US00RE40072E

(19) **United States**

(12) **Reissued Patent**

Prager et al.

(10) **Patent Number: US RE40,072 E**

(45) **Date of Reissued Patent: Feb. 19, 2008**

(54) **LOSS AND NOISE REDUCTION IN POWER CONVERTERS**

(75) Inventors: **Jay Prager**, Groton, MA (US); **Patrizio Vinciarelli**, Boston, MA (US)

(73) Assignee: **VLT Corporation**, San Antonio, TX (US)

(21) Appl. No.: **11/062,350**

(22) Filed: **Feb. 18, 2005**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **6,522,108**
Issued: **Feb. 18, 2003**
Appl. No.: **09/834,750**
Filed: **Apr. 13, 2001**

(51) **Int. Cl.**
G05F 1/56 (2006.01)

(52) **U.S. Cl.** **323/222**

(58) **Field of Classification Search** 323/220, 323/222, 282; 363/39, 50, 59, 60
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,119,972	A	1/1964	Fischman	
3,259,829	A	7/1966	Feth	
3,529,228	A	9/1970	Cordy, Jr.	
3,543,130	A	11/1970	Reijnders	
3,582,754	A	6/1971	Hoffmann	
3,621,362	A	11/1971	Schwarz	
3,663,940	A	5/1972	Schwarz	
3,953,779	A	4/1976	Schwarz	
4,007,413	A	2/1977	Fisher et al.	
4,017,784	A	4/1977	Simmons et al.	
4,024,453	A	5/1977	Corry	
4,138,715	A	2/1979	Miller	
4,158,881	A	6/1979	Simmons et al.	
4,318,164	A	3/1982	Onodera et al.	
4,415,959	A	11/1983	Vinciarelli	
5,229,707	A	7/1993	Szepesi et al.	323/222
5,477,131	A	12/1995	Gegner	
5,568,041	A	10/1996	Hesterman	323/907
5,841,268	A	11/1998	Mednik	323/222
5,880,940	A	3/1999	Poon	
5,977,754	A	11/1999	Cross	323/222
6,051,963	A *	4/2000	Eagar	323/282

FOREIGN PATENT DOCUMENTS

DE	2218055	10/1973
DE	2756799	6/1978
DE	2756773	7/1978
JP	6-36384	5/1994
JP	11-127575	5/1999

OTHER PUBLICATIONS

EPO Communication, Mar. 3, 2005 Rejection.
JPO Communication, Mar. 15, 2005 Allowance.
EPO Communication, Aug. 18, 2005, Reversal of Rejection of Mar. 3, 2005.
EPO Communication, Jan. 13, 2006, Allowance including claim amendments (pp. 17, 19).
Maruhashi et al., "A High Power Switching Regulator System Driven By High–Frequency Resonant Thyristor Chopper Circuit," Memoirs of the Faculty of Engineering, Kobe University, No. 22, pp. 99–111, Mar. 1976.

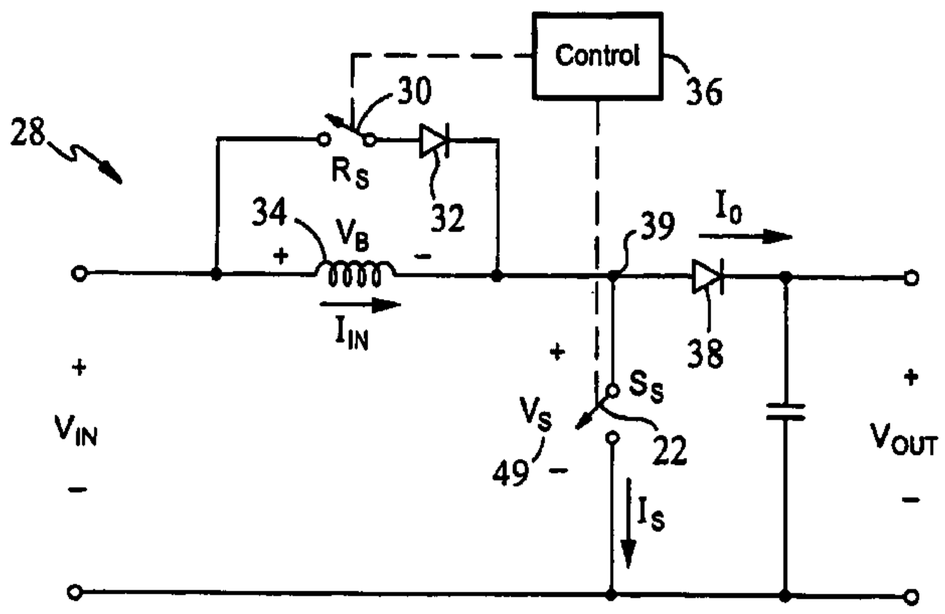
* cited by examiner

Primary Examiner—Adolf Berhane
(74) *Attorney, Agent, or Firm*—Fish & Richardson P.C.

(57) **ABSTRACT**

An apparatus includes (a) switching power conversion circuitry including an inductive element connected to deliver energy via a unidirectional conducting device from an input source to a load during a succession of power conversion cycles, and circuit capacitance that can resonate with the inductive element during a portion of the power conversion cycles to cause a parasitic oscillation, and (b) clamp circuitry connected to trap energy in the inductive element and reduce the parasitic oscillation.

35 Claims, 6 Drawing Sheets



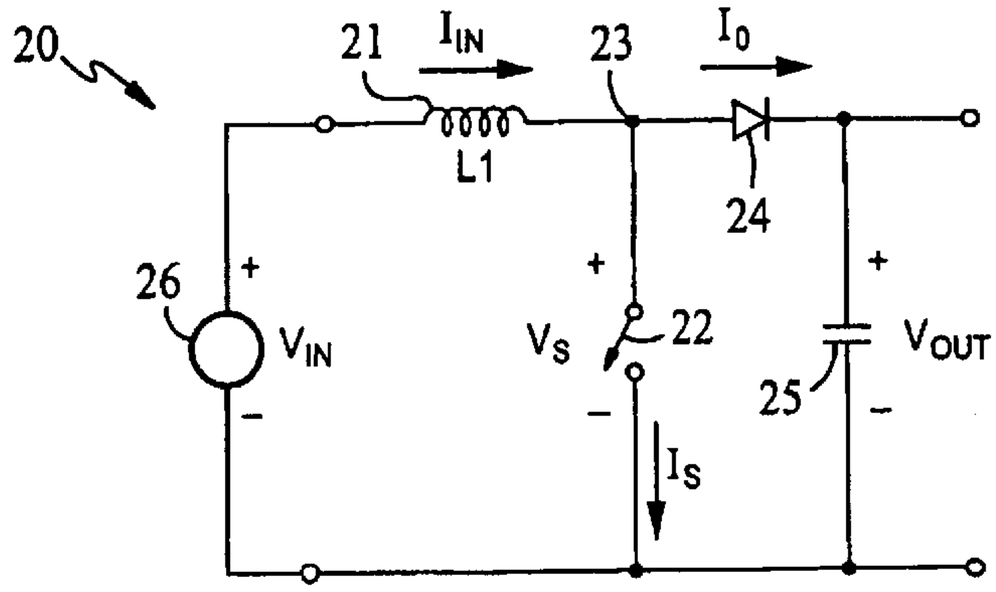


FIG. 1

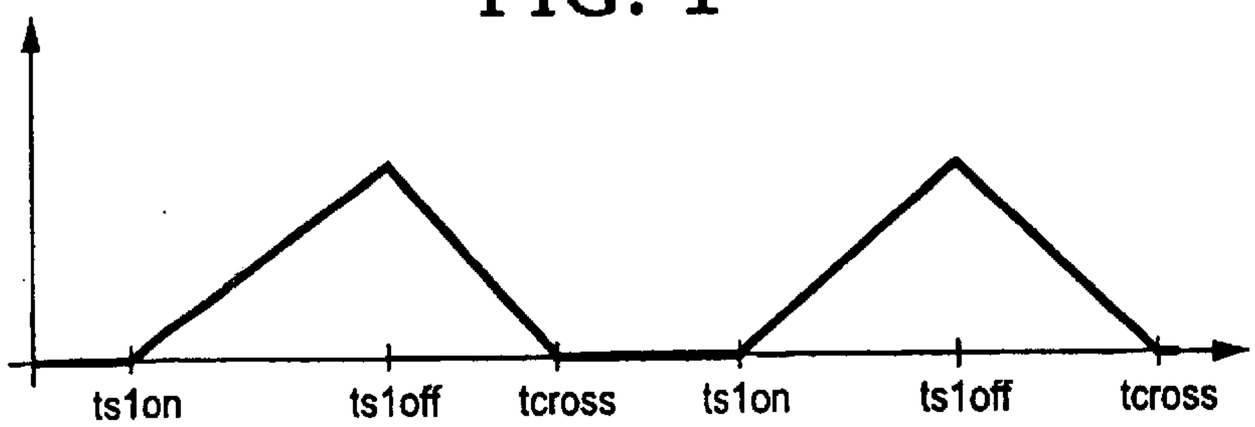


FIG. 2A

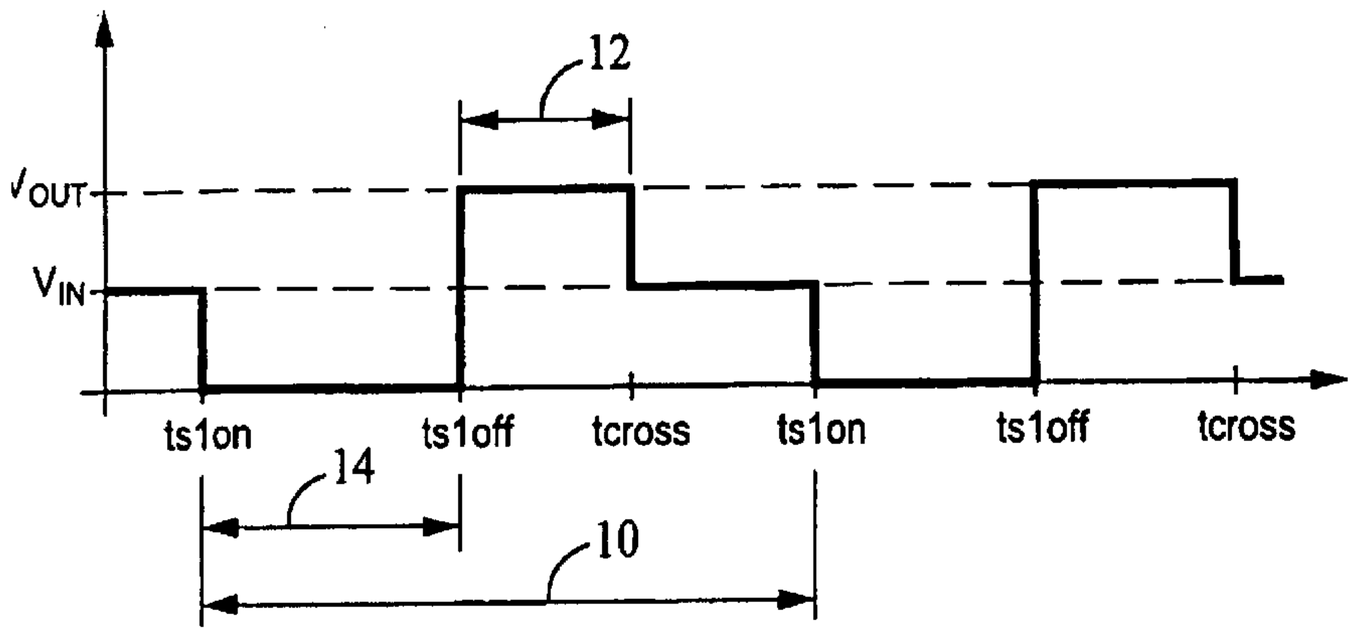


FIG. 2B

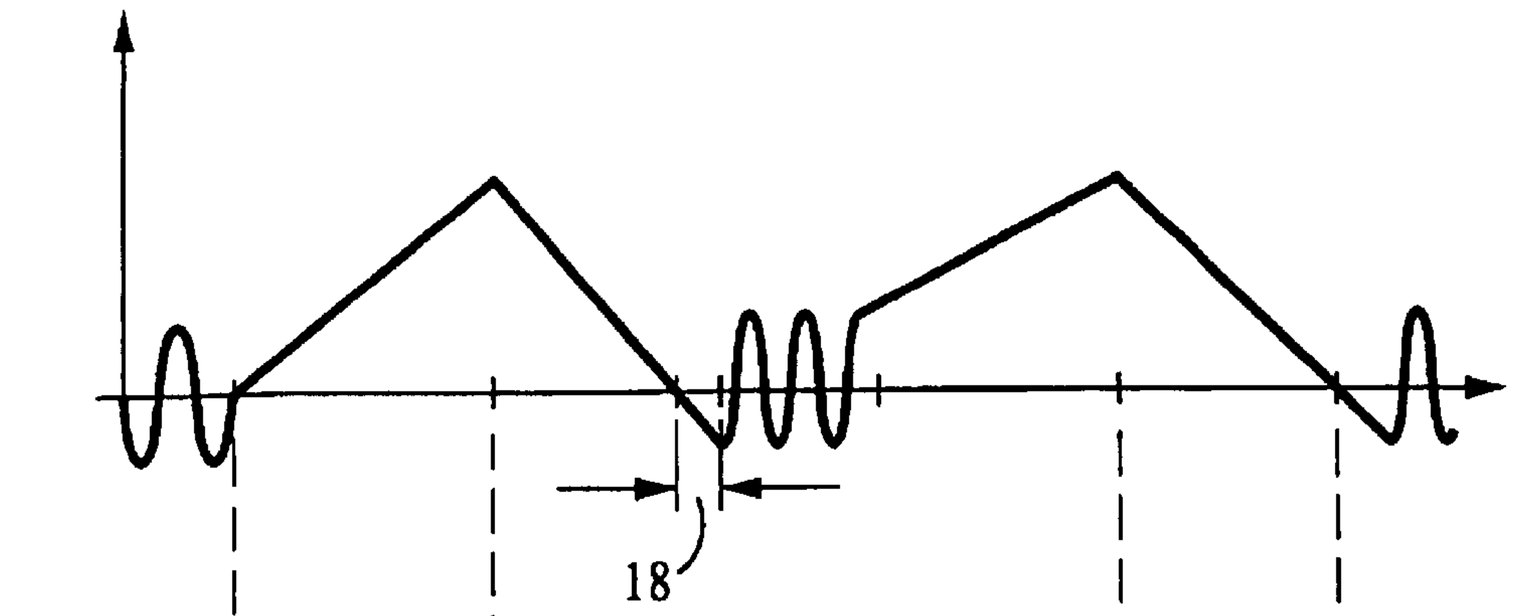

18

FIG. 2C

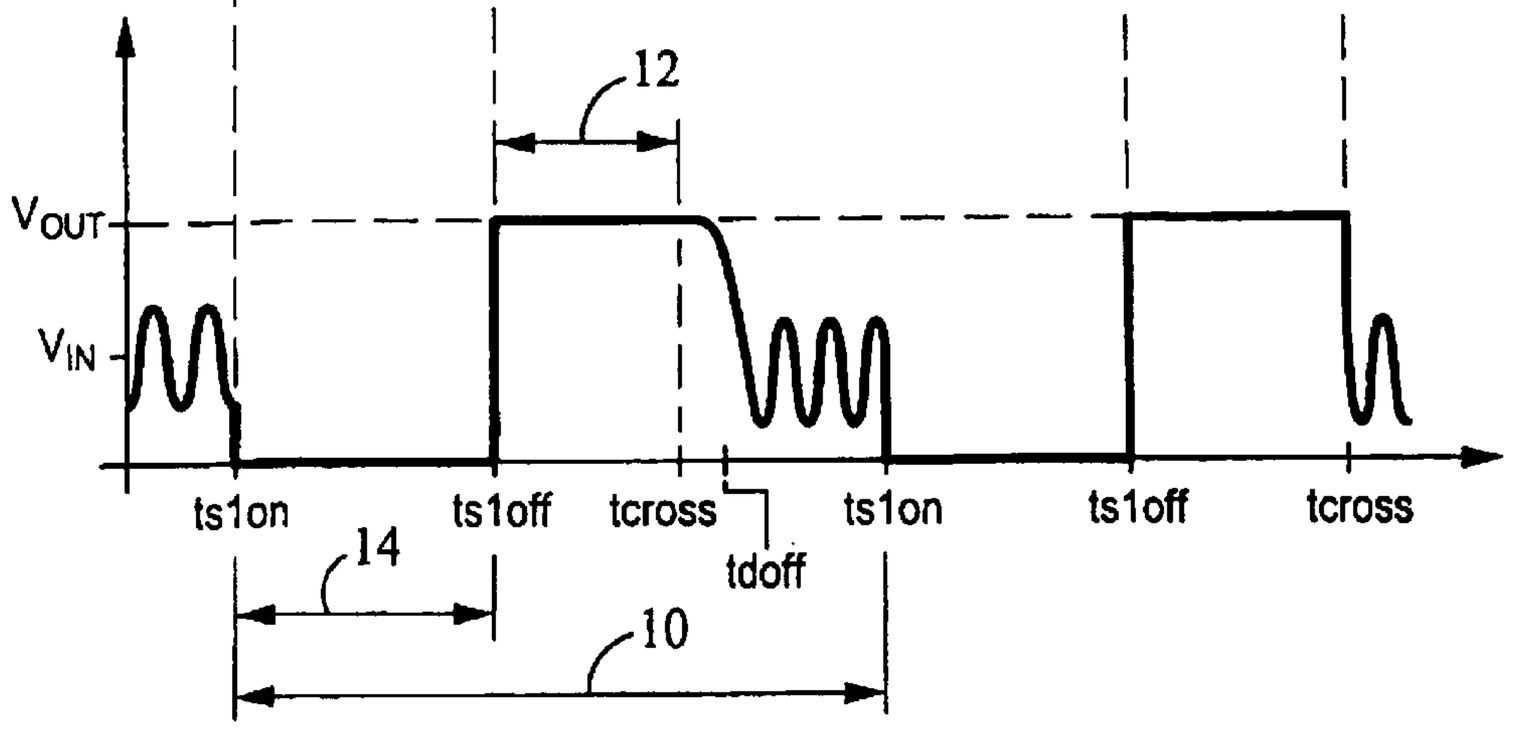

12
VOUT
VIN
ts1on
ts1off
tcross
tdoff
ts1on
ts1off
tcross
14
10

FIG. 2D

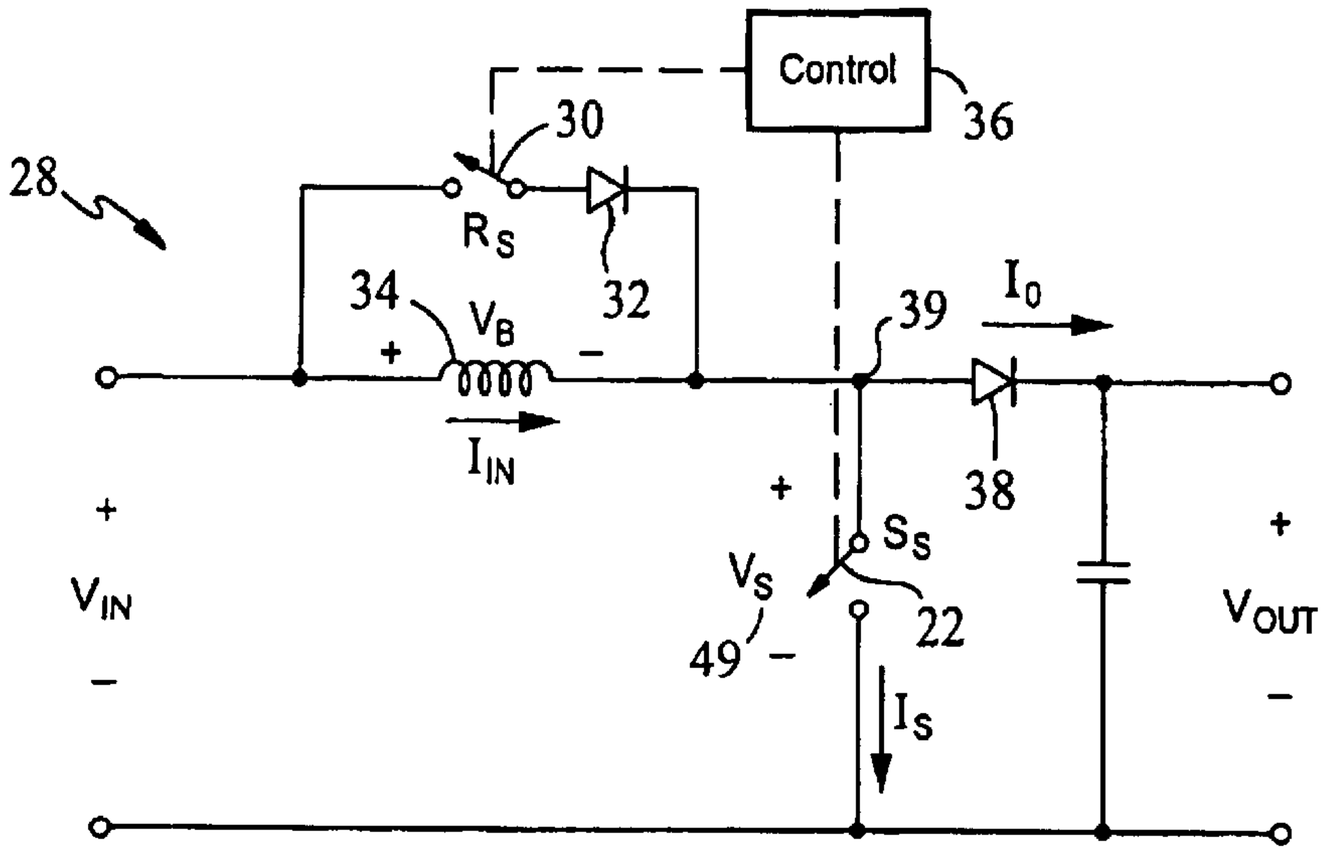

Control
36
30
28
R_S
34
V_B
32
39
I_0
I_{IN}
38
+
V_{IN}
−
+
S_S
V_S
49
−
22
I_S
+
V_{OUT}
−

FIG. 3

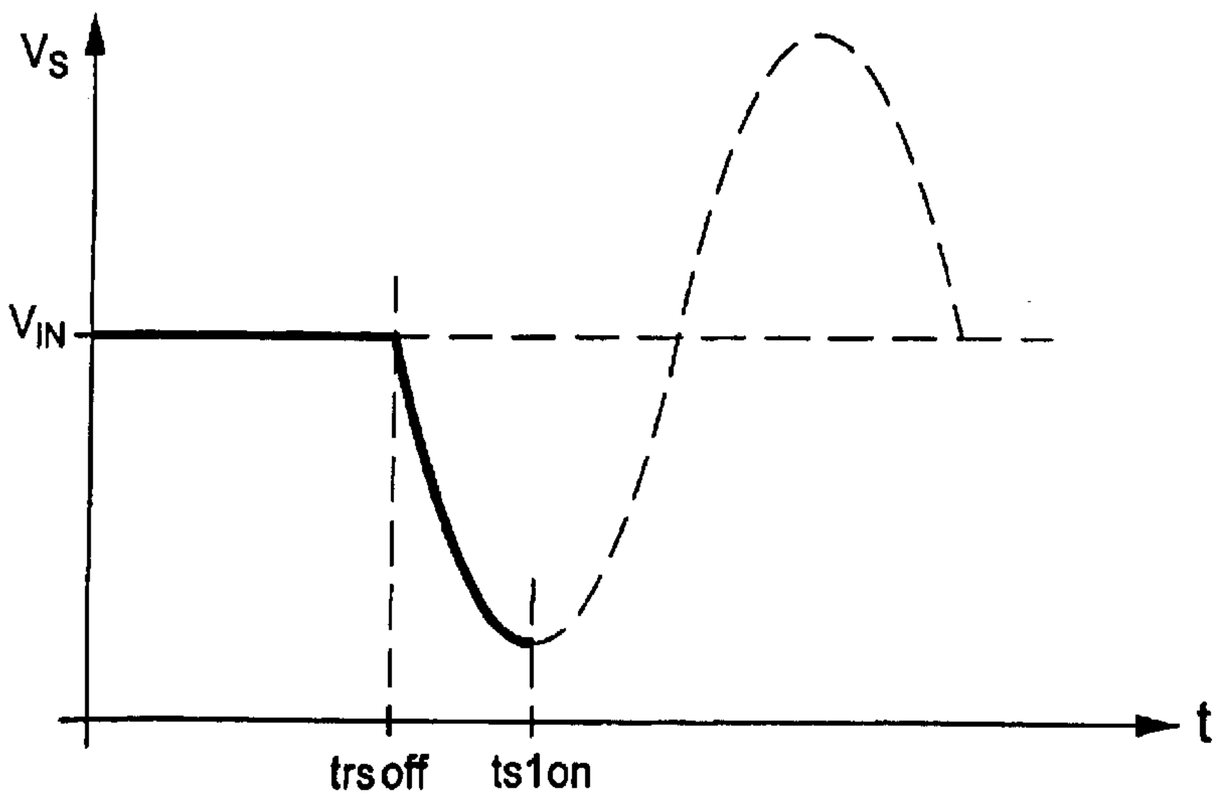

V_S
V_{IN}
t
trsoff
ts1on

FIG. 4

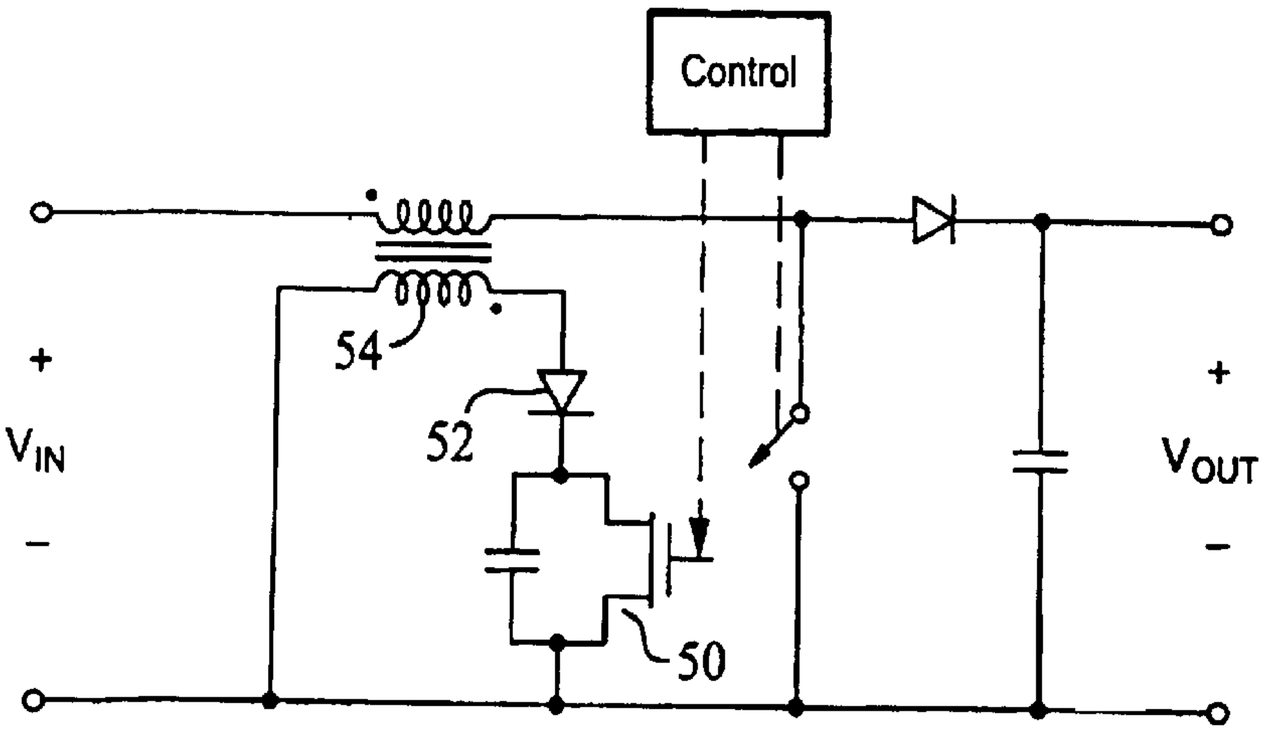

Control
54
52
50
+
V_{IN}
–
+
V_{OUT}
–

FIG. 5

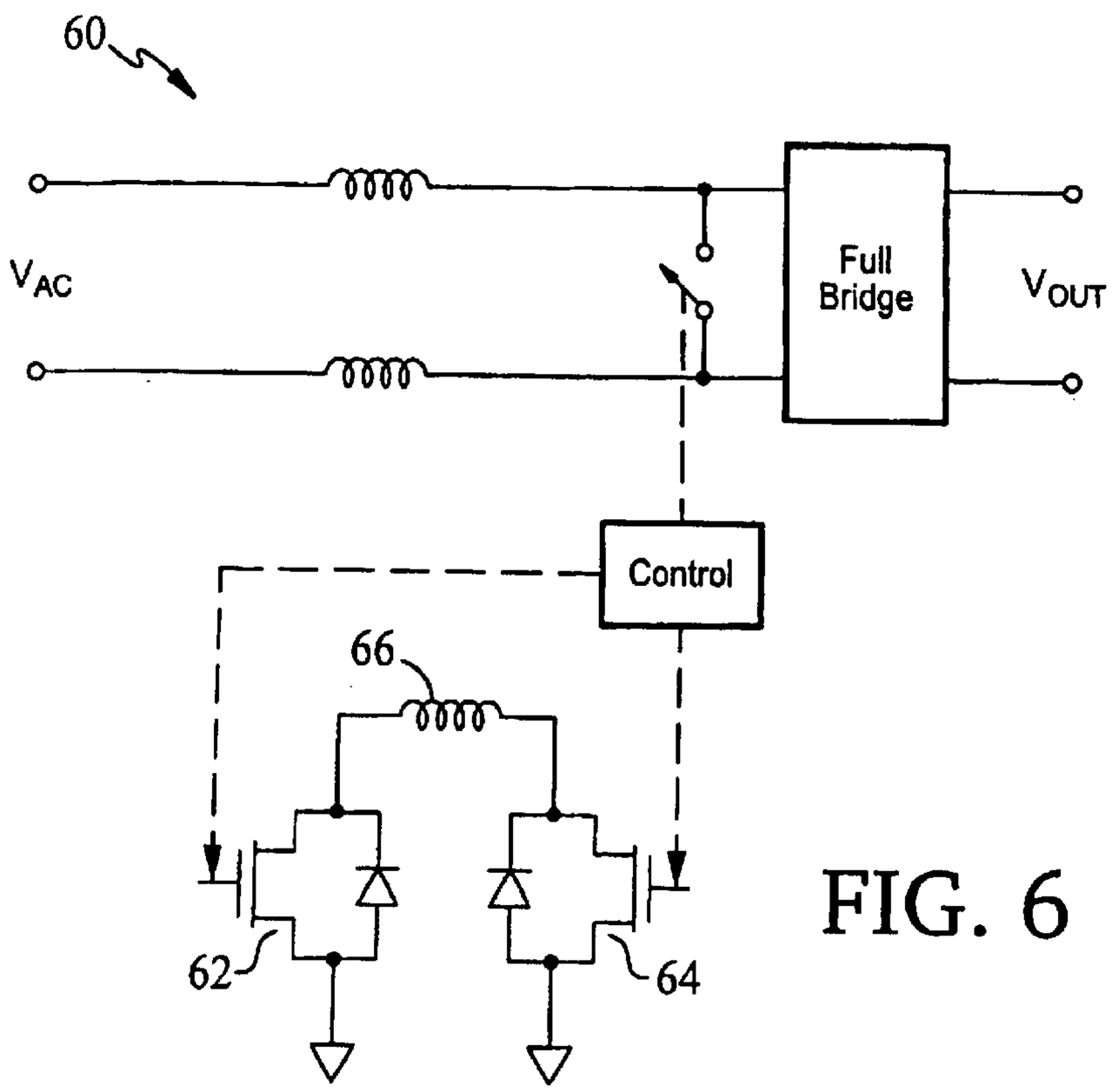

60
V_{AC}
Full Bridge
V_{OUT}
Control
66
62
64

FIG. 6

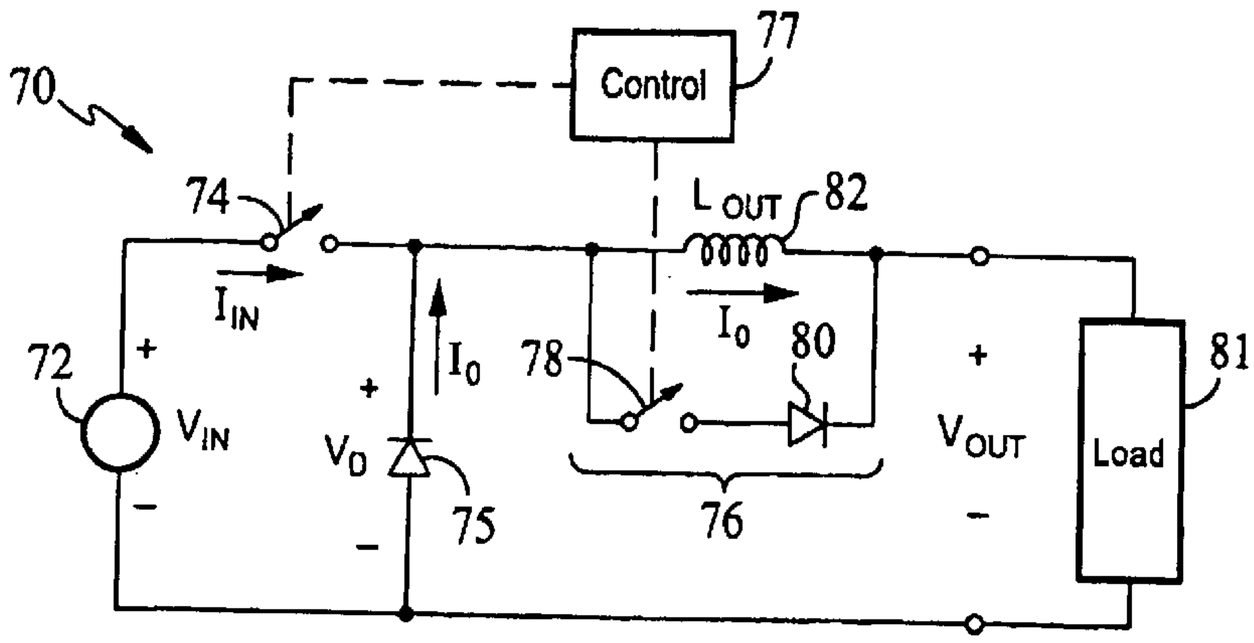


FIG. 7

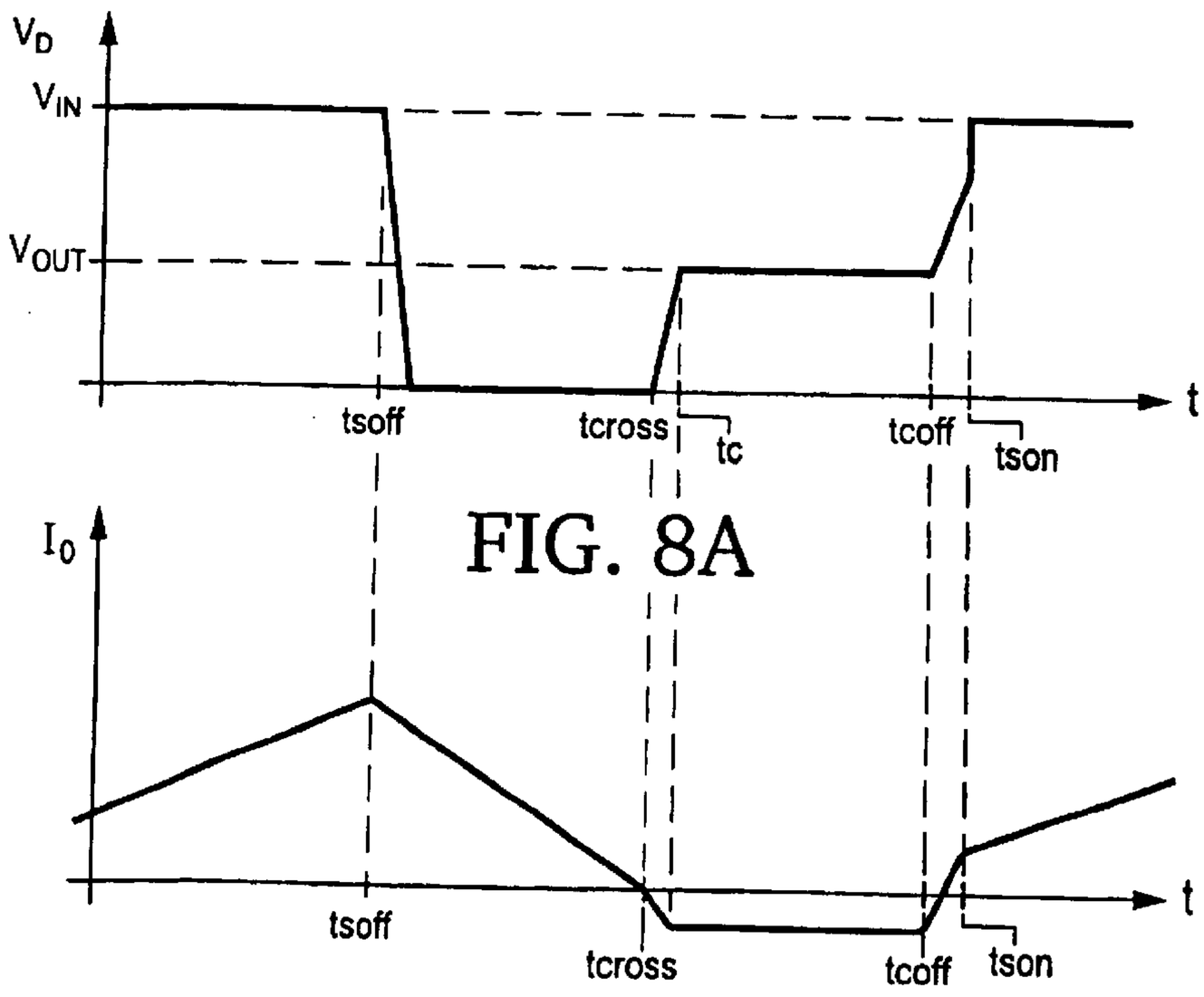


FIG. 8A

FIG. 8B

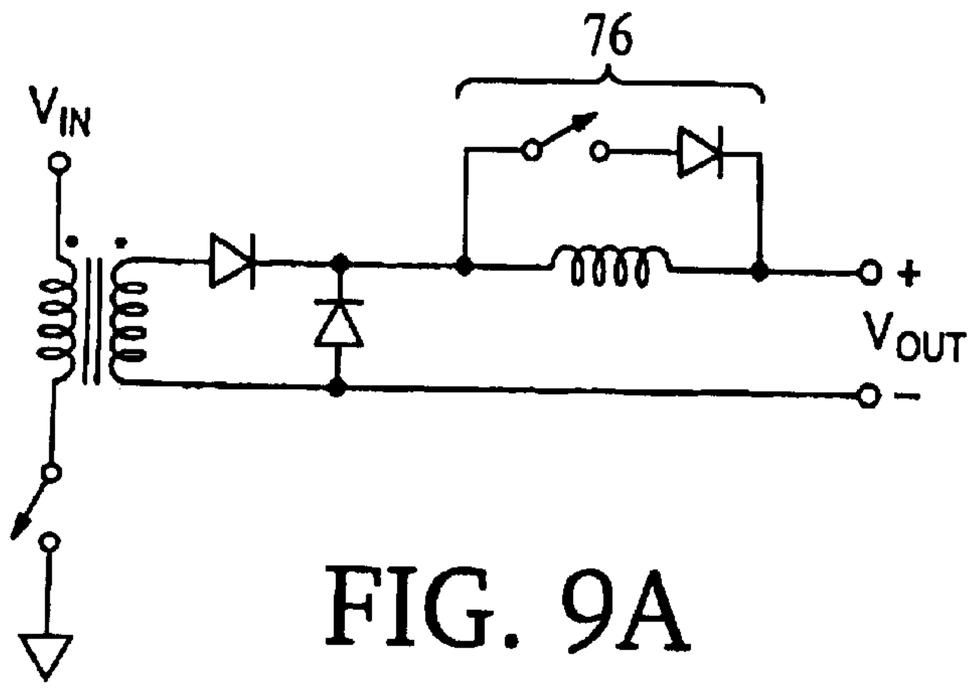


FIG. 9A

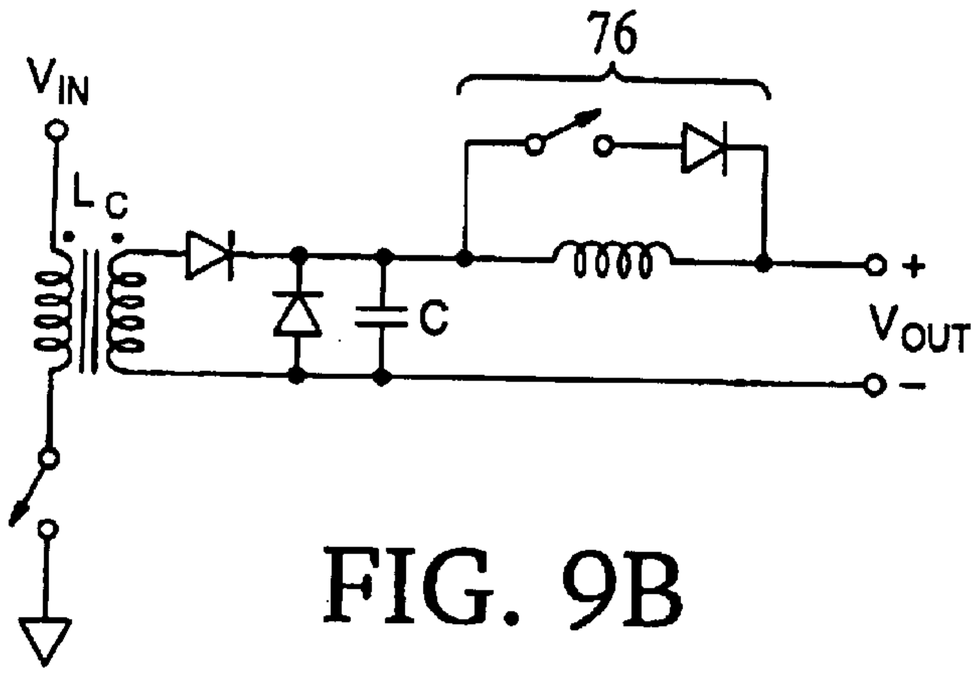


FIG. 9B

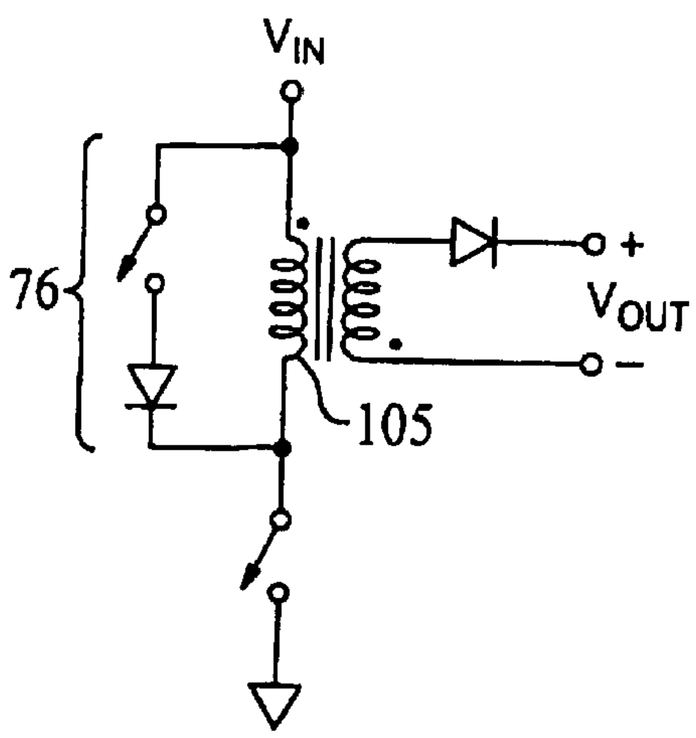


FIG. 9C

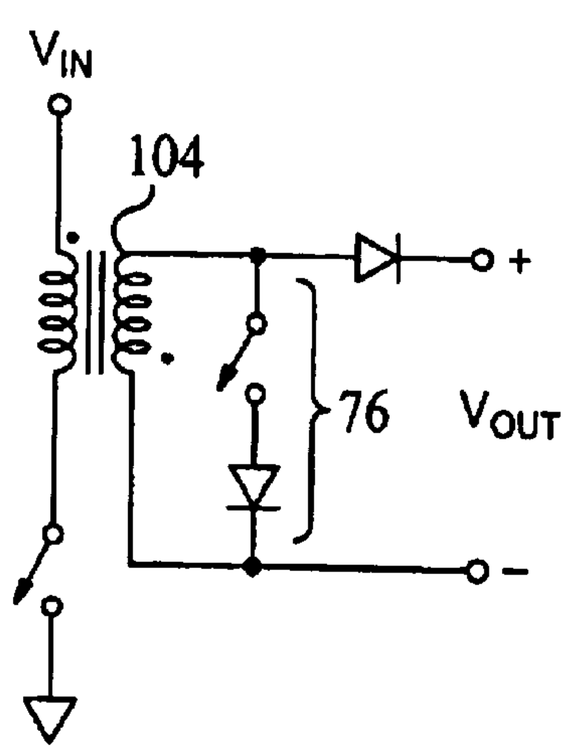


FIG. 9D

LOSS AND NOISE REDUCTION IN POWER CONVERTERS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND

This invention relates to reducing energy loss and noise in power converters.

As shown in FIGS. **1** and **2**, in a typical PWM non-isolated DC-to-DC shunt boost converter **20** operated in a discontinuous mode, for example, power is processed in each of a succession of power conversion cycles **10**. During a power delivery period **12** of each power conversion cycle **10**, while a switch **22** is open, power received at an input voltage Vin from a unipolar input voltage source **26** is passed forward as a current that flows from an input inductor **21** through a diode **24** to a unipolar load (not shown) at a voltage Vout. Vout is higher than the input voltage, Vin.

FIGS. **2**A and **2**B show waveforms for an ideal converter in which there are no parasitic capacitances or inductances and in which the diode **24** has zero reverse recovery time. During the power delivery period **12**, the current in the inductor falls linearly and reaches a value of zero at time tcross. At tcross, the ideal diode immediately switches off, preventing current from flowing back from the load towards the input source, and the current in the inductor remains at zero until the switch **22** is closed again at the next time ts**1**off. Thus, no energy is stored in the inductor **21** between times tcross and ts**1**on.

During another, shunt period **14** of each cycle, while switch **22** is closed, the voltage at the left side of the diode (node **23**) is grounded, and no current flows in the diode. Instead, a shunt current (Is) is conducted from the source **26** into the inductor **21** via the closed switch **22**. In a circuit with ideal components, the current in the inductor would begin at zero and rise linearly to time ts**1**off, when switch **22** is turned off to start another power delivery period **12**.

In a non-ideal converter, in which there are parasitic circuit capacitances and the diode is non-ideal (e.g., for a bipolar diode there will be a reverse recovery period and for a Schottky diode there will be diode capacitance), an oscillatory ringing will occur after tcross.

In one example, waveforms for a non-ideal converter of the kind shown in FIG. **1** are shown in FIGS. **2**C and **2**D. Because of the reverse recovery characteristic of the diode, the diode does not block reverse current flow at time tcross. Instead, current flows in the reverse direction through the diode **24** and back into the inductor **21** during a period **18**. At time tdoff, the diode snaps fully off and the flow of reverse current in the diode goes to zero.

Because of the reverse flow of current in the diode during the diode recovery period, energy has been stored in the inductor as of the off time tdoff (the "recovery energy"). In addition, parasitic circuit capacitances (e.g., the parasitic capacitances of the switch **22**, the diode **24**, and the inductor **24**, not shown) also store energy as of time tdoff (e.g., the parasitic capacitance of switch **22** will be charged to a voltage approximately equal to Vout).

After time tdoff, energy is exchanged between the inductor and parasitic capacitances in the circuit. As shown in FIGS. **2**C and **2**D, the energy exchange causes oscillatory ringing noise in the circuit. Furthermore, the presence of oscillatory current will generally result in energy being dissipated wastefully in the circuit at the start of the next shunt period when the switch is closed at time ts**1**on. The energy loss can amount to several percent of the total energy processed during a cycle.

SUMMARY

In general, in one aspect, the invention features apparatus that includes (a) switching power conversion circuitry including an inductive element connected to deliver energy via a unidirectional conducting device from an input source to a load during a succession of power conversion cycles, and circuit capacitance that can resonate with the inductive element during a portion of the power conversion cycles to cause a parasitic oscillation, and (b) clamp circuitry connected to trap energy in the inductive element and reduce the parasitic oscillation.

Implementations of the invention may include one or more of the following. The power conversion circuitry comprises a unipolar, non-isolated boost converter comprising a shunt switch. The power conversion circuitry is operated in a discontinuous mode. The clamp circuitry is configured to trap the energy in the inductor in a manner that is essentially non-dissipative. The clamp circuitry comprises elements configured to trap the energy by short-circuiting the inductor during a controlled time period. The inductive element comprises a choke or a transformer. The elements comprise a second switch connected effectively in parallel with the inductor. The second switch is connected directly in parallel with the inductor or is inductively coupled in parallel with the inductor. The second switch comprises a field effect transistor in series with a diode.

The power conversion circuitry comprises a unipolar, non-isolated boost converter comprising a shunt switch and a switch controller, the switch controller being configured to control the timing of a power delivery period during which the shunt switch is open and a shunt period during which the shunt switch is closed.

The shunt switch is controlled to cause the power conversion to occur in a discontinuous mode. The second switch is opened for a period before the shunt switch is closed in order to discharge parasitic capacitances in the apparatus. The power conversion circuitry comprises at least one of a unipolar, isolated, single-ended forward converter, a buck converter, a flyback converter, a zero-current switching converter, a PWM converter, a bipolar, non-isolated, boost converter, a bipolar, non-isolated buck converter, a bipolar, isolated boost converter, or a bipolar, isolated buck converter.

In general, in another aspect, the invention features, a method that reduces parasitic oscillations by trapping energy in the inductive element during a portion of the power conversion cycles.

Implementations of the invention include releasing the energy from the inductor essentially non-dissipatively. The energy is trapped by short-circuiting the inductive element during a controlled time period. The short-circuiting is done by a second switch connected effectively in parallel with the inductive element. The second switch is opened for a portion of the power conversion cycle in order to discharge parasitic capacitances. The invention reduces undesirable ringing noise generated in a power converted by oscillatory transfer of energy between inductive and capacitive elements in the converter and recycles this energy to reduce or eliminate the dissipative loss of energy associated with turn-on of a switching element in the converter.

Other advantages and features will become apparent from the following description and from the claims.

DESCRIPTION

FIG. **1** shows a power conversion circuit.

FIGS. **2**A–**2**D shows timing diagrams.

FIGS. **3**, **5** and **6** show power conversion circuits with recovery switches.

FIG. **4** shows a timing diagram.

FIG. **7** shows a PWM, unipolar, isolated buck converter comprising a clamp circuit.

FIGS. **8**A and **8**B show waveforms for the converter of FIG. **7**.

FIGS. **9**A, **9**B, **9**C, and **9**D show isolated, single-ended converters which comprise a clamp circuit.

With reference to FIGS. **1**, **2**C and **2**D, at time tdoff the parasitic capacitance across the switch **22** is charged to a voltage (approximately equal to Vout) which is greater than Vin and a current flows in L**1** owing to the reverse recovery of the diode **24**.

After tdoff, with the switch **22** open and the diode non-conductive, energy stored in the resonant circuit formed by the circuit parasitic capacitances and inductor L**1** causes oscillatory ringing in Iin and Vs. This oscillation (referred to herein as "parasitic oscillation" or simply "noise") is unrelated to the power conversion process, and may require that noise filtering components be added to the converter (not shown). In addition, closure of the switch **22** after tdoff will result in a wasteful loss of some or all of this energy ("switching loss").

By providing mechanisms for clamping the circuit voltages, the noise can be reduced or eliminated, and the stored energy can be trapped in an inductor and then released essentially losslessly back to the circuit. Generally, the capturing and later release of the energy is achieved by effectively shorting and then un-shorting the two ends of an inductor at controlled times.

As shown in FIG. **3**, in one implementation, a unipolar, non-isolated, discontinuous boost converter circuit **28** includes a series circuit, comprising a recovery switch Rs **30** and a diode **32**, that is connected across the ends of the inductor **34**, and a controller **36** that regulates the on and off periods of both the recovery switch **30** and the shunt switch **22**.

The recovery switch **30** is turned on and off in the following cycle. The switch may be turned on any time during the power delivery period **12** when the voltage across the inductor, VB (FIG. **3**), is negative, because this will result in diode **32** being reverse biased. During the reverse recovery period, the diode **32** prevents the current that is flowing backward from the diode **38** from flowing in recovery switch **30**. Instead, the reverse recovery energy is stored in the inductor.

After the diode snaps off, the energy stored in circuit parasitic capacitances will be exchanged with the inductor and the voltage, Vs, across shunt switch **22** will ring down. When the input voltage Vs rings down to the input voltage, Vin, the voltage VB will equal zero, the recovery diode **32** will conduct and the recovery switch **30** and the diode **32** will short the ends of the inductor **34**. In that state, the inductor **34** cannot exchange energy with any other circuit components. Therefore, the energy is "trapped" in the inductor and ringing in the main circuit is essentially eliminated.

Later, prior to the shunt switch being closed to start the shunt period, the recovery switch is opened. Because the current trapped in the inductor flows in the direction back toward the input source, opening the recovery switch **30** will result in an essentially lossless charging and discharging of parasitic circuit capacitances and a reduction in the voltage, Vs, across the shunt switch. By providing for a reduction in shunt switch voltage, Vs, the loss in the shunt switch associated with discharging of parasitics ("turn-on loss") can be reduced or, in certain cases, essentially eliminated.

As shown in FIG. **4**, the delay between the opening of the recovery switch **30** and the closing of the shunt switch **22** may be adjusted so that the closure of the shunt switch corresponds in time to approximately the time of occurrence of the first minimum in the voltage Vs following the opening of the recovery switch at time trsoff (the dashed line in the Figure shows how the voltage Vs would continue to oscillate after ts**1**on if the shunt switch **22** were not turned on at that time). In case where the voltage rings all the way down to zero (not shown in the Figure) the turn-on loss in the shunt switch can be essentially eliminated. Since capacitance energy is proportional to the square of the voltage, however, any amount of voltage reduction is important.

As shown in FIG. **5**, in another approach, instead of wiring the recovery switch and diode directly across the inductor, a recovery switch **50** and a diode **52** are connected in series with a secondary winding **54** that is transformer-coupled to the inductor. The series circuit is connected to the ground side of the circuit for convenience in controlling the switch. The control switch may be implemented as a MOSFET in series with a diode. Turn-on losses will occur as a result of the body capacitor of the switch **50**, but they are relatively small because the switch die is relatively small.

As shown in FIG. **6**, in another implementation, a bipolar discontinuous boost converter **60** operating from a bipolar input source, Vac, uses the transformer-coupled switching technique of FIG. **5**, but includes two recovery switches **62**, **64** connected to respective ends of the winding **66**. One of the recovery switches is always on for one polarity of input source Vac, and the other recovery switch is turned on and off using the same strategy as in FIG. **5**. The scenario is reversed when the polarity of the input source reverses.

Care must be taken not to have the shunt switch and the recovery switch on at the same time, which would short-circuit the source.

The energy-trapping technique may be applied to any power converter, isolated or non-isolated, PWM or resonant, in which energy storage in inductive and capacitive circuit elements results in parasitic oscillations within the converter.

FIG. **7**, for example, shows a PWM, unipolar, isolated buck converter **70** comprising a clamp circuit **76**. In such a converter, the voltage delivered by the input source **72**, Vin, is higher than the DC output voltage, Vout, delivered to the load **81**. In a first part of a converter operating cycle, the switch **74** is closed and energy is delivered to the load from the input source **72** via the output inductor **82**. In a second part of a converter operating cycle, the switch is open and energy stored in the inductor **82** flows as output current, Io, to the load via the diode **75**. For load values above some lower limit, the output current, Io, flows continuously in the output inductor Lout **82**. Below that lower limit, however, the instantaneous current in the output inductor **82** drops to zero and attempts to reverse. Under these circumstances the diode will block and, in the absence of the clamp circuit **76**, an oscillation will begin as energy is transferred back and forth between the inductor **82** and circuit parasitic capacitances (e.g., the parasitic capacitances of the switch **74**, the

diode **75**, the inductor **82** and the clamp circuit **76**, not shown). Waveforms for the converter of FIG. **7**, with the clamp circuit, are shown in FIGS. **8**A and **8**B.

In FIGS. **8**A and **8**B, the switch **74** is on at time t=0, the voltage VD is approximately equal to Vin, and the current Io is increasing owing to the polarity of the voltage impressed across Lout. At time tsoff, switch **74** turns off and the voltage VD drops to essentially zero volts as the parasitic capacitances across the diode **75** are discharged and the diode conducts. The clamp switch **78** may be turned on any time after the voltage VD drops below Vout.

At time tcross the current Io declines to zero and attempts to reverse. After the diode **75** ceases conducting, the voltage VD rings up until the clamp diode **80** begins to conduct at time tc, when the voltage VD is approximately equal to Vout. Between times tc and tcoff the clamp circuit clamps the inductor and prevents parasitic oscillations. At time tcoff, the clamp switch is opened and the voltage VD rings up toward Vin. At time tson the switch **74** is closed, initiating another converter operating cycle. A switch controller **77** controls the relative timing of the two switches **74**, **78**. As for the timing discussed in FIG. **4**, the delay between the opening of the clamp switch **78** and the closing of the switch **74** is adjusted so that the closure of switch **74** corresponds in time to approximately the time of occurrence of the first maximum in the voltage Vs following the opening of the clamp switch **78**. This minimizes or eliminates the switching loss associated with closure of switch **74**.

The transformer coupled clamp circuit of FIG. **5** may be used in the converter of FIG. **7**.

Other embodiments are within the scope of the following claims.

For example, the technique may be applied to any switching power converter in which there is a time period during which undesired oscillations occur as a result of energy being transferred back and forth between unclamped inductive and capacitive energy storing elements.

For example, FIGS. **9**A through **9**D show isolated, single-ended converters which comprise a clamp circuit **76** according to the invention. FIG. **9**A is a unipolar, single-ended, forward PWM converter; FIG. **9**B is a unipolar, single-ended, zero-current switching forward converter (as described in U.S. Pat. No. 4,415,959, incorporated by reference); FIG. **9**C is a unipolar, single-ended, flyback converter with a clamp circuit **76** connected to the primary winding **105** of the flyback transformer; and FIG. **9**D is a unipolar, single-ended, flyback converter with a clamp circuit **76** connected to the secondary winding **104** of the flyback transformer.

The clamp circuit may be modified to be of the magnetically coupled kind shown in FIG. **5**, above. Other topologies to which the technique may be applied include resonant and quasi-resonant non-isolated, boost, buck and buck-boost converters. By use of bipolar clamp circuitry of FIG. **6**, or equivalent circuitry, the technique may be applied to bipolar equivalents of unipolar PWM, resonant and quasi-resonant non-isolated, boost, buck and buck-boost converters.

What is claimed is:

1. Apparatus comprising:

switching power conversion apparatus for converting power from an input source for delivery to a load comprising an inductive element connected to deliver energy via a unidirectional conducting device from said input source to said load during a succession of power conversion cycles,

circuit capacitance which can resonate with said inductive element during a potion of said power conversion cycle to cause a parasitic oscillation unrelated to the power conversion process, and

clamp circuitry configured to trap energy in the inductive element and prevent said parasitic oscillation.

2. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a unipolar, non-isolated boost converter comprising a shunt switch.

3. The apparatus of claim **2** in which the shunt switch is controlled to cause the power conversion to occur in a discontinuous mode.

4. The apparatus of claim **1** in which the clamp circuitry is configured to trap the energy in the inductor in a manner that is essentially non-dissipative.

5. The apparatus of claim **1** in which the clamp circuitry comprises elements configured to trap the energy by short-circuiting the inductor during a controlled time period.

6. The apparatus of claim **1** in which the inductive element comprises a choke.

7. The apparatus of claim **1** in which the inductive element comprises a transformer.

8. The apparatus of claim **5** in which the elements comprise a second switch connected effectively in parallel with the inductor.

9. The apparatus of claim **8** in which the second switch is connected directly in parallel with the inductor.

10. The apparatus of claim **8** in which the second switch is inductively coupled in parallel with the inductor.

11. The apparatus of claim **8** in which the second switch comprises a field effect transistor in series with a diode.

12. The apparatus of claim **8** wherein said power conversion apparatus **[**is**]** *comprises* a unipolar, non-isolated boost converter comprising a shunt switch and a switch controller, said switch controller controlling the timing of a power delivery period during which said shunt switch is open and a shunt period during which the shunt switch is closed.

13. The apparatus of claim **12** in which the shunt switch is controlled to cause the power conversion to occur in a discontinuous mode.

14. The apparatus of claim **12** in which the second switch is opened for a period before the shunt switch is closed in order to discharge parasitic capacitances in the apparatus.

15. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a unipolar, isolated, single-ended forward converter.

16. The apparatus of claim **15** wherein said power conversion apparatus **[**is**]** *comprises* a buck converter.

17. The apparatus of claim **15** wherein said power conversion apparatus **[**is**]** *comprises* a flyback converter.

18. The apparatus of claim **15** wherein said single-ended forward converter **[**is**]** *comprises* a zero-current switching converter.

19. The apparatus of claim **15** wherein said single-ended forward converter **[**is**]** *comprises* a PWM converter.

20. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a bipolar, non-isolated, boost converter.

21. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a bipolar, non-isolated boost converter.

22. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a bipolar, non-isolated buck converter.

23. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a bipolar, non-isolated boost converter.

24. The apparatus of claim **1** wherein said power conversion apparatus **[**is**]** *comprises* a bipolar, isolated buck converter.

25. In a power converter which converts power from an input source for delivery to a load during a succession of power conversion cycles and which comprises an inductive element connected to deliver power via a unidirectional conducting device from said input source to said load and a circuit capacitance which can resonate with said inductive element during a portion of said power conversion cycle to cause a parasitic oscillation unrelated to the power conversion process,

a method for preventing said parasitic oscillations comprising

providing clamp circuitry for trapping energy in the inductive element during a portion of the power conversion cycle.

26. The method of claim **25** also including releasing the energy from the inductor essentially non-dissipatively.

27. The method of claim **17** wherein the trapping of energy comprises short-circuiting the inductive element during a controlled time period.

28. The method of claim **27** in which the short-circuiting is done by a second switch connected effectively in parallel with the inductive element.

29. The apparatus of claim **28** also including opening the second switch for a portion of the power conversion cycle in order to discharge parasitic capacitances.

30. Apparatus comprising

switching power conversion apparatus for converting power from an input source for delivery to a load comprising an inductive element connected to deliver energy from said input source to said load during a succession of power conversion cycles,

clamp circuitry configured to hold energy in the inductive element, and

control circuitry configured to regulate the on and off periods of the clamp circuitry such that the clamp circuitry is configured to carry a reverse current flowing in the inductor and is turned off at a time when a remaining current is flowing in the inductor, wherein the remaining current has a level that is at least a substantial portion of a peak value of the reverse current.

31. The apparatus of claim 30 wherein the remaining current is used to charge or discharge parasitic capacitances.

32. A method comprising:

providing power conversion circuitry having an inductive element connected to deliver power from an input source to a load during a succession of power conversion cycles;

providing clamp circuitry for holding energy in the inductive element during a portion of the power conversion cycle;

providing control circuitry for controlling the on and off times of the clamp circuitry,

configuring the on and off times of the clamp circuitry to hold energy in the inductive element during the on time of the clamp and to release a substantial portion of the held energy during the off time of the clamp.

33. The method of claim 32 wherein the release of the held energy is used to charge or discharge parasitic capacitances.

34. A method comprising:

providing power conversion circuitry having an inductive element connected to deliver power from an input source to a load during a succession of power conversion cycles;

providing clamp circuitry for conducting a current flowing in the inductive element during a portion of the power conversion cycle;

providing control circuitry for controlling the on and off times of the clamp circuitry;

configuring the on and off times of the clamp circuitry to carry a reverse current flowing in the inductor and to turn off the clamp circuitry before the reverse current flowing in the inductor decays essentially to zero.

35. The method of claim 34 wherein the reverse current flowing in the inductor is used to charge or discharge parasitic capacitances during the off time of the clamp.

* * * * *