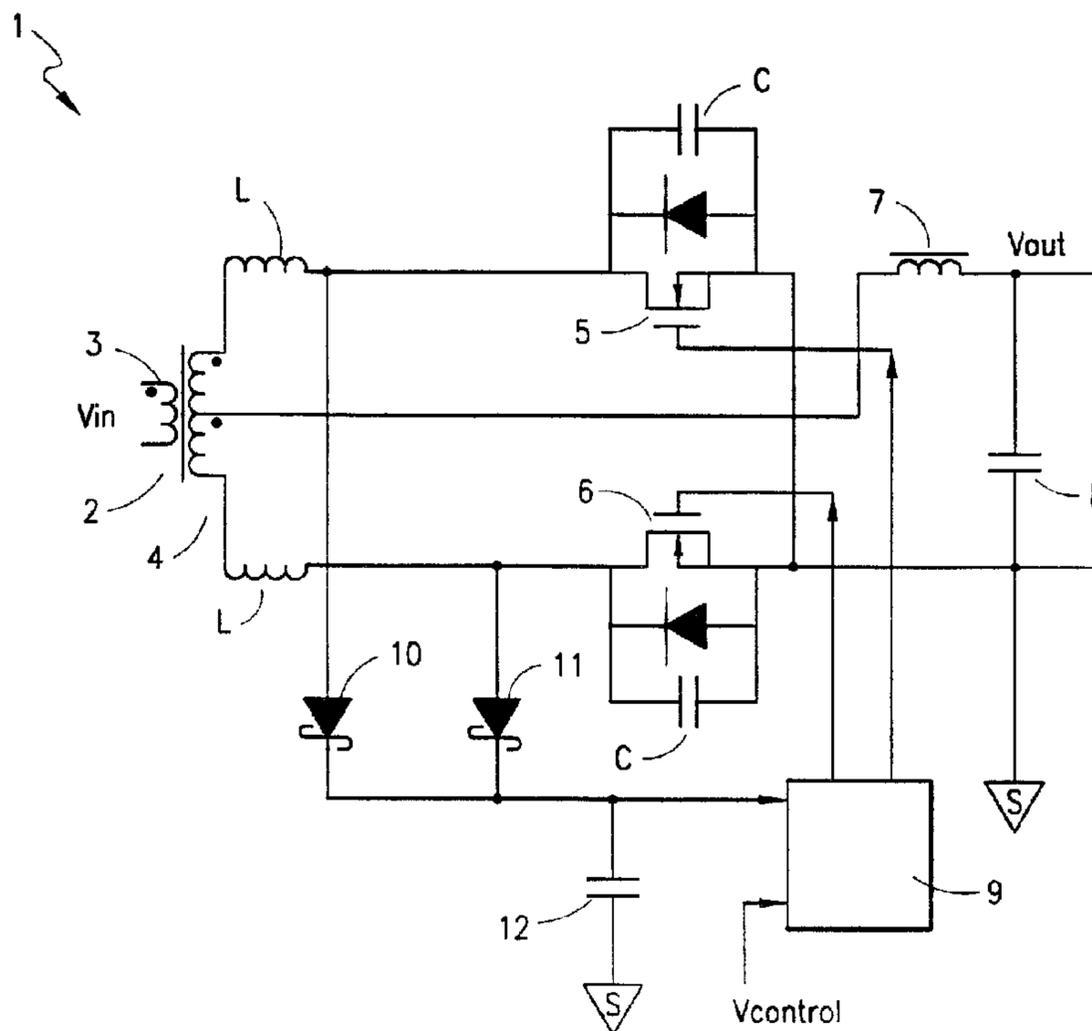




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 (72) Inventeurs/Inventors:
SUN, MARK N., US;
HART, WILLIAM, US
 (73) Propriétaire/Owner:
ERICSSON INC., US
 (74) Agent: MARKS & CLERK

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 (54) Title: CLAMPING CIRCUIT AND METHOD FOR SYNCHRONOUS RECTIFICATION



(57) **Abrégé/Abstract:**

A rectifier circuit having voltage clamping circuitry is disclosed. The rectifier circuit includes a transformer having a primary winding and a secondary winding and transistor switches each being connected to an end of the secondary winding of the transformer. The rectifier circuit further includes a first diode having an anode terminal connected to a first end of the secondary winding and a second diode having an anode terminal connected to a second end of the secondary winding. The cathode terminals of the first and second diodes are coupled to a capacitor. The energy stemming from voltage spikes and/or high frequency ringing appearing at the transistor switches due to parasitic effects is effectively absorbed by the first and second diodes and collected in the capacitor. The collected energy is recycled to control the operation of the transistor switches.



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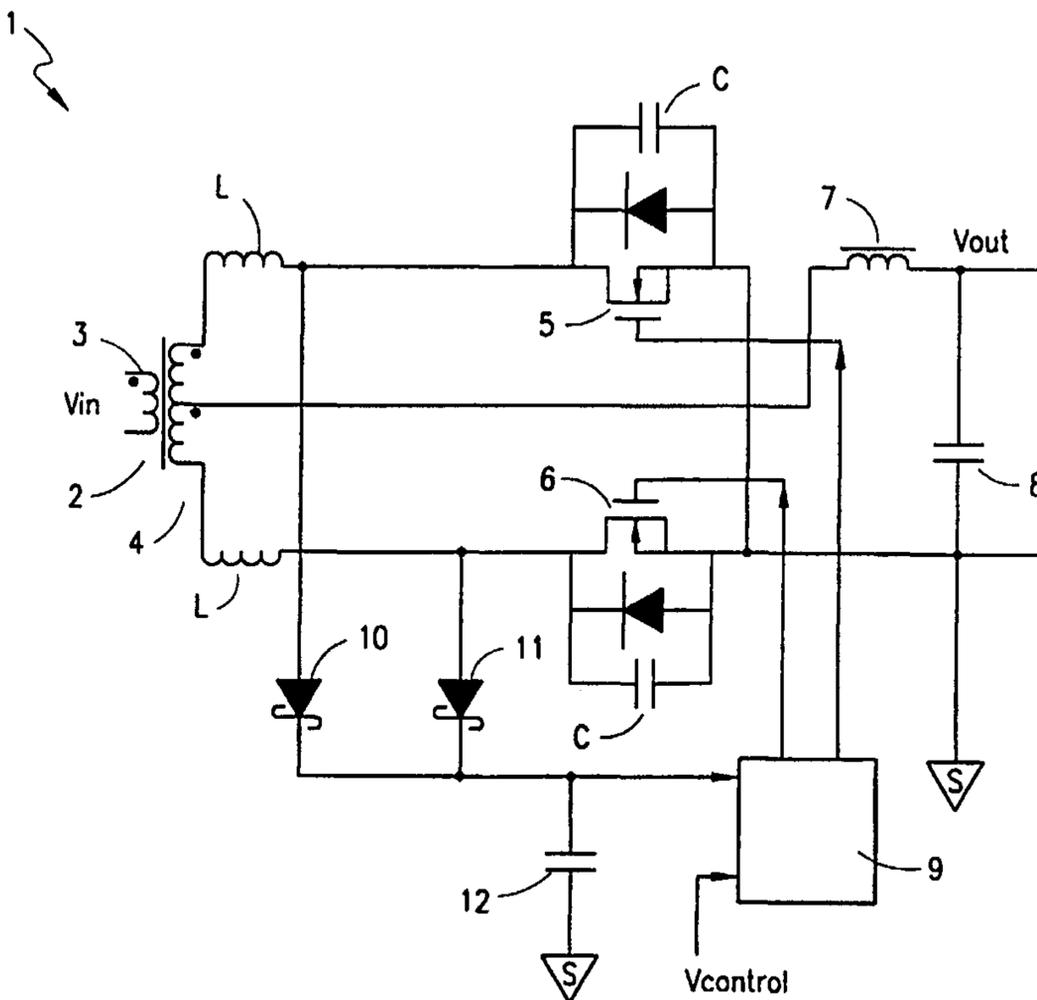
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(21) International Application Number: PCT/US00/06350 (22) International Filing Date: 10 March 2000 (10.03.00) (30) Priority Data: 09/267,000 12 March 1999 (12.03.99) US (71) Applicant: ERICSSON INC. [US/US]; 7001 Development Drive, P.O. Box 13969, Research Triangle Park, NC 27709 (US). (72) Inventors: SUN, Mark, N.; 3504 Wandering Trail, Plano, TX 75075 (US). HART, William; 7700 Ludwig Castle Way, Plano, TX 75025 (US). (74) Agents: CRISMAN, Thomas, L. et al.; Jenkins & Gilchrist, P.C., Suite 3200, 1445 Ross Avenue, Dallas, TX 75202 (US).	(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>	

(54) Title: CLAMPING CIRCUIT AND METHOD FOR SYNCHRONOUS RECTIFICATION**(57) Abstract**

A rectifier circuit having voltage clamping circuitry is disclosed. The rectifier circuit includes a transformer having a primary winding and a secondary winding and transistor switches each being connected to an end of the secondary winding of the transformer. The rectifier circuit further includes a first diode having an anode terminal connected to a first end of the secondary winding and a second diode having an anode terminal connected to a second end of the secondary winding. The cathode terminals of the first and second diodes are coupled to a capacitor. The energy stemming from voltage spikes and/or high frequency ringing appearing at the transistor switches due to parasitic effects is effectively absorbed by the first and second diodes and collected in the capacitor. The collected energy is recycled to control the operation of the transistor switches.



**CLAMPING CIRCUIT AND METHOD
FOR SYNCHRONOUS RECTIFICATION**

BACKGROUND OF THE INVENTION

Technical Field of the Invention

The present invention relates to a power converter, and particularly to a synchronous rectifier
5 having voltage limiting circuitry.

Background and Objects of the Invention

Power converters are known to convert an input
voltage waveform having a DC component into a DC
10 voltage waveform. Power converters employing an
isolation transformer require employment of a
rectification circuit to perform waveform conversion.
Traditionally, rectifier circuits utilize diodes
connected to the secondary side of the isolation
15 transformer which conduct current only when forward
biased. Synchronous rectifiers instead utilize
transistor switches which are selectively turned on and
off in synchronicity with the signal to be rectified in
order to control conduction of current from the
20 isolation transformer to the rectifier output.

The advancement in computational speeds and
densities of integrated circuitry and corresponding
systems has led to a reduction in the operating
voltages thereof. Power supplies are accordingly

expected to provide increased current at lower voltages while occupying less area. Because power loss through the diodes or transistor switches within a rectifier may account for nearly 40-50% of the total power loss
5 in the power supply, employment of diodes having a low forward bias and/or transistor switches having low on-resistances are most desirous.

Large voltage spikes and high frequency ringing are typically generated within a rectifier during fast
10 switching transitions, primarily due to the presence of parasitic inductances in the transformer and parasitic capacitances in the transistor switches. As a result, higher rated devices are needed to prevent breakdown of the diodes and/or transistor switches. Because use of
15 the higher rated devices increases the power loss, such use to suitably handle the excessive voltage spikes and high frequency ringing conflicts with the need for employing diodes and transistor switches to suitably maintain low power loss.

20 In response to this situation, attempts have been previously made to suppress the high voltage spikes and high frequency ringing using additional circuitry. For instance, RC snubber circuits have been utilized which somewhat reduce peak voltages and dampening
25 oscillations. However, the snubber circuits (Figure 1) dissipate a noticeable amount of power and peak voltages within the rectifier nonetheless remain.

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A prior snubber circuit is shown in Garcia, "Save Energy In Snubber Network", Electronic Design, May 1, 1995, p. 118. The article shows a flyback regulator that provides multiple output voltages with a single magnetic structure.

5

Another prior snubber circuit is shown in EPO application EP-A-0 614 267 to Digital Equipment Corporation. The application shows a snubber circuit including switch-diode-capacitor combinations across each rectifier. Controlled switches are turned on with a specific delay after the primary voltage reaches a magnitude close to the input voltage in order to allow the rectifier diodes to be commutated.

10

Active clamping circuits (Figure 2) have been previously proposed to suppress the voltage spikes. The active clamping circuits, however, substantially increase the complexity and component count of the
5 rectifier. Consequently, there exists a need for a rectifier having reduced voltage spikes and high frequency ringing.

It is an object of the present invention to provide a rectifier circuit for use in a power supply
10 which substantially eliminates voltage spikes and high frequency ringing.

It is another object of the present invention to provide a rectifier circuit having reduced power loss.

Another object of the present invention is to
15 provide a rectifier circuit which minimally increases component count and power consumption of the rectifier.

Still another object of the present invention is to provide a rectifier circuit for a power supply which is simple in design and inexpensive to manufacture.

20

SUMMARY OF THE INVENTION

The present invention overcomes the shortcomings in existing power supplies and satisfies a significant need for a power supply having improved performance
25 levels.

According to a first embodiment of the present invention, there is provided a rectifier circuit which

reduces voltage spikes and high frequency ringing caused by parasitic components therein. The rectifier circuit is a synchronous rectifier having at least two transistor switches connected to the secondary side of a transformer. The transistor switches are selectively switched between conductive and non-conductive states by control signals generated from the primary side and secondary side of the isolation transformer via a control circuit. The present invention includes a first voltage clamping component having a first terminal which is connected to a first end of the secondary side of the transformer, and a second voltage clamping component having a first terminal which is connected to a second end of the secondary side of the transformer. The present invention further includes a third component connected to a second terminal of the first and second voltage clamping components. The third component additionally drives the control circuit.

When either of the transistor switches is switched into the non-conductive state, a relatively large voltage spike and high frequency ringing are induced thereat due to a parasitic inductance and capacitance in the transformer and transistor switch, respectively. The energy corresponding to the voltage spike and high frequency ringing is absorbed by the first and second voltage clamping components and collected in the third

component. The absorbed energy is recycled to the control circuit for controlling the transistor switches.

5 In a first preferred embodiment of the present invention, the rectifier circuit is a full wave synchronous rectifier. The present rectifier circuit also may be implemented as a half wave synchronous
10 rectifier, a full wave diode rectifier and a half wave diode rectifier.

According to an aspect of the invention there is provided a rectifier circuit, including:

15 a transformer having a primary winding and a secondary winding;

a first rectifying element having a first terminal connected to a first end of the secondary winding of the transformer and a second terminal connected to a reference
20 voltage, the first rectifying element comprising a transistor having a first terminal connected to the first end of the secondary winding of the transformer and a second terminal connected to the reference voltage;

a second rectifying element having a first terminal
25 connected to a second end of the secondary winding of the transformer and a second terminal connected to the reference voltage, the first and second rectifying elements rectifying a voltage provided to the primary winding of the transformer, the second rectifying element comprising a
30 transistor having a first terminal connected to the second end of the secondary winding of the transformer and a second terminal connected to the reference voltage;

a first voltage clamping element having a first terminal connected to the first end of the secondary winding of the transformer and a second terminal, the first voltage clamping element comprising a Schottky diode;

5 a second voltage clamping element having a first terminal connected to the second end of the secondary winding of the transformer and a second terminal, the second voltage clamping element comprising a Schottky diode;

10 a first capacitive element having a first terminal coupled to the second terminal of the first and second voltage clamping elements and a second terminal connected to the reference voltage, the first capacitive element cooperates with the first and second voltage clamping elements to collect energy appearing at the first and
15 second ends of the secondary winding of the transformer so that a voltage appearing on each of the first and second ends of the secondary winding is clamped to a maximum voltage approximately equalling a voltage appearing across the first capacitive element;

20 an inductive element having a first end connected to the secondary winding and a second end comprising an output terminal of the rectifier circuit;

a second capacitive element having a first terminal connected to the second end of the inductive element and a
25 second terminal connected to the reference voltage; and characterized by further including control circuitry for driving a control terminal of the transistor of the first rectifying element and a control terminal of the transistor of the second rectifying element so as to switch the first
30 and second rectifying elements between conductive and non-conductive states based upon a voltage appearing across the first capacitive element.

According to another aspect of the invention there is provided a method of reducing unwanted voltage spikes appearing across a secondary winding of a transformer in a rectifier circuit having a first and second rectifying switch elements, comprising the steps of:

absorbing, by a first Schottky diode, the energy pertaining to a voltage spike appearing at a first end of the secondary winding of the transformer and storing the absorbed energy in a first capacitor within the rectifier circuit;

absorbing, by a second Schottky diode, the energy pertaining to a voltage spike appearing at a second end of the secondary winding of the transformer and storing the absorbed energy in the first capacitor; and characterized by

recycling the energy absorbed in the first capacitor for controlling an activation of the first and second rectifying switch elements.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the system and method of the present invention may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

Figure 1 is a schematic diagram of a conventional RC snubber circuit;

Figure 2 is a schematic diagram of a known active clamp circuit for a synchronous rectifier;

Figure 3 is a schematic diagram of a full wave rectifier circuit according to a preferred embodiment of the present invention;

5 Figures 4A and 4B illustrate voltage waveforms which are internal to the rectifiers of Figures 1 and 3, respectively;

Figures 5A-5H are a series of voltage waveforms illustrating the operation of the present invention shown in Figure 3;

5 Figure 6 is a schematic diagram of a full wave rectifier circuit according to a second preferred embodiment of the present invention;

Figure 7 is a schematic diagram of a half wave rectifier circuit according to a third preferred embodiment of the present invention;

10 Figure 8 is a schematic diagram of a full wave diode rectifier according to a fourth preferred embodiment of the present invention;

Figure 9 is a schematic diagram of a half wave diode rectifier according to a fifth preferred embodiment of the present invention; and

15

Figure 10 is a schematic diagram of a full wave rectifier according to a sixth preferred embodiment of the present invention.

20 **DETAILED DESCRIPTION**

The present invention will now be described more fully hereinafter with reference to the accompanying drawings in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be

25 construed as being limited to the embodiments set forth herein. Rather, the embodiments are is provided so

that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

Referring to Figure 3, there is shown a rectifier circuit 1 according to a preferred embodiment of the present invention as part of a power supply. Rectifier circuit 1 of Figure 3 is a full wave synchronous rectifier circuit including transformer 2 having primary side or winding 3 and secondary side or winding 4, and transistor switch 5 having a first terminal connected to a first end of secondary winding 4 and a second terminal connected to a ground reference. Rectifier circuit 1 further includes a second transistor switch 6 having a first terminal connected to a second end of secondary winding 4 and a second terminal connected to the ground reference. Although transistor switches 5 and 6 are implemented in Figure 3 as field-effect transistors and particularly n-channel field-effect transistors, it is understood that switches 5 and 6 may be implemented as other transistors and/or switching elements.

Rectifier circuit 1 further includes inductor 7 having a first terminal connected to secondary winding 4 and a second terminal connected to a first plate of capacitor 8. The second plate of capacitor 8 is tied to the ground reference. The output of the power

supply is a substantially DC voltage signal V_{out} , shown in Figure 3.

Rectifier circuit 1 further includes control circuitry 9, having outputs which drive the control (gate) terminals of transistor switches 5 and 6. Control circuitry 9 includes, among other inputs, a control signal $V_{control}$ which is based upon the voltage appearing across transformer 2. As a result, transistor switches 5 and 6 are selectively switched between conductive and non-conductive states, i.e., turned on and off, in synchronicity with the voltage appearing across transformer 2.

In rectifier circuit 1, parasitic devices may be present which adversely impact the performance of rectifier circuit 1. In particular, transformer 2 may include leakage inductances L formed at the ends of the secondary side 4 thereof. Further, transistor switches 5 and 6 may each include a parasitic capacitance C appearing between the drain and source terminals thereof. It has been observed that, due to the presence of parasitic leakage inductances L and parasitic capacitances C , a relatively sizeable voltage spike and high frequency ringing appear at transistor switches 5 and 6 when switches 5 and 6 are individually turned off. To eliminate this parasitic effect, the present invention preferably includes clamping diodes 10 and 11 having their respective anode terminals tied

to the first end and second end of the secondary side 4 of transformer 2, respectively, and having their cathode terminals tied to a first plate of capacitor 12.

5 Clamping diodes 10 and 11 are preferably Schottky diodes in order to provide a small forward bias. Capacitor 12 is preferably relatively large sized such that the energy stemming from the voltage spikes and high frequency oscillations appearing at the ends of
10 the secondary side 4 of transformer 2 are absorbed by capacitor 12. The voltage appearing across capacitor 12 is substantially a DC voltage having a voltage amplitude V_c approximately represented by

$$V_c = (N_2/N_1) * V_{in},$$

15 where N_1 is the number of turns in the primary winding 3 of transformer 2, N_2 is the number of turns in the secondary winding 4 of transformer 2, and V_{in} is the input voltage appearing at the primary side 3 of transformer 2.

20 Figures 4A and 4B illustrate the ability of the present rectifier circuit 1 to clamp voltages so as to eliminate excessive voltage spikes and ringing effects. Figure 4A shows the voltage appearing across a transistor switch 5 or 6 when an RC snubber circuit is
25 employed in the power supply, and Figure 4B shows the voltage appearing across a transistor switch 5 or 6

with the present rectifier circuit 1 is employed in the power supply.

In addition to capacitor 12 and clamping diodes 10 and 11 acting to clamp excessive voltages appearing at either end of the secondary winding 4 of transformer 2, capacitor 12 and clamping diodes 10 and 11 also recycle the energy absorbed by capacitor 12 to control the operation of transistor switches 5 and 6. The voltage appearing across capacitor 12 is applied to control circuitry 9. Control circuitry 9 receives the digital control signal $V_{control}$ and generates output signals for driving the gate terminals of transistor switches 5 and 6. The amplitude of the output signals of control circuit 9 is preferably based upon the voltage appearing across capacitor 12. In this way, the energy absorbed by capacitor 12 through diodes 10 and 11 are cycled back through rectifier circuit 1 so as to prevent instability.

Figures 5A-5H illustrate the operation of rectifier circuit 1 according to the present invention. Figure 5A shows the input signal V_{in} applied to the primary side 3 of transformer 2. On the secondary side, with suitable rectification, the voltage appearing at the top end of secondary winding 4 is shown in Figure 5B, and the voltage appearing at the bottom end of secondary winding 4 is shown in Figure 5C. Illustrated in dashed lines in Figures 5B and 5C

are the voltage spike and high frequency ringing effect seen in conventional designs which are substantially eliminated in the present invention. The energy from the voltage spike and high frequency ringing is absorbed through diodes 10 and 11 and collected in capacitor 12 as a substantially DC voltage (Figure 5D). The voltage across capacitor 12 (and hence the energy absorbed from the voltage spikes and high frequency ringing) is recycled through control circuit 9 to drive the gate terminals of transistor switches 5 and 6. The amplitude of the gate drive signals, shown in Figures 5E and 5F, is based upon the voltage across capacitor 12. As can be seen, transistor switch 5 is turned on primarily during the positive phase of input voltage V_{in} (Figure 5A) and transistor switch 6 is turned on primarily during the negative phase thereof. The voltage and current waveforms of inductor 7 are shown in Figures 5G and 5H, respectively. Noting that the amplitude of the current levels in Figure 5H is small relative to the voltage across output capacitor 8, the output of rectifier circuit 1 is substantially a DC voltage waveform.

It is understood that the present invention may be implemented in a number of ways. First, the present rectifier circuit 1 may include a resistor 13 disposed between the cathodes of diodes 10 and 11 the upper plate of capacitor 12 (Figure 6). The presence of

resistor 13 reduces surge current charging capacitor 12 during initial turn-on of transformer 2.

Further, the present rectifier circuit 1 may be implemented as a half wave synchronous rectifier circuit 1A. As shown in Figure 7, clamping diodes 10A and 11A are connected between capacitor 12A and the upper and lower ends of the second windings of transformer 2A, respectively. Diode 10A, diode 11A and capacitor 12A clamp the signals appearing on the secondary winding of transformer 2A in the same way as the embodiment of Figure 3. The energy absorbed by capacitor 12A is recycled to drive transistor switches 5A and 6A as described above. Consequently, rectifier circuit 1A provides suitable conversion without the adverse effects of voltage spikes and high frequency ringing.

The present invention may be implemented as a full wave diode rectifier. As shown in Figure 8, rectifier 1B includes Schottky diodes 14 and 15 each having their anode terminal connected to the top and bottom end of transformer 2C, respectively. Clamping diodes 10C and 11C are connected to the secondary windings of transformer 2C and to capacitor 12C so as to absorb the energy generated from parasitic components for collection at capacitor 12C. Noting that since Schottky diodes 14 and 15 are utilized in rectifier circuit 1B, the energy absorbed by diodes 10C and 11C

and capacitor 12C is not recycled as in the case of the synchronous rectifiers of Figures 3, 6 and 7. The energy collected by capacitor 12C is dissipated by control circuit 9C in order to ensure the voltage across capacitor 12C maintains its relationship with the transformer input voltage V_{in} as specified above.

Still further, the present invention may be implemented as a half wave diode rectifier 1D which employs Schottky diodes 16 and 17. As shown in Figure 9, rectifier 1D includes Schottky diodes 10D and 11D having an anode terminal connected to the top and bottom ends of the secondary winding of transformer 2D, respectively, and capacitor 12D which is connected to the cathode terminal of diodes 10D and 11D. Diode 10D, diode 11D and capacitor 12D absorb the energy generated by parasitic inductances and parasitic capacitances in rectifier 1D so as to substantially eliminate voltage spikes and high frequency ringing therein.

The present invention may also be implemented in a full wave rectifier 1E which only partially clamps excessive voltage spikes and ringing therein. As shown in Figure 10, synchronous rectifier 1E includes transistor switches 5E and 6E which are connected to the top and bottom ends of the secondary windings of transformer 2E; control circuit 9E which switches transistor switches 5E and 6E between conductive and non-conductive states; and Schottky diodes 10E and 11E

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having an anode terminal connected to central portions
of the secondary winding of transformer 2E and a
cathode terminal connected to capacitor 12E. The
voltage across capacitor 12E is an input to control
5 circuit 9E so as to recycle energy absorbed thereby via
diodes 10E and 11E. Because diodes 10E and 11E are
tapped from a middle portion of the secondary winding
of transformer 2E, voltage spikes and high frequency
ringing are not clamped as well as in the rectifier
10 circuit 1 of Figure 3. However, the bias voltage
across capacitor 12E of rectifier 1E is advantageously
lowered.

The invention being thus described, it will be
obvious that the same may be varied in many ways. Such
15 variations are not to be regarded as a departure from
the invention, and all such modifications as would be
obvious to one skilled in the art are intended to be
included within the scope of the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A rectifier circuit, including:

a transformer having a primary winding and a secondary winding;

a first rectifying element having a first terminal connected to a first end of the secondary winding of the transformer and a second terminal connected to a reference voltage, the first rectifying element comprising a transistor having a first terminal connected to the first end of the secondary winding of the transformer and a second terminal connected to the reference voltage;

a second rectifying element having a first terminal connected to a second end of the secondary winding of the transformer and a second terminal connected to the reference voltage, the first and second rectifying elements rectifying a voltage provided to the primary winding of the transformer, the second rectifying element comprising a transistor having a first terminal connected to the second end of the secondary winding of the transformer and a second terminal connected to the reference voltage;

a first voltage clamping element having a first terminal connected to the first end of the secondary winding of the transformer and a second terminal, the first voltage clamping element comprising a Schottky diode;

a second voltage clamping element having a first terminal connected to the second end of the secondary winding of the transformer and a second terminal, the second voltage clamping element comprising a Schottky diode;

a first capacitive element having a first terminal coupled to the second terminal of the first and second voltage clamping elements and a second terminal connected

to the reference voltage, the first capacitive element cooperates with the first and second voltage clamping elements to collect energy appearing at the first and second ends of the secondary winding of the transformer so that a voltage appearing on each of the first and second ends of the secondary winding is clamped to a maximum voltage approximately equalling a voltage appearing across the first capacitive element;

an inductive element having a first end connected to the secondary winding and a second end comprising an output terminal of the rectifier circuit;

a second capacitive element having a first terminal connected to the second end of the inductive element and a second terminal connected to the reference voltage; and characterized by further including control circuitry for driving a control terminal of the transistor of the first rectifying element and a control terminal of the transistor of the second rectifying element so as to switch the first and second rectifying elements between conductive and non-conductive states based upon a voltage appearing across the first capacitive element.

2. The rectifier circuit of claim 1, wherein:

the first capacitive element comprises a capacitor that is sized so that a substantially DC voltage appears across the first and second terminals thereof.

3. The rectifier circuit of claim 1, wherein:

the first voltage clamping element comprises an anode terminal connected to the first end of the secondary winding of the transformer and a cathode terminal connected to the first capacitive element.

4. The rectifier circuit of claim 1, wherein:

the second voltage clamping element comprises an anode terminal connected to the second end of the secondary winding of the transformer and a cathode terminal connected to the first capacitive element.

5. The rectifier circuit of claim 1, wherein:

the rectifier circuit comprises a synchronous rectifier.

6. The rectifier circuit of claim 5, wherein:

the transistor of the first rectifying element has a first drain/source terminal connected to the first end of the secondary winding of the transformer and a second drain/source terminal connected to the reference voltage; and

the transistor of the second rectifying element has a first drain/source terminal connected to the second end of the secondary winding of the transformer and a second drain/source terminal connected to the reference voltage.

7. The rectifier circuit of claim 1, wherein:

the control circuitry has as an input signal appearing across the first capacitive element such that an amplitude of a signal driving the control terminal of the first rectifying element and a signal driving the control terminal of the second rectifying element are based upon the voltage appearing across the first capacitive element.

8. A method of reducing unwanted voltage spikes appearing across a secondary winding of a transformer in a rectifier circuit having a first and second rectifying switch elements, comprising the steps of:

absorbing, by a first Schottky diode, the energy pertaining to a voltage spike appearing at a first end of the secondary winding of the transformer and storing the absorbed energy in a first capacitor within the rectifier circuit;

absorbing, by a second Schottky diode, the energy pertaining to a voltage spike appearing at a second end of the secondary winding of the transformer and storing the absorbed energy in the first capacitor; and characterized by

recycling the energy absorbed in the first capacitor for controlling an activation of the first and second rectifying switch elements.

9. The method of claim 8, wherein the step of recycling comprises the steps of:

generating a first control signal for switching the first rectifying switch element between a conductive state and a non-conductive state based upon the energy stored in the first capacitor; and

generating a second control signal for switching the second rectifying switch element between a conductive state and a non-conductive state based upon the energy stored in the first capacitor.

10. The rectifier circuit of claim 1, further comprising:

a resistor connected between the first terminal of the first capacitive element and the second terminal of the first and second voltage clamping elements.

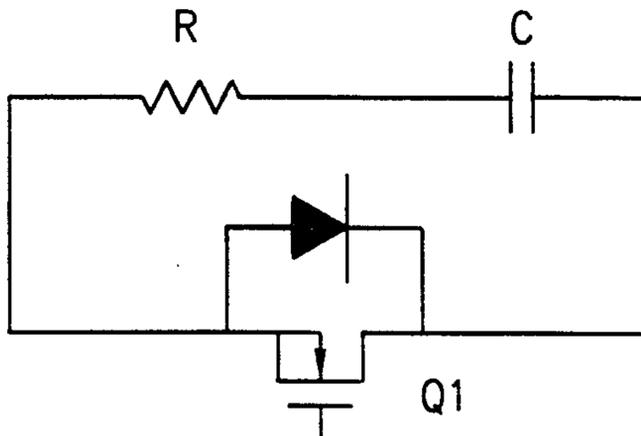


FIG. 1
(PRIOR ART)

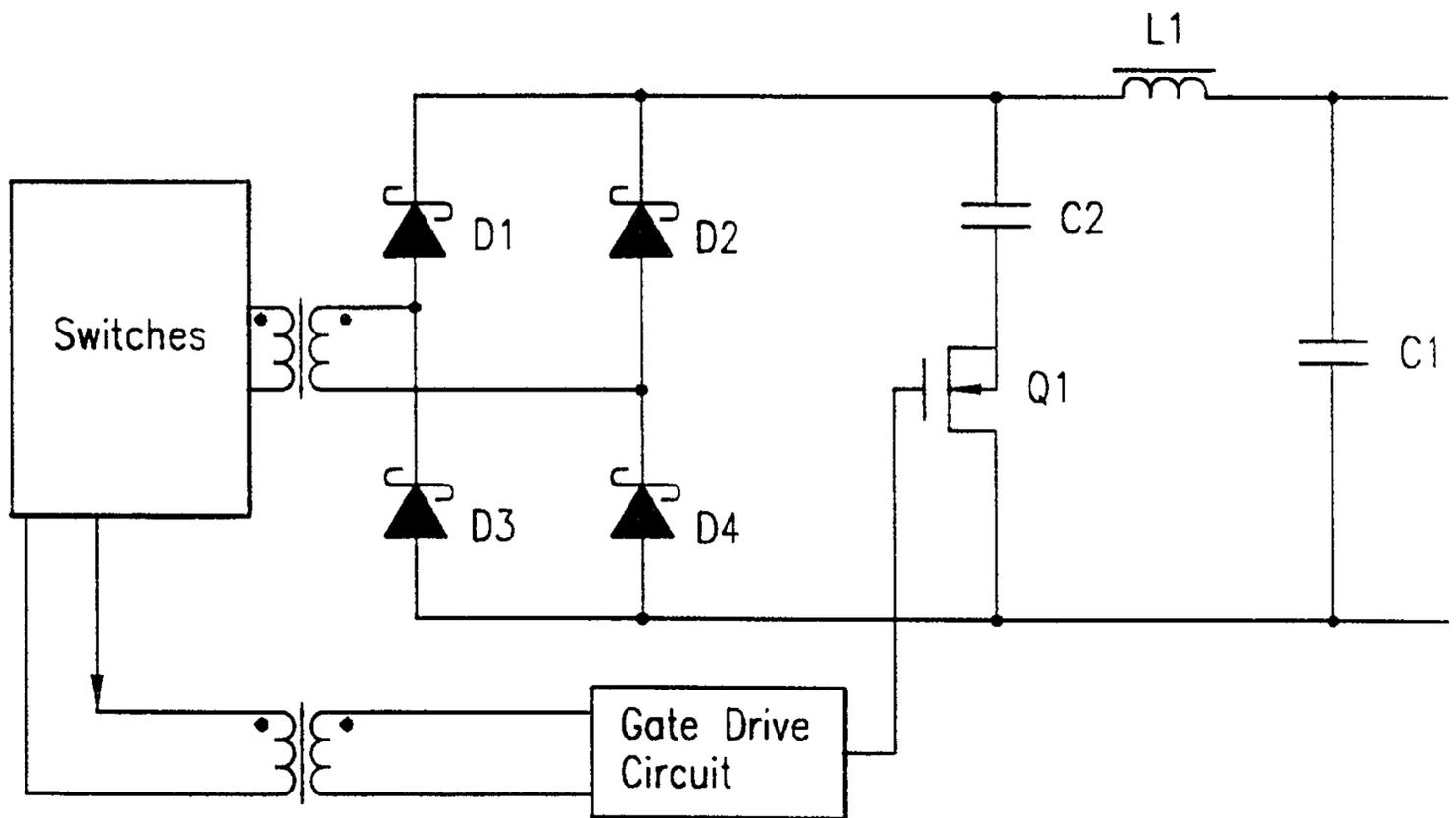


FIG. 2
(PRIOR ART)

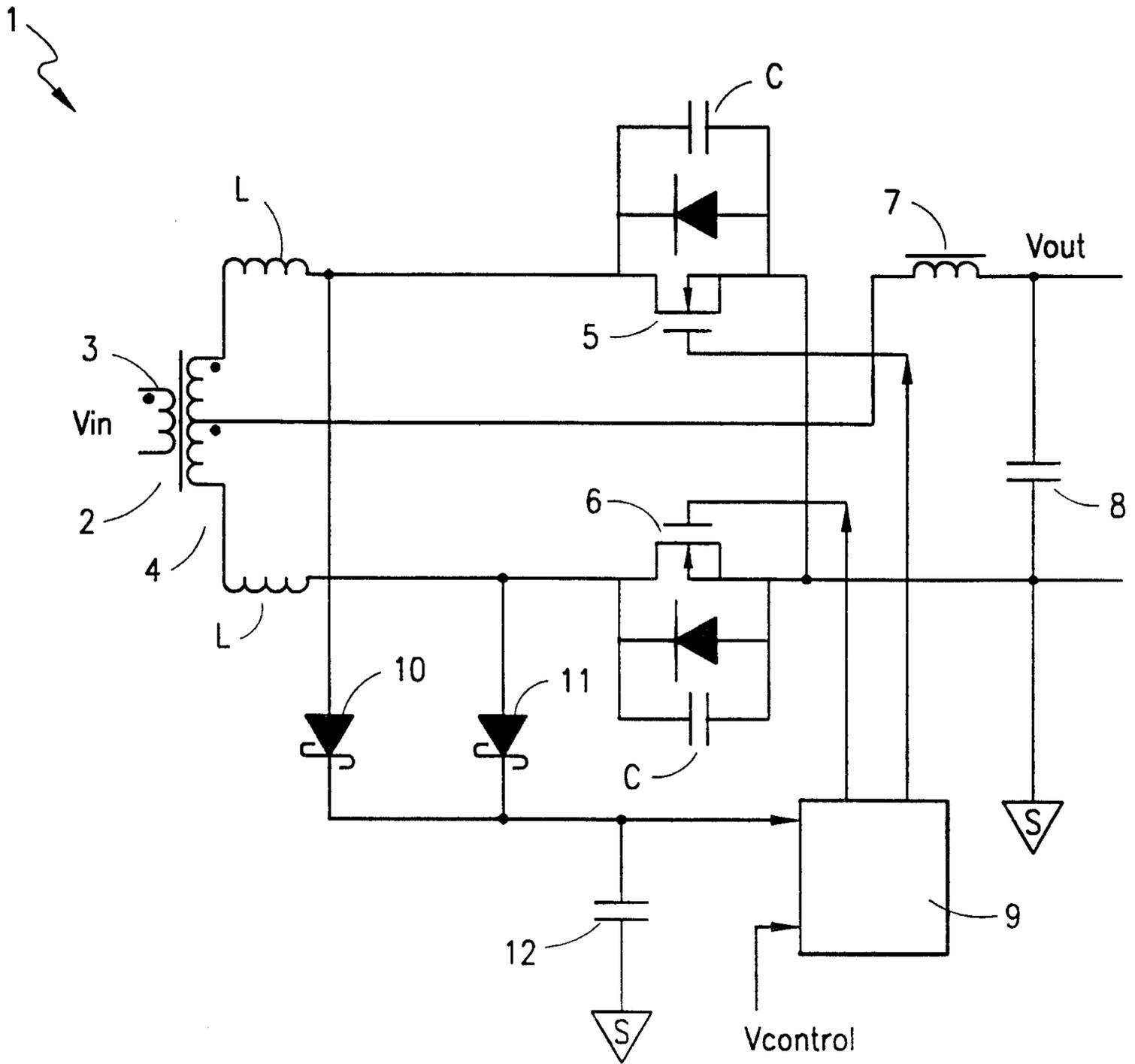


FIG. 3

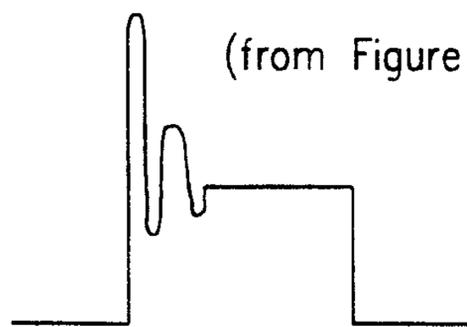


FIG. 4A

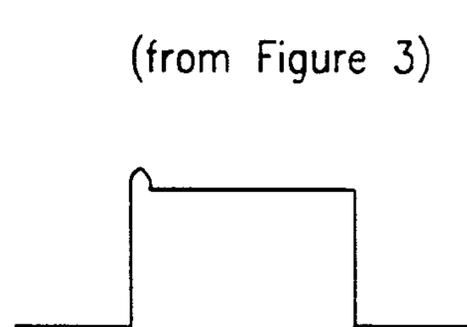


FIG. 4B

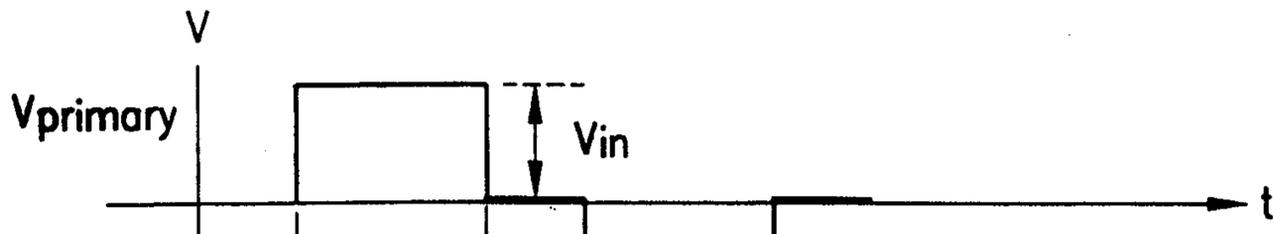


FIG. 5A

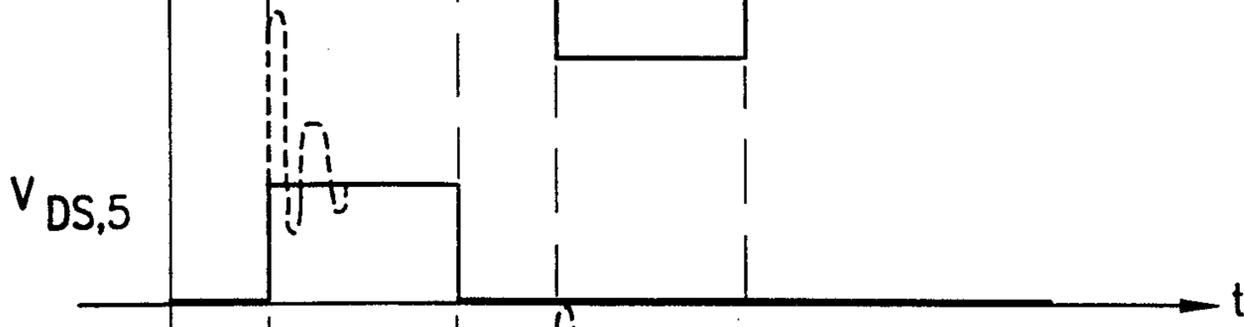


FIG. 5B

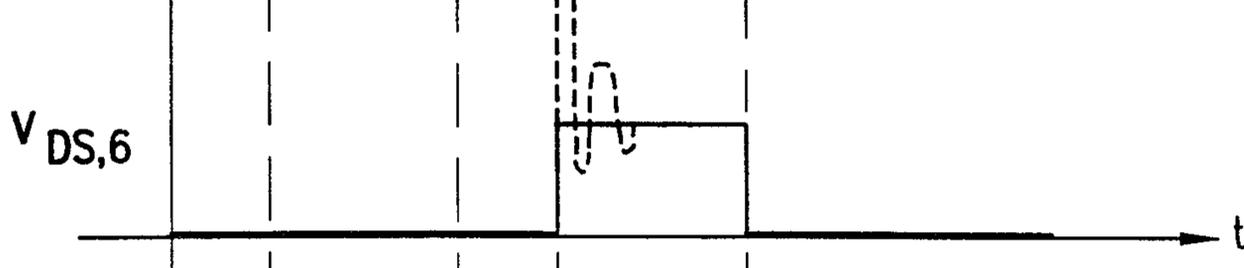


FIG. 5C

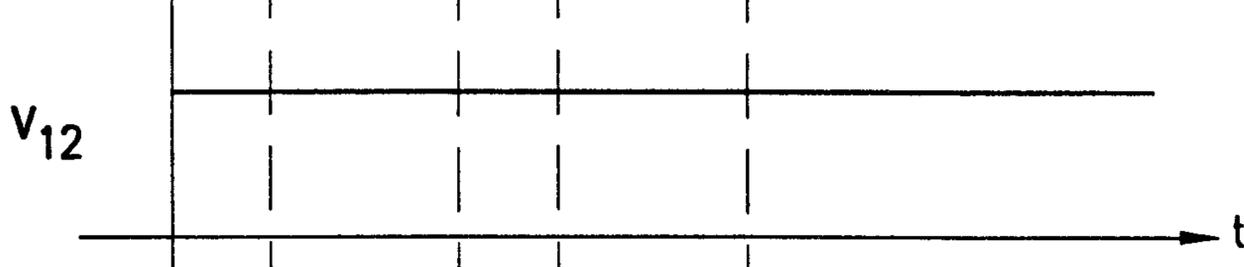


FIG. 5D



FIG. 5E

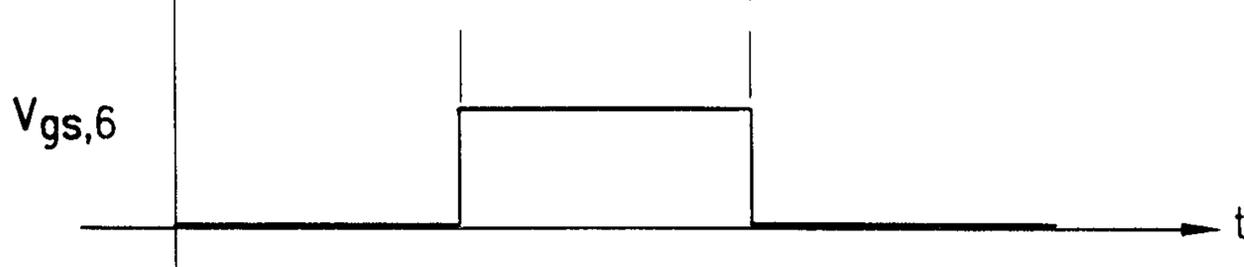


FIG. 5F

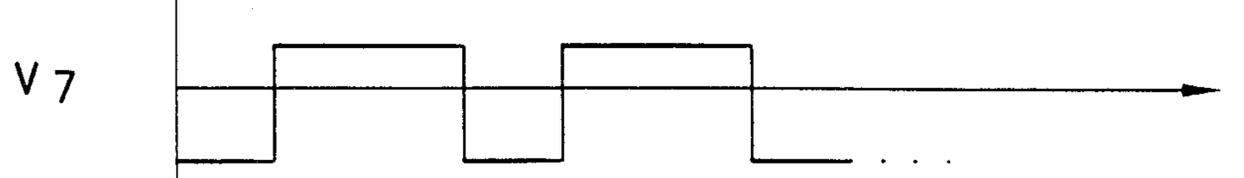


FIG. 5G

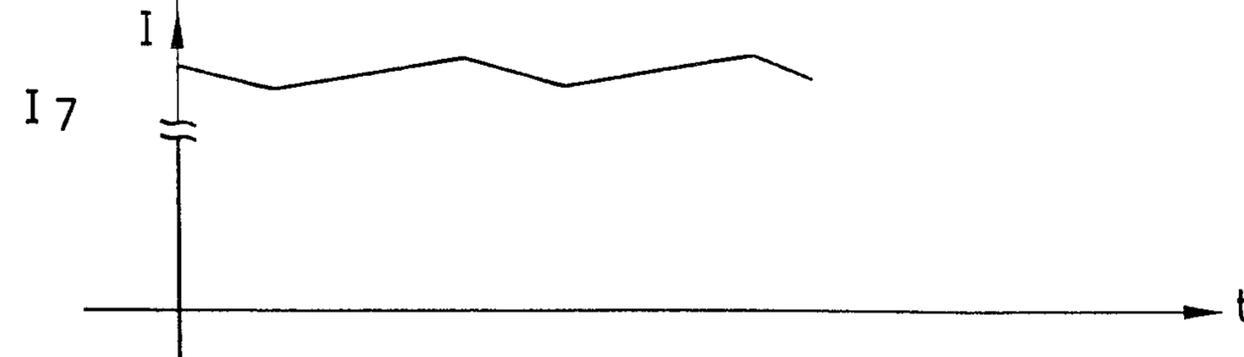


FIG. 5H

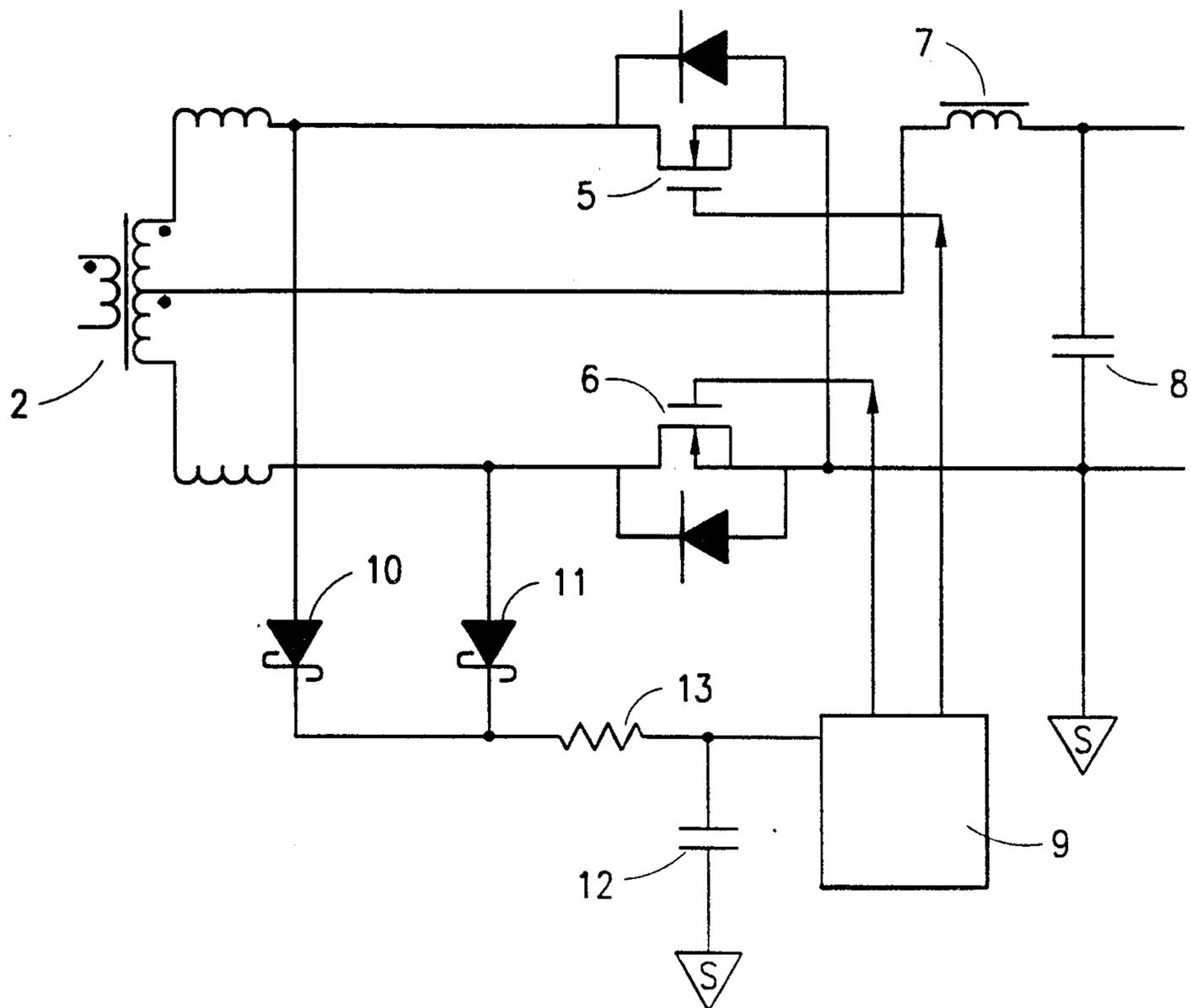


FIG. 6

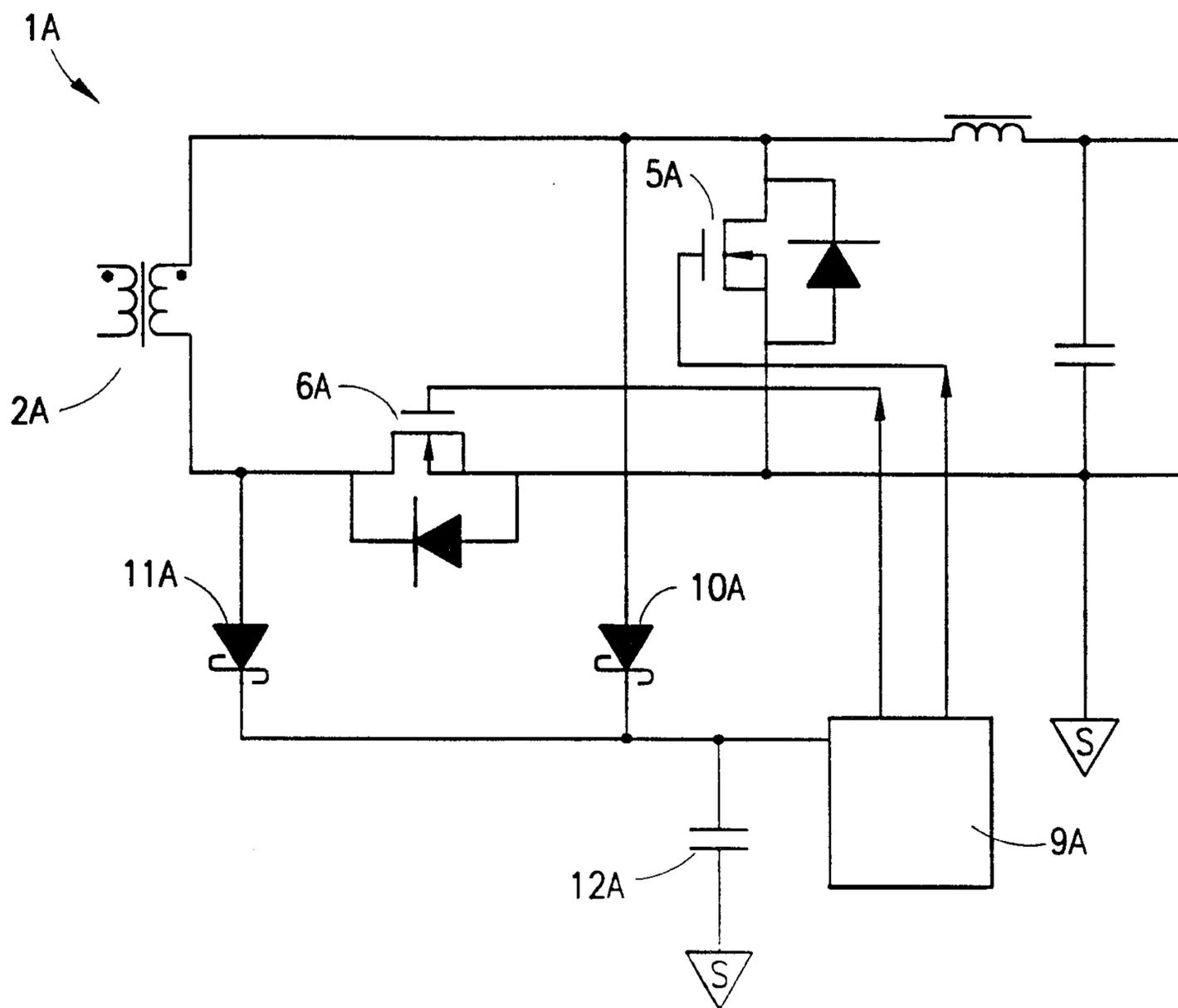


FIG. 7

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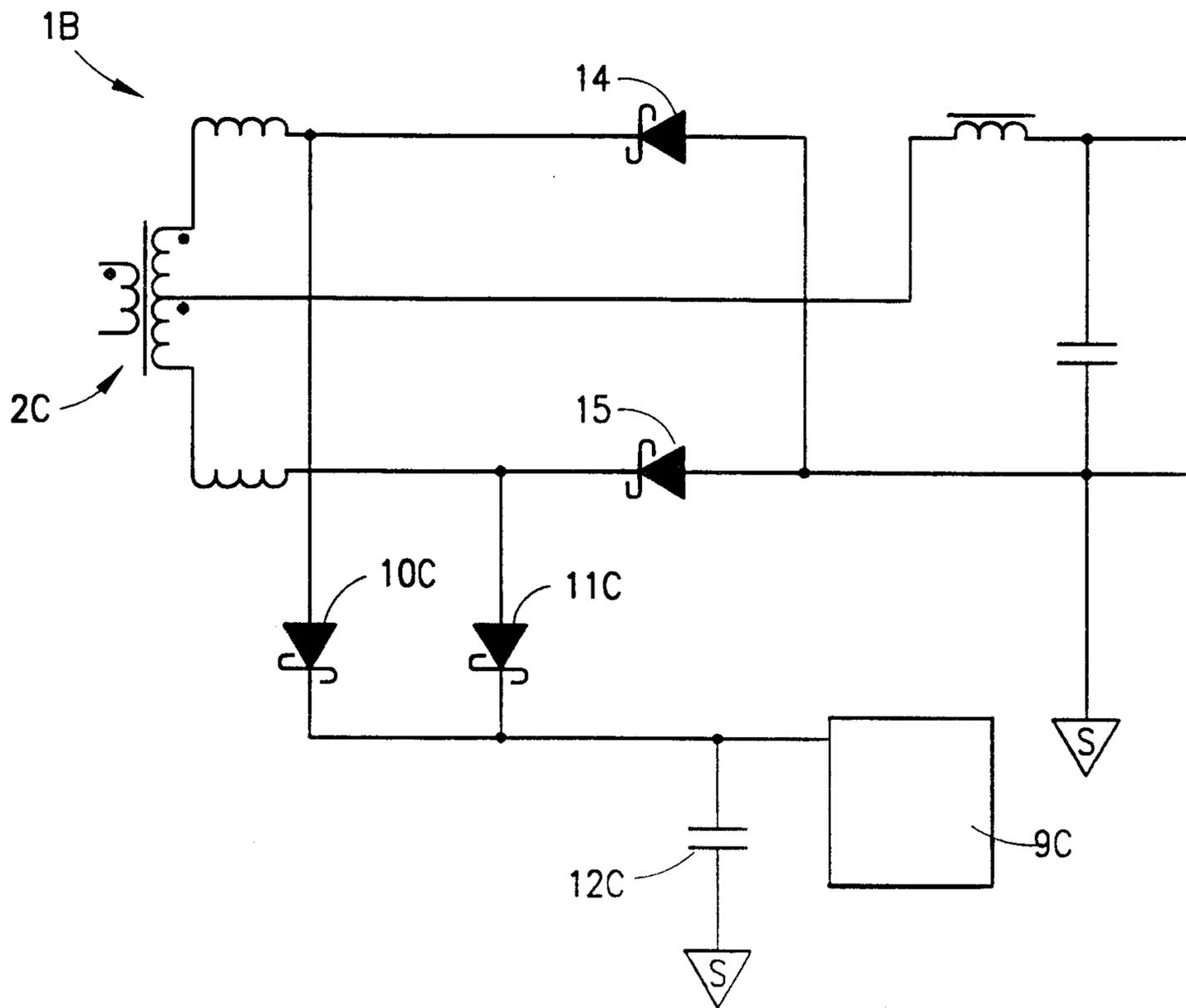


FIG. 8

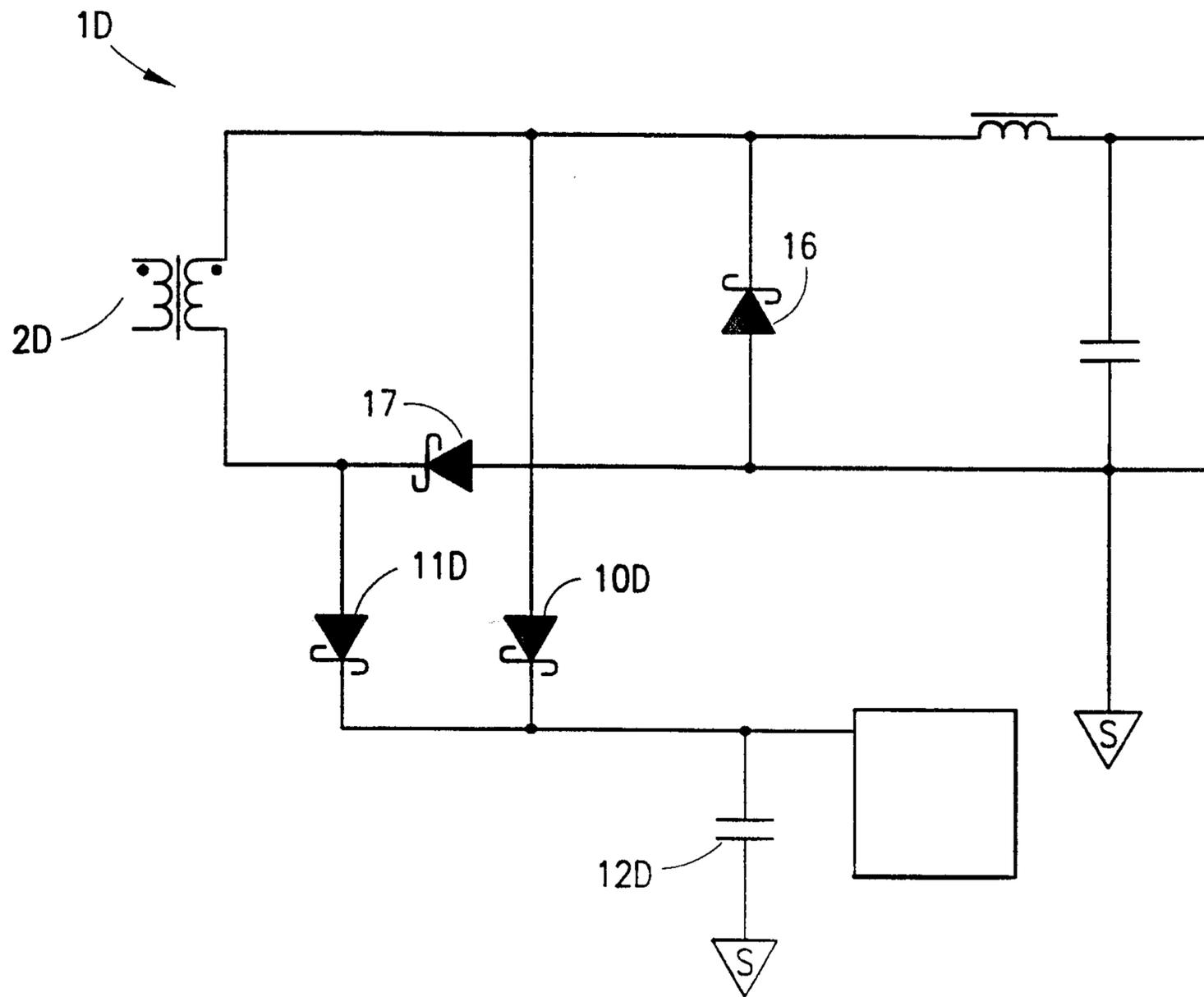
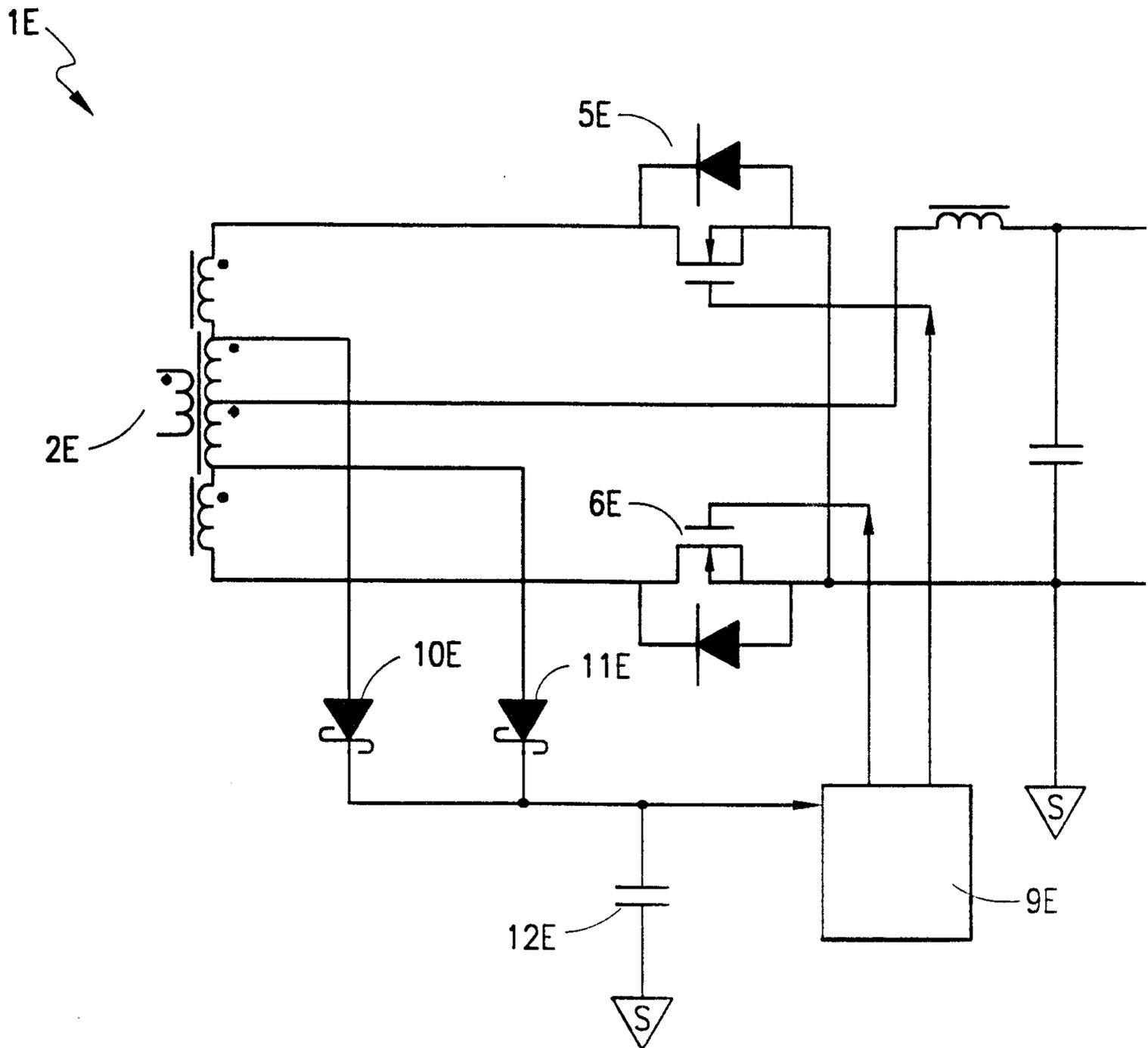


FIG. 9

*FIG. 10*

