could be formed using two MOSFETs having their source terminals coupled together and their gate terminals configured to receive the control signal G3. The drain terminals of the MOSFETs could be coupled to the energy storage or source and the switch node 106. In particular embodiments, the power converter 100 may use a total of four MOSFET or other switches.

[0020] During operation, the control signals G1 and G2 (for controlling the switches 102-104) can be identical to those used in half bridge architectures. The control signal G3 (for controlling the switch 118) can be asserted (on) whenever both control signals G1 and G2 are not asserted (off). As a result, when the switches 102-104 are both turned off (not conducting), the switch 118 is turned on (conducting). A voltage on the switch node 106 may therefore be similar to that of a half bridge except that, during the on-time of the switch 118, the voltage is clamped to a voltage V_{120} stored on the capacitor 120 (or a voltage from another energy storage or source). Depending on the implementation, the voltage V_{120} could average one-half of the supply voltage $V+$.

[0021] In this way, the three-quarter bridge power converter 100 can reduce or eliminate "dead time" during its operation so that, at all times, the switch node 106 is connected to a power rail, a power storage component, or some other energy storage or source. This can substantially eliminate commutation diode conduction losses.

[0022] The load 116 represents any suitable structure for receiving power from the power converter 100. The load 116 could, for instance, include a wireless power receiver for receiving power wirelessly from the power converter 100. The wireless power receiver could form part of a larger device, such as a mobile telephone, portable computer, or other electronic device. The load 116 could also represent a motor, such as a

reversible DC or AC motor. Any other suitable load 116 could be used, such as an RL load.

[0023] FIGURE 2 illustrates example simulated waveforms related to the three-quarter bridge power converter 100 of FIGURE 1. As shown in FIGURE 2, the control signals G1 and G2 contain pulses for turning on the switches 102-104. If the control signals G1 and G2 define a 50% duty factor, there would be no dead time when neither switch 102-104 is conducting. However, as shown in FIGURE 2, there can be significant dead time between pulses in the control signals G1 and G2 at lower duty factors. As noted above, the control signal G3 pulses high at times when both control signals G1 and G2 are low, thereby activating the switch 118 to couple the node 106 to the capacitor 120. This helps to reduce or eliminate the dead time in the power converter 100.

[0024] FIGURE 2 also illustrates the voltage on the switch node 106 (V_{106}), the current through the inductor 108 (I_L), and the voltage on the capacitor 120 (V_{120}). In addition, FIGURE 2 illustrates the currents through the three switches 102, 104, 118 (I_{102} , I_{104} , and I_{118}). As shown in FIGURE 2, the voltage V_{106} on the switch node 106 does not merely swing between high and low levels as the switches 102-104 alternately couple the switch node 106 to the source voltage $V+$ and ground. In between those times (which would otherwise be dead time), the switch node 106 is coupled to the capacitor 120 and, in this example, receives a voltage that is approximately one-half of the source voltage $V+$.

[0025] The simulated waveforms here show a particular control signal-to-inductor current I_L phase relationship. This is a function of a resonant frequency and an operating frequency chosen for the simulation. Different selections can result in different phase relationships. Operation of the three-quarter bridge power converter 100 does not specifically require that a resonant circuit at all switch currents (I_{102} , I_{104} , and I_{118})

account for full 360° of the conducted current I_L , so in theory the current I_L may always flow in a low resistive path. In practice, some non-overlapping time between switch operations is typically used to ensure that there is no current shoot-thru.

5 [0026] FIGURE 3 illustrates a second example three-quarter bridge power converter 300. As shown in FIGURE 3, the power converter 300 includes switches 302-304 coupled to a switch node 306, an inductor 308, and an output capacitor 310. The capacitor 310 is coupled to a coil, which in this example represents the
10 primary side of a transformer 314. A load 316 is coupled to the secondary side of the transformer 314 and could represent a wireless power receiver. A switch 318 couples an energy storage or source such as a capacitor 320 to the switch node 306. In FIGURE 3, the power converter 300 operates using a series
15 resonance formed by the inductor 308, the output capacitor 310, and the primary side of the transformer 314.

[0027] FIGURE 4 illustrates a third example three-quarter bridge power converter 400. As shown in FIGURE 4, the power converter 400 includes switches 402-404 coupled to a switch node
20 406. An output capacitor 410 is coupled to the switch node 406 and a coil, which in this example represents the primary side of a transformer 414. A load 416 is coupled to the secondary side of the transformer 414 and could represent a wireless power receiver. A switch 418 couples an energy storage or source such
25 as a capacitor 420 to the switch node 406. In FIGURE 4, the power converter 400 operates using a series resonance formed by the output capacitor 410 and leakage inductance of the primary side of the transformer 414.

[0028] FIGURE 5 illustrates a fourth example three-quarter
30 bridge power converter 500. As shown in FIGURE 5, the power converter 500 includes switches 502-504 coupled to a switch node 506. A DC blocking capacitor 512 is coupled to the switch node 506 and to a coil, which here represents the primary side of a

transformer 514. A load 516 is coupled to the secondary side of the transformer 514. A switch 518 is coupled to a node 522 between the DC blocking capacitor 512 and the transformer 514. The switch 518 selectively couples the node 522 to ground. In
5 FIGURE 5, the power converter 500 operates in a non-resonant manner. However, the switch 518 can still be turned on during the non-conducting times of the switches 502-504 to avoid problems associated with dead times. In this embodiment, the capacitor 512 is effectively acting as the energy storage or
10 source that is coupled to the switch node 506, and the switch 518 causes the voltage on the capacitor 512 to be seen at the switch node 506.

[0029] FIGURE 6 illustrates a fifth example three-quarter bridge power converter 600. As shown in FIGURE 6, the power
15 converter 600 includes switches 602-604 coupled to a switch node 606. A DC blocking capacitor 612 is coupled to the switch node 606 and to a load 616, which in this example is represented by an inductor 614 and a resistor 615. A switch 618 is coupled to a node 622 between the DC blocking capacitor 612 and the load 616.
20 The switch 618 selectively couples the node 622 to ground. In FIGURE 6, the power converter 600 operates in a non-resonant and non-isolated manner with an inductive load rather than a wireless power transfer system. Once again, however, the switch 618 can still be turned on during the non-conducting times of the
25 switches 602-604 to avoid problems associated with dead times. In this embodiment, the capacitor 612 is effectively acting as the energy storage or source that is coupled to the switch node 606, and the switch 618 causes the voltage on the capacitor 612 to be seen at the switch node 606.

30 [0030] Compared to conventional half bridge architectures, three-quarter bridge power converters can have improved efficiency without compromising waveform symmetry. Compared to conventional full bridge architectures, three-quarter bridge

power converters can have a transformer with a primary side connected to ground, which may facilitate easy switching among a matrix of transmit coils and easy measurements of transformer voltages and currents.

5 [0031] Although FIGURES 1 through 6 illustrate examples of three-quarter bridge power converters and related details, various changes may be made to FIGURES 1 through 6. For example, each component in a three-quarter bridge power converter described above could be implemented in any suitable manner.

10 Also, the waveforms shown in FIGURE 2 are for illustration only, and a three-quarter bridge power converter could operate using different waveforms depending on the implementation. Further, the use of a capacitor as a mechanism for sourcing/sinking energy during operation of the power converter is for illustration only.

15 Other energy storage elements or energy sources could also be used. For instance, in other embodiments, the capacitor can be replaced by a bidirectional converter that outputs a voltage of approximately $V+/2$. The bidirectional converter can source energy to the third switch 118, 318, 418 by operating in

20 synchronous buck mode and sink energy from the switch 118, 318, 418 (and return it to $V+$) by operating in synchronous boost mode. Moreover, various components in FIGURES 1 through 6 could be combined, omitted, or further subdivided and additional components could be added according to particular needs. In

25 addition, any of the power converters in this patent document could use multiple switches during normal half bridge operation to selectively couple a switch node to different voltage rails, such as a higher voltage $V+$ and a lower voltage (not necessarily ground).

30 [0032] FIGURE 7 illustrates an example control circuit 700 for a three-quarter bridge power converter according to this disclosure. The control circuit 700 could, for example, be used to generate the control signals G1-G3 for any of the three-

quarter bridge power converters described above or below. In this example, the control circuit 700 uses a hybrid analog and digital approach to generate the control signals.

[0033] As shown in FIGURE 7, the control circuit 700 includes a frequency word unit 702 and a duty word unit 704. These units 5 702-704 output values denoting the frequency and duty cycle of a control signal used to drive the power converter. The values could represent 24-bit values. A phase accumulator 706 operates using the output of the frequency word unit 702. An output of 10 the phase accumulator 706 is provided to an adder 708, which adds the output of the phase accumulator 706 to the output of the duty word unit 704.

[0034] A high-order bit of the phase accumulator's output is identified and extracted using a most significant bit (MSB) 15 extraction unit 710. The high-order bit of the phase accumulator's output is used as a reference phase. A high-order bit of the adder's output is identified and extracted using an MSB extraction unit 712. The high-order bit of the adder's output is used as a variable phase.

[0035] The difference between the reference and variable 20 phases is used to generate the control signals G1 and G2 (which here are PWM signals). In particular, the output of the MSB extraction unit 710 is provided to an inverter 714 and an AND gate 720, and the output of the inverter 714 is provided to an 25 AND gate 716. The output of the MSB extraction unit 712 is provided to an inverter 718 and the AND gate 716, and the output of the inverter 718 is provided to the AND gate 720. The AND gates 716 and 720 output the control signals G1 and G2, respectively. The control signal G3 is generated by performing a 30 logical NOR operation of the G1 and G2 signals using a NOR gate 722. The signal G3 is therefore asserted whenever neither G1 nor G2 is asserted. Duty factor resolution in this example could be about 1.2×10^{-7} , which is likely far better than needed.

[0036] The control signals G1, G2, and G3 in this example could have low phase jitter, such as a phase jitter of one clock period. For a 100MHz clock, this results in a phase jitter of only 10ns. This methodology, which is mathematically related to direct digital synthesis (DDS), can inherently implement a dithering scheme that forces the duty factor average to be exactly equal to:

$$\text{Duty} = (2 \times \text{Duty Word}) / 2^{24}$$

(assuming 24-bit values are used). For resonant converters, jitter in the load can be reduced due to the high frequency roll-off of the resonant network.

[0037] Although FIGURE 7 illustrates one example of a control circuit 700 for a three-quarter bridge power converter, various changes may be made to FIGURE 7. For example, any other suitable combinatorial logic or other mechanisms could be used to produce appropriate control signals. Also, various components in FIGURE 7 could be combined, omitted, or further subdivided and additional components could be added according to particular needs.

[0038] The power converter topologies described above could be used in various applications. For example, a three-quarter bridge power converter could be useful in any application that might use a half bridge converter. The three-quarter bridge converter has greater efficiency for any duty factor that would result in dead time for the half bridge converter (less than a 50% duty factor).

[0039] Another application of the three-quarter bridge converter is as a substitute for full bridge converters in situations where it is desirable to connect one side of a load or one side of a transformer to ground. This may include, for example, applications where multiple transmit coils are used, and one or more coils can be selectively coupled to the bridge. An example of this is shown in FIGURE 8, which illustrates an

example three-quarter bridge power converter 800 with multiple transmit coils according to this disclosure.

[0040] As shown in FIGURE 8, the power converter 800 includes two switches 802-804 selectively coupling a node 806 to a source voltage $V+$ and ground, respectively. The node 806 is also coupled to a switch 818, which selectively couples the node 806 to an energy storage or source (such as a capacitor 820). In this example, the node 806 is coupled to multiple strings, where each string includes a coil 814a-814n (such as an inductor) and a transistor 815a-815n (such as a MOSFET) coupled in series. The coils 814a-814n represent multiple coils used to transmit power to a load 816. The coils 814a-814n could, for instance, form part of a multi-coil power transmit pad that allows great freedom in how a receive coil 822 of the load 816 is positioned with respect to the pad.

[0041] The combination of a series capacitor 810a-810n and the body diode of the transistor 815a-815n allows a DC level shift in each string, which effectively decouples that string from the rest of the circuit in FIGURE 8. A small bias current (such as FET leakage) flows to maintain the disconnect. This allows single MOSFETs to be used as the transistors 815a-815n for selecting between coils 814a-814n.

[0042] Although FIGURE 8 illustrates one example of a three-quarter bridge power converter 800 with multiple transmit coils, various changes may be made to FIGURE 8. For example, the power converter 800 could include any number of transmit coils.

[0043] Another three-quarter bridge power converter may involve the use of current and voltage sensing instrumentation, an example of which is shown in FIGURE 9. In FIGURE 9, a three-quarter bridge power converter 900 includes switches 902-904 coupled to a node 906, which is also coupled to a capacitor 910. The capacitor 910 is coupled to a coil 914, which could be an inductor or part of a transformer (such as a wireless power

transfer coil). A switch 918 couples an energy storage or source (such as a capacitor 920) to the node 906.

[0044] In this example, a voltage sensing unit 924 is coupled across the coil 914, and a current sensing unit 926 is coupled in series with the coil 914. The voltage sensing unit 924 includes any suitable structure for measuring a voltage, and the current sensing unit 926 includes any suitable structure for measuring a current. In this example, the three-quarter bridge architecture facilitates the use of sensing units 924-926 in a single-ended fashion, meaning these units do not require the use of differential signaling. This can help to reduce or eliminate the need for high common-mode rejection in these units.

[0045] Although FIGURE 9 illustrates one example of a three-quarter bridge power converter 900 with current and voltage sensing instrumentation, various changes may be made to FIGURE 9.

For example, the sensing units 924-926 could be used with any of the embodiments of the three-quarter bridge described above. Also, the power converter 900 could include one of the sensing units 924-926 while omitting the other.

[0046] Each component shown in the circuits above could be implemented using any suitable structure(s). Moreover, these figures illustrate example implementations of the circuits. In these circuits, components could be added, omitted, combined, further subdivided, or moved according to particular needs. In addition, the waveforms shown above are for illustration only and represent possible or simulated behaviors of specific implementations of the circuits.

[0047] FIGURE 10 illustrates an example method 1000 for power conversion using a three-quarter bridge power converter according to this disclosure. As shown in FIGURE 10, at least one drive signal is received for a three-quarter bridge power converter at step 1002. This could include, for example, an external component providing one or more signals identifying a desired

frequency and duty factor for driving the three-quarter bridge power converter. The external component could denote any suitable source for controlling the power converter, such as an external processing device or controller.

5 [0048] Control signals for switches in the three-quarter bridge power converter are generated at step 1004. This could include, for example, a control circuit generating the G1-G3 control signals for the power converter. As a particular example, this could include the control circuit generating the G1
10 and G2 control signals to drive the power converter at a desired duty factor. This could also include the control circuit generating the G3 control signal so that it is active (high) whenever the G1 and G2 control signals are inactive (low).

[0049] First and second switches in the three-quarter bridge
15 power converter are turned on and off at step 1006. This is done to couple a switch node in the power converter to higher and lower rail voltages, such as $V+$ and ground. The amount of time that the switch node spends coupled to the higher rail voltage versus the lower voltage rail defines the duty factor, and some
20 dead time may exist where both the first and second switches are turned off. The first and second switches can be controlled by the G1 and G2 control signals.

[0050] A third switch is used to couple the switch node to a voltage during the off times of the first and second switches at
25 step 1008. This could include, for example, the third switch closing so that a voltage on a capacitor is received at the switch node. The third switch can be opened whenever the switch node is coupled to a rail by either of the first and second switches. This substantially reduces or eliminates dead time in
30 the three-quarter bridge power converter. The third switch can be controlled by the G3 control signal.

[0051] Although FIGURE 10 illustrates one example of a method 1000 for power conversion using a three-quarter bridge power

converter, various changes may be made to FIGURE 10. For example, while shown as a series of steps, various steps in FIGURE 10 could overlap, occur in parallel, occur multiple times, or occur in a different order.

5 [0052] It may be advantageous to set forth definitions of certain words and phrases that have been used within this patent document. The term "couple" and its derivatives refer to any direct or indirect communication between components, whether or not those components are in physical contact with each other.
10 The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrases "associated with" and "associated therewith," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be
15 contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like.

[0053] While this disclosure has described certain embodiments
20 and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without
25 departing from the spirit and scope of this disclosure, as defined by the following claims.

WHAT IS CLAIMED IS:

1. A three-quarter bridge power converter comprising:
a first switch configured to selectively couple a switch node to a higher voltage;
5 a second switch configured to selectively couple the switch node to a lower voltage; and
a third switch configured to selectively cause a third voltage to be provided to the switch node when the first and second switches are not coupling the switch node to the higher
10 and lower voltages.
2. The power converter of Claim 1, wherein the third switch is configured to selectively couple the switch node to an energy storage or energy source.
15
3. The power converter of Claim 2, wherein the third switch is configured to selectively couple the switch node to a capacitor.
- 20 4. The power converter of Claim 1, wherein the third switch is configured to selectively couple an energy storage or energy source to ground, the energy storage or energy source coupled to the switch node.
- 25 5. The power converter of Claim 1, further comprising:
a circuit coupled to the switch node and configured to provide power to a load, the circuit comprising at least one coil or transformer winding.

6. The power converter of Claim 5, further comprising at least one of:

a single-ended voltage sensor configured to measure a voltage across the coil or transformer winding; and

5 a single-ended current sensor configured to measure a current through the coil or transformer winding.

7. The power converter of Claim 1, further comprising:

10 a control circuit configured to generate control signals for the first, second, and third switches.

8. The power converter of Claim 7, wherein the control circuit comprises:

15 a phase accumulator configured to receive a value associated with a drive frequency;

an adder configured to add an output of the phase accumulator and a value associated with a drive duty factor;

20 at least one extraction unit configured to identify a most significant bit in an output of the phase accumulator and a most significant bit in an output of the adder; and

combinatorial logic configured to generate the control signals using the most significant bits.

9. The power converter of Claim 1, wherein:

25 the higher voltage comprises a supply voltage;

the lower voltage comprises ground; and

the third voltage is approximately one-half of the supply voltage.

10. A system comprising:

a load; and

a three-quarter bridge power converter configured to provide power to the load, the power converter comprising:

5 a first switch configured to selectively couple a switch node to a higher voltage;

a second switch configured to selectively couple the switch node to a lower voltage; and

10 a third switch configured to selectively cause a third voltage to be provided to the switch node when the first and second switches are not coupling the switch node to the higher and lower voltages.

11. The system of Claim 10, wherein the third switch is
15 configured to selectively couple the switch node to an energy storage or energy source.

12. The system of Claim 11, wherein the third switch is
20 configured to selectively couple the switch node to a capacitor.

13. The system of Claim 10, wherein the third switch is
25 configured to selectively couple an energy storage or energy source to ground, the energy storage or energy source coupled to the switch node.

14. The system of Claim 10, wherein the power converter
further comprises:

30 a circuit coupled to the switch node and configured to provide power to a load, the circuit comprising at least one coil or transformer winding.

15. The system of Claim 14, wherein the power converter further comprises at least one of:

a single-ended voltage sensor configured to measure a voltage across the coil or transformer winding; and

5 a single-ended current sensor configured to measure a current through the coil or transformer winding.

16. The system of Claim 10, further comprising:

10 a control circuit configured to generate control signals for the first, second, and third switches.

17. The system of Claim 16, wherein the control circuit comprises:

15 a phase accumulator configured to receive a value associated with a drive frequency;

an adder configured to add an output of the phase accumulator and a value associated with a drive duty factor;

20 at least one extraction unit configured to identify a most significant bit in an output of the phase accumulator and a most significant bit in an output of the adder; and

combinatorial logic configured to generate the control signals using the most significant bits.

18. The system of Claim 10, wherein:

25 the three-quarter bridge power converter comprises a portion of a wireless power transmitter; and

the load comprises a wireless power receiver.

19. The system of Claim 18, wherein the three-quarter
30 bridge power converter is coupled to a matrix comprising multiple transmit coils or transformer windings.

20. A method comprising:

repeatedly coupling a switch node to a higher voltage and a lower voltage using first and second switches, respectively; and

selectively providing a third voltage to the switch node
5 using a third switch when the first and second switches are not
coupling the switch node to the higher and lower voltages.

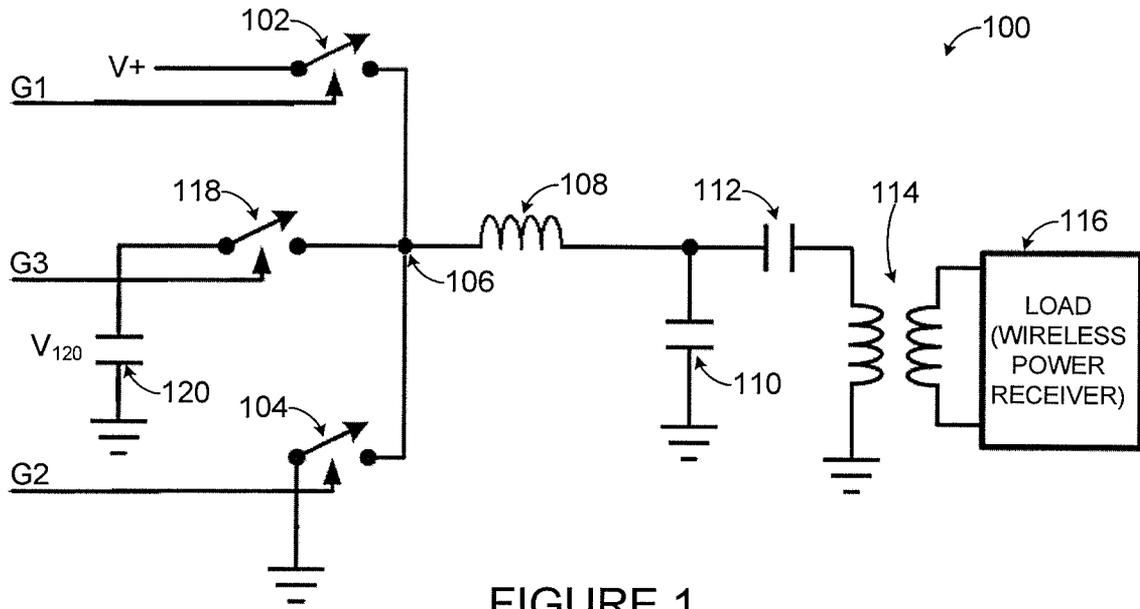


FIGURE 1

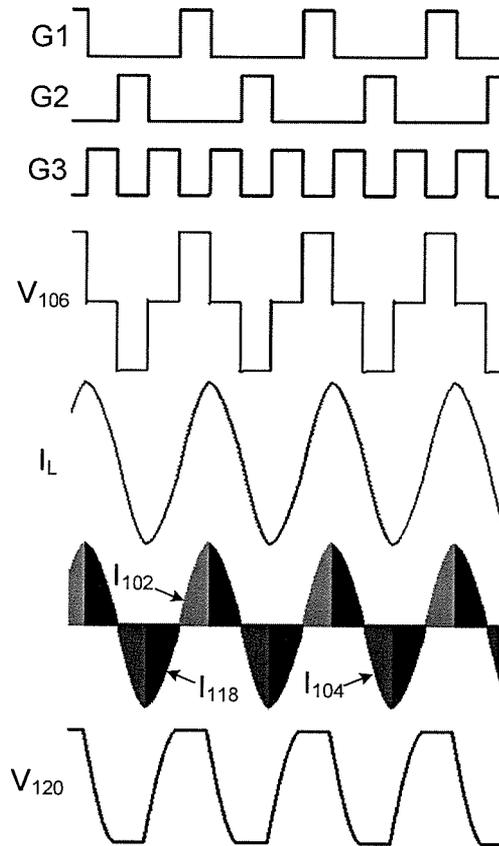


FIGURE 2

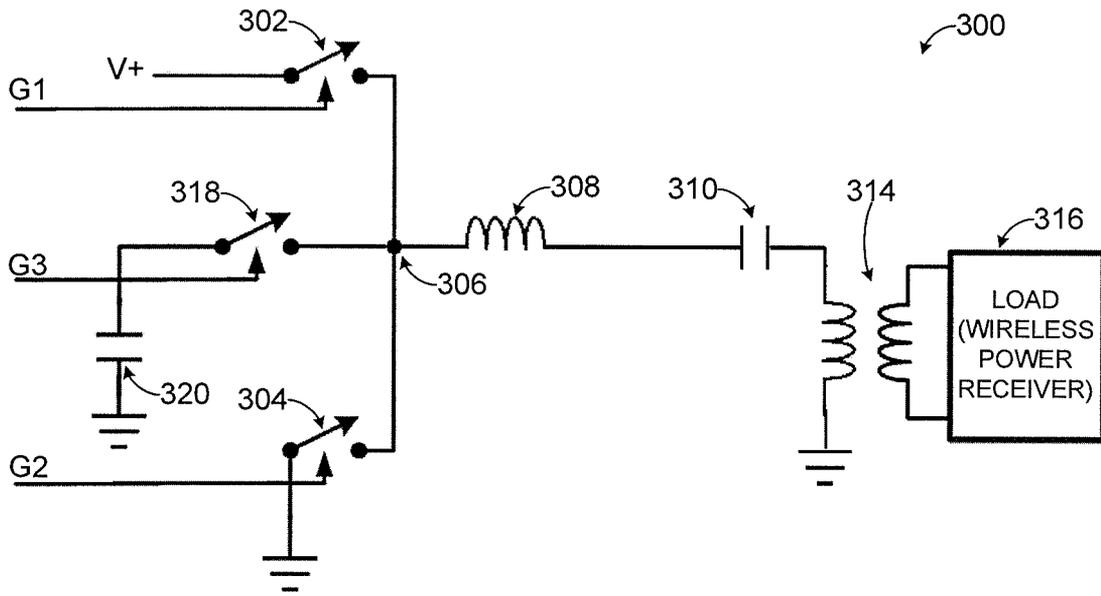


FIGURE 3

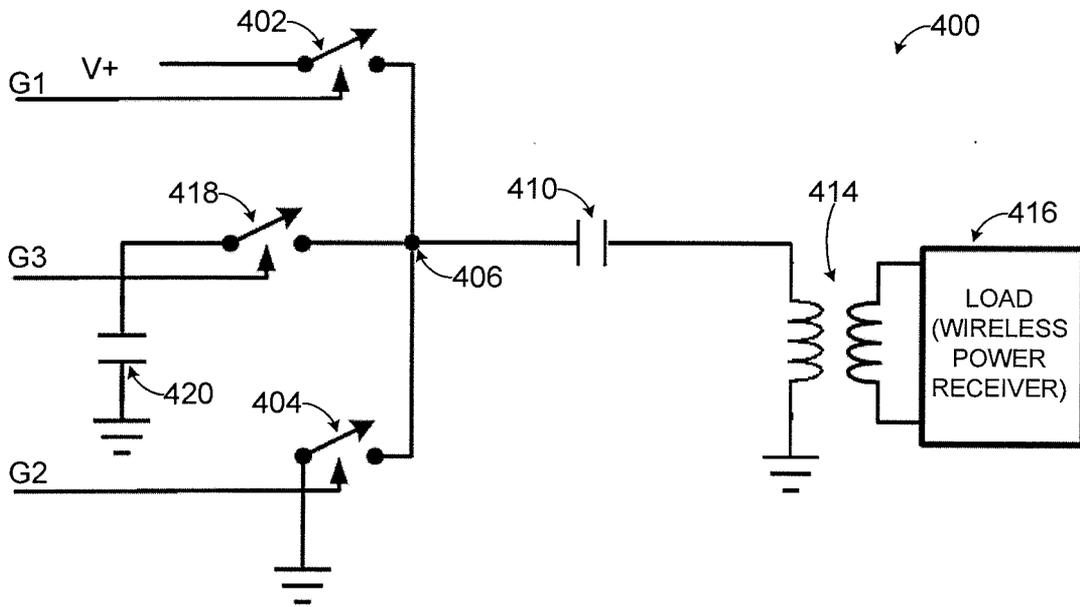


FIGURE 4

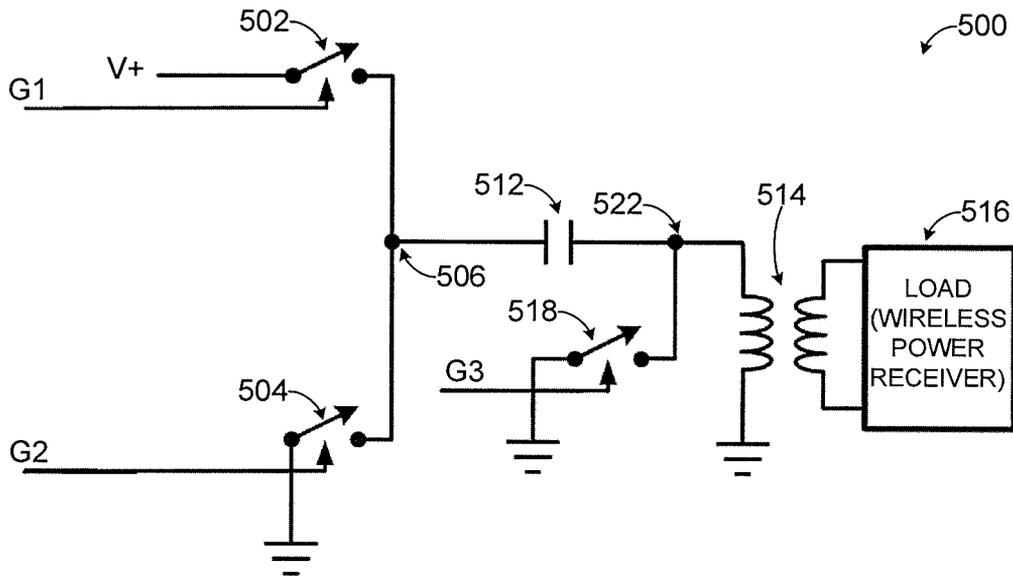


FIGURE 5

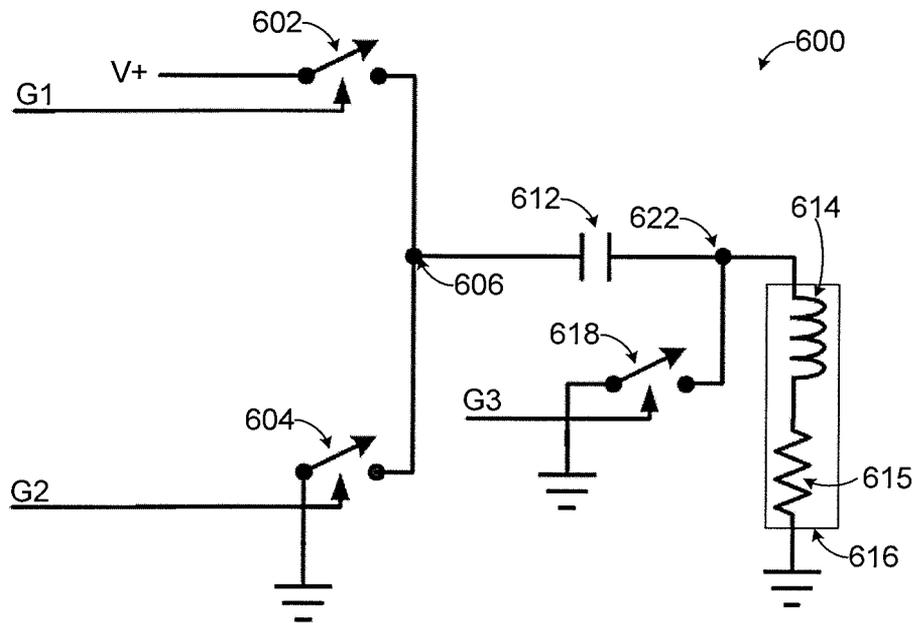


FIGURE 6

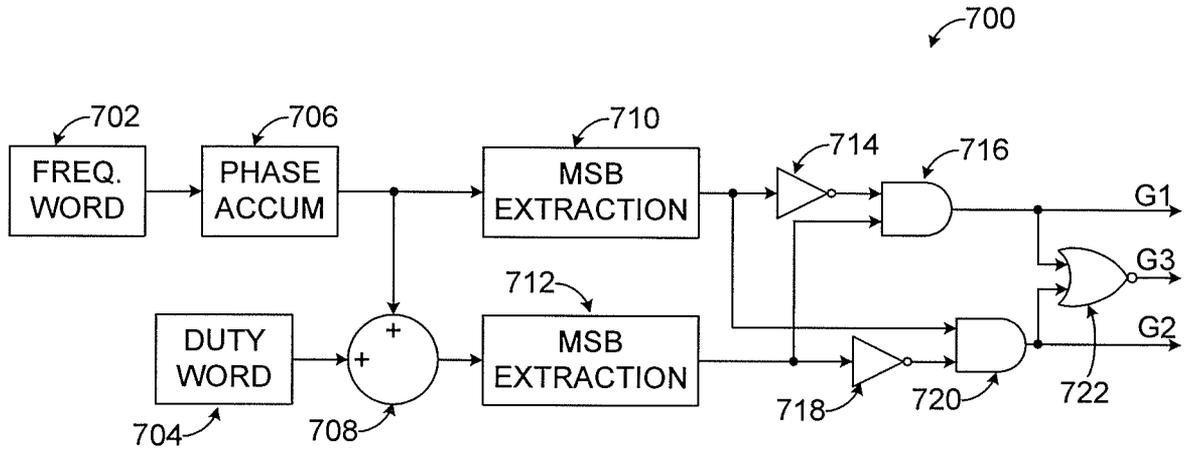


FIGURE 7

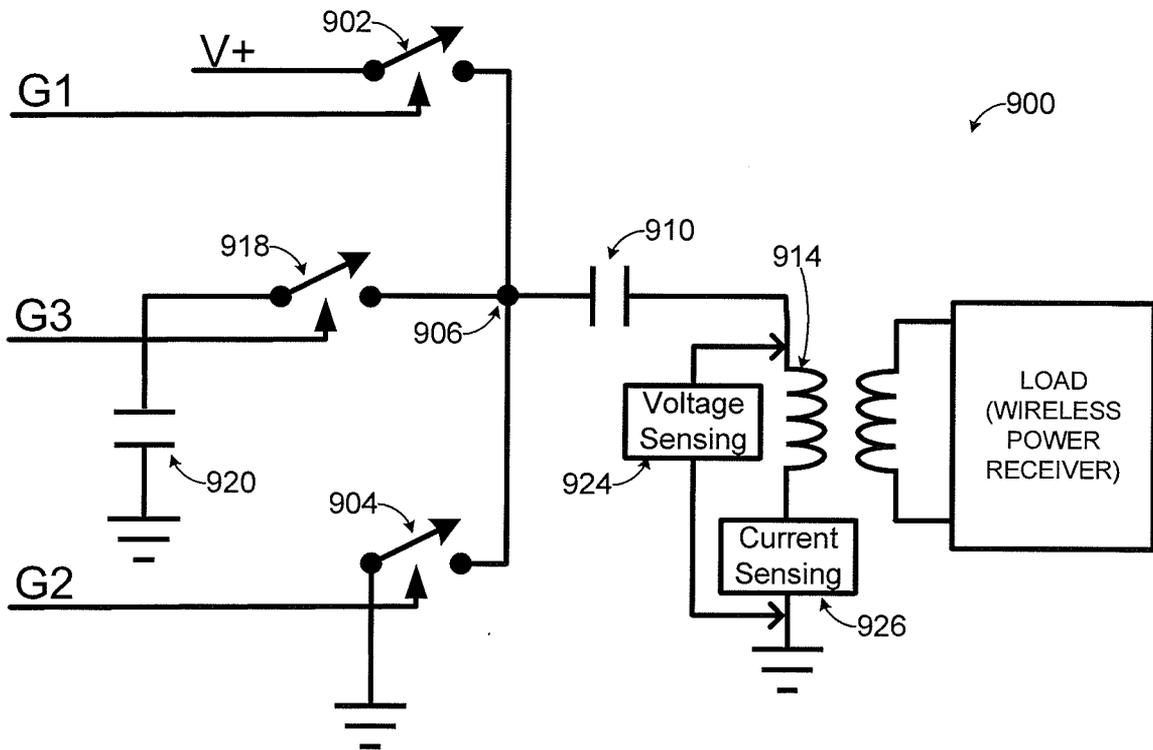


FIGURE 9

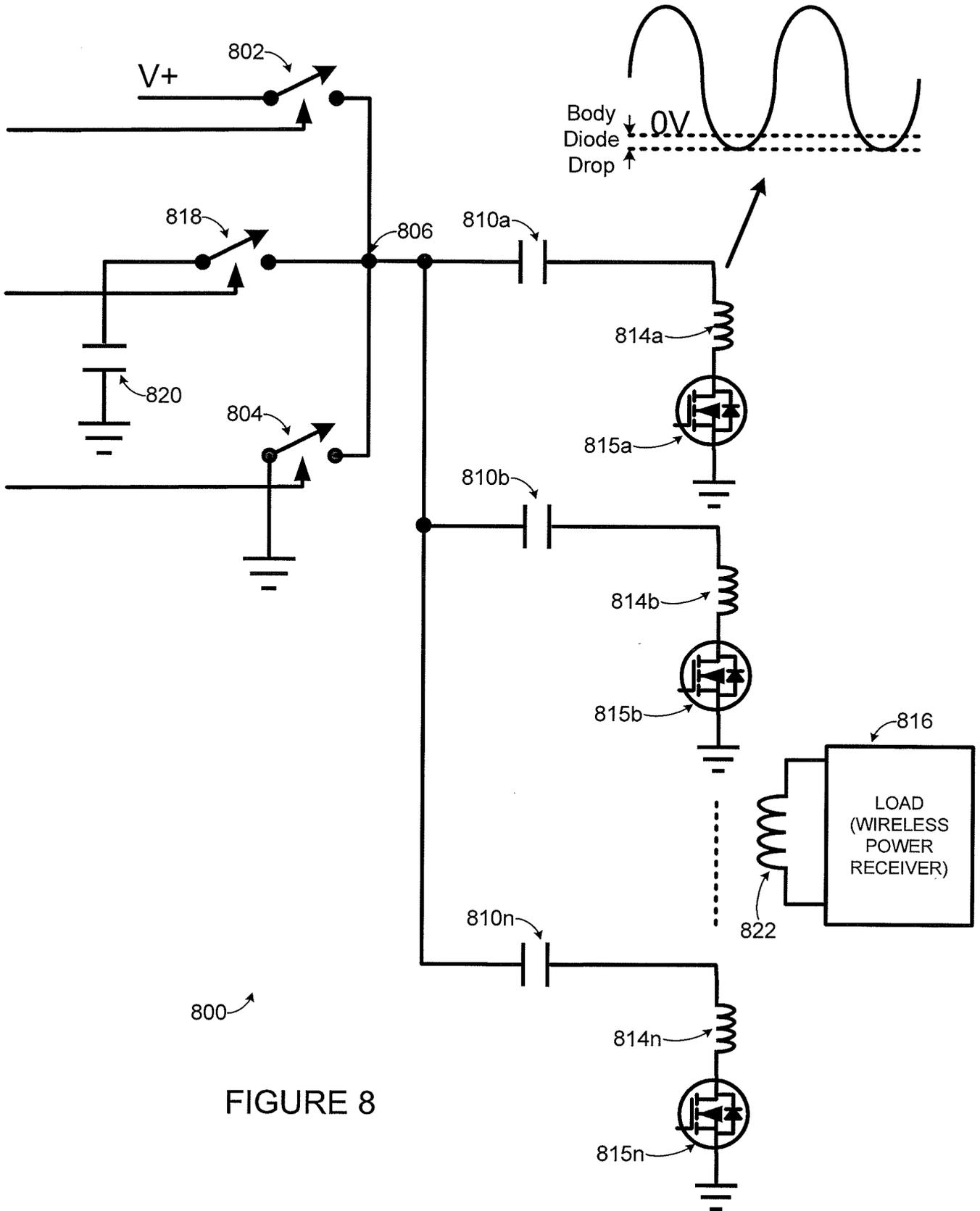


FIGURE 8

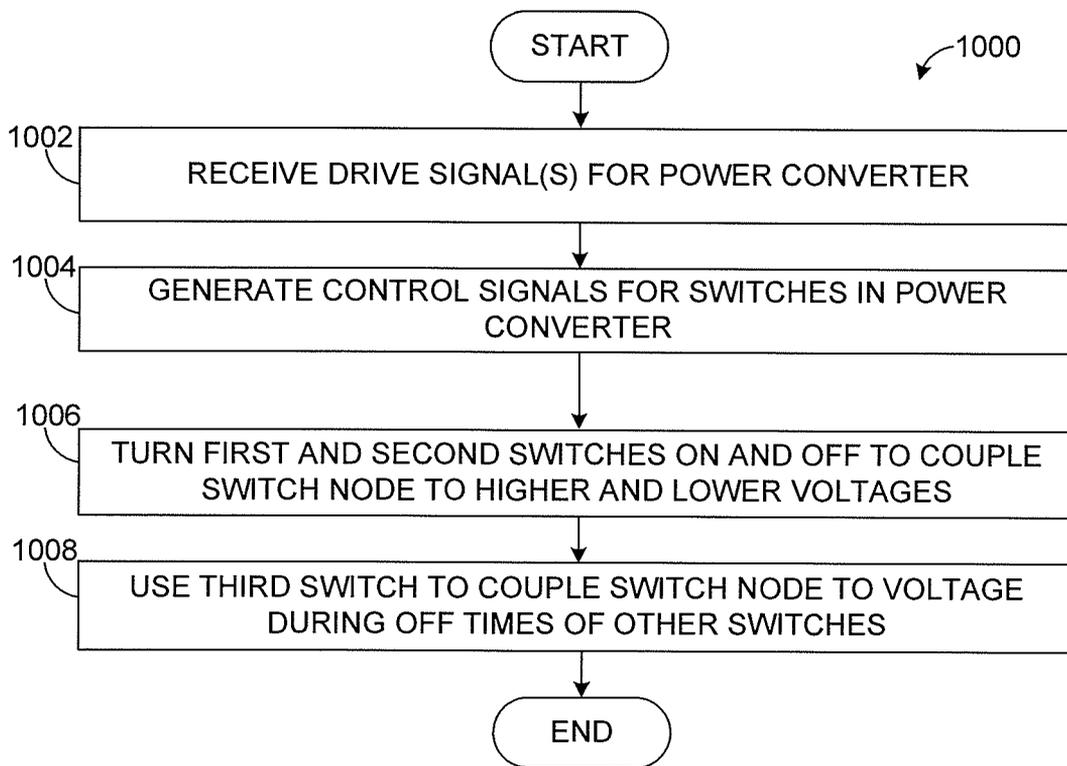


FIGURE 10