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PTO/SB/16 (8-00)

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Krishna Siamak	Shenai Abedinpour	Naperville, Illinois

☐ Additional inventors are being named on the _____ separately numbered sheets attached hereto

TITLE OF THE INVENTION (280 characters max)

Novel DC-DC Step-Down Converter with Resonant Gate Drive

Direct all correspondence to:

CORRESPONDENCE ADDRESS



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ENCLOSED APPLICATION PARTS (check all that apply)



Specification Number of Pages

7



CD(s), Number



Drawing(s) Number of Sheets

3



Other (specify)



Application Data Sheet. See 37 CFR 1.76

Postcard receipt

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT (check one)



Applicant claims small entity status. See 37 CFR 1.27.



A check or money order is enclosed to cover the filing fees



The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number

23-0920



Payment by credit card. Form PTO-2038 is attached.

FILING FEE
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\$80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.



No.



Yes, the name of the U.S. Government agency and the Government contract number are.

Respectfully submitted,

Date

11-05-01

SIGNATURE

TYPED or PRINTED NAME

Jon P. Christensen

REGISTRATION NO.

34,137

(if appropriate)

Docket Number:

6455-84075

TELEPHONE

312-655-1500

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is used by the public to file (and by the PTO to process) a provisional application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the complete provisional application to the PTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Washington, D.C. 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Box Provisional Application, Assistant Commissioner for Patents, Washington, D.C.

P19SMALL/REV05

FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

Complete if Known

TOTAL AMOUNT OF PAYMENT (\$ 80.00)

Application Number	
Filing Date	concurrently herewith
First Named Inventor	Krishna SHENAI et al
Examiner Name	
Group/Art Unit	
Attorney Docket Number	6455-84075

METHOD OF PAYMENT (check one)

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Small Entity Fee Code	Fee Description	Fee Paid
101 710	201 355	Utility filing fee	
106 320	206 160	Design filing fee	
107 490	207 245	Plant filing fee	
108 710	208 355	Reissue filing fee	
114 150	214 75	Provisional filing fee	80.00

SUBTOTAL (1)

(\$ 80.00)

2. EXTRA CLAIM FEES

Total Claims	Extra Claims	Fee from below	Fee Paid
-20** =	x	=	
Independent Claims	-3** =	x	=
Multiple Dependent Claims		=	

**or number previously paid, if greater; For Reissues, see below

Large Entity Fee Code	Small Entity Fee Code	Fee Description
103 18	203 9	Claims in excess of 20
102 80	202 40	Independent claims in excess of 3
104 270	204 135	Multiple dependent claim, if not paid
109 80	209 40	**Reissue independent claims over original patent
110 18	210 9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2)

(\$)

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Small Entity Fee Code	Fee Description	Fee Paid
105 130	205 65	Surcharge-late filing fee or oath	
127 50	227 25	Surcharge-late provisional filing fee or cover sheet	
139 130	139 130	Non-English Specification	
147 2,520	147 2,520	For filing a request for reexamination	
112 920*	112 920*	Requesting publication of SIR prior to Examiner action	
113 1,840*	113 1,840*	Requesting publication of SIR after Examiner action	
115 110	215 55	Extension for reply within first month	
116 390	216 195	Extension for reply within second month	
117 890	217 445	Extension for reply within third month	
118 1,390	218 695	Extension for reply within fourth month	
128 1,890	228 945	Extension for reply within fifth month	
119 310	219 155	Notice of Appeal	
120 310	220 155	Filing a Brief in support of an appeal	
121 270	221 135	Request for oral hearing	
138 1,510	138 1,510	Petition to institute a public use proceeding	
140 110	240 55	Petition to revive - unavoidable	
141 1,240	241 620	Petition to revive - unintentional	
142 1,240	242 620	Utility issue fee (or reissue)	
143 440	243 220	Design issue fee	
144 600	244 300	Plant issue fee	
122 130	122 130	Petitions to the Commissioner	
123 50	123 50	Petitions related to provisional applications	
126 240	126 240	Submission of Information Disclosure Stmt	
581 40	581 40	Recording each patent assignment per property (times number of properties)	
146 710	246 355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149 710	249 355	For each additional invention to be examined (37 CFR § 1.129(b))	
179 710	279 355	Request for Continued Examination (RCE)	
169 900	169 900	Request for expedited examination of a design application	

Other fee (specify) _____

SUBTOTAL (3)

(\$)

*Reduced by Basic Filing Fee Paid

SUBMITTED BY

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Date

November 5, 2001

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Application Data Sheet

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Application Information

Title Line One::	Novel DC-DC Step-Down Converter with
Title Line Two::	Resonant Gate Drive
Total Drawing Sheets::	3
Formal Drawings?::	No
Application Type::	Provisional
Docket Number::	6455-84075

Representative Information

Registration Number One::	24,003
Registration Number Two::	22,839
Registration Number Three::	28,903
Registration Number Four::	27,429
Registration Number Five::	25,060
Registration Number Six::	22,053
Registration Number Seven::	27,466
Registration Number Eight::	29,434
Registration Number Nine::	29,054
Registration Number Ten::	29,381
Registration Number Eleven::	34,044
Registration Number Twelve::	27,600
Registration Number Thirteen::	34,137
Registration Number Fourteen::	39,724
Registration Number Fifteen::	37,963
Registration Number Sixteen::	37,135
Registration Number Seventeen::	40,604
Registration Number Eighteen::	37,435
Registration Number Nineteen::	38,110
Registration Number Twenty::	39,021

Novel DC-DC Step-Down Converter with Resonant Gate Drive [12 claims]

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ABSTRACT

A novel monolithic step-down dc-dc buck converter is proposed that uses a resonant gate drive for lossless switching, resulting in a highly efficient topology. The main converter includes two semiconductor switches connected in series. The common point of the switches is connected to a filter inductor and capacitor that provide the output of the dc-dc voltage converter. The converter

also includes a control circuit that controls the switching of the synchronous rectifier switches by comparing the output voltage to predetermined threshold values in order to regulate the output voltage against load and input variations. The control circuit also contains a resonant inductor and a capacitor to provide lossless switching in the converter. The resonance of the network is initiated by a series semiconductor switch in the drive circuit. The synchronous rectifier semiconductor switches, filter inductance and capacitance, resonant inductance and capacitance, and the control circuit are fabricated as part of a single integrated circuit.

FIELD OF THE INVENTION

The field of the invention is related to dc-dc converters and more particularly to voltage step-down dc-dc converters.

BACKGROUND OF THE INVENTION

As VLSI circuits are scaled down to deep sub-micron dimensions, there is a need for highly efficient low-voltage power supplies. A step-down synchronous buck converter is popularly used to convert an unregulated input voltage to a lower regulated dc voltage to provide power to a rapidly varying load. Very high efficiency (up to 90%) is desired for ultra low-power loads. The primary contributions to losses in a power electronic circuit come from the switch and the magnetic elements. Higher switching frequencies are needed to reduce the weight and volume of circuit components. As switching frequency is increased, switching losses of the switch become dominant. Resonant circuits have been used to control the ramp rate of current and/or voltage of the switch during turn-off, thus reducing the switching losses. When using MOS-gated switches in low-voltage power supplies, the energy loss in charging and discharging the input gate is usually the dominant factor affecting the efficiency of power conversion.

A resonant gate-drive circuit has been proposed in prior art to ensure lossless switching of the gate in switched-capacitor dc-dc converters. In this configuration, the input gate capacitor of the switch forms a resonant network with a parallel-connected inductor. Energy circulates within this network, thus leading to lossless switching. A switch is provided in series with the LC-circuit. This switch is turned on for a very short time at the end of each resonant cycle. By doing this, the inductor is allowed to charge up in order to compensate for the energy lost per cycle due to stray resistance. This technique has been shown to result in significant reduction in switching losses of a switched capacitor network.

One limitation of such an implementation is the lack of control over the switching. The switch is turned on every cycle to recharge the inductor, and the duty ratio is fixed. This mode of operation is acceptable for a switched-capacitor realization, which is a charge-transfer technique. However, the synchronous rectifier is a duty-ratio controlled circuit where the amount of power transfer critically depends on the ratio of the on-to-off duration of the switch. Hence, lossless switching of the switches must be achieved with variable duty ratio.

SUMMARY

A novel monolithic step-down dc-dc buck converter is proposed that uses a resonant gate drive for lossless switching, resulting in a highly efficient topology. The main converter includes two semiconductor switches connected in series. The common point of the switches is connected to a filter inductor and capacitor that provide the output of the dc-dc voltage converter. The converter also includes a control circuit that controls the switching of the synchronous rectifier switches by comparing the output voltage to predetermined threshold values in order to regulate the output voltage against load and input variations. The control circuit also contains a resonant

inductor and a capacitor to provide lossless switching in the converter. The resonance of the network is initiated by a series semiconductor switch in the drive circuit. The synchronous rectifier semiconductor switches, filter inductance and capacitance, resonant inductance and capacitance, and the control circuit are fabricated as part of a single integrated circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a dc-dc voltage converter in accordance with an embodiment of the invention;

FIG. 2 is an illustration showing the resonant waveforms at the gate terminal of the semiconductor switches in the converter; and

FIG. 3 is an illustration of the potential improvement in system efficiency by the use of the proposed control technique.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a schematic diagram of a dc-dc step-down voltage converter in accordance with an embodiment of the invention. The converter would be fabricated as an integral part of a multifunctional chip by the use of existing chip fabrication techniques. The step-down converter is fabricated using CMOS technology. The synchronous rectifier uses a pMOSFET in the main current path, and an nMOSFET to divert the inductor current when the pMOSFET is turned off. The resonant gate-drive for each device operates out-of-phase and accounts for the different polarity of the two switches. This is accomplished by the circuit configuration in FIG. 1. A control circuit, based on the feedback of output voltage, determines the switching sequence. Out-of-phase signals are provided to the two switches.

The drive circuit of the semiconductor switches utilizes a series resonance of the inductor and capacitor. The input capacitance of the switch and an external inductor constitute the resonant network. A switch is placed between the control voltage source and the resonant network. Turning the switch on activates the resonant network. At the end of each cycle, the capacitor voltage and current return to zero. The auxiliary switch is then turned off under zero-current conditions. Turning the switch off disconnects the voltage source from the tank and also opens the circuit. Thus, no change occurs until the switch is turned on again. Since the time of turning on the switch again is controllable, this circuit offers flexibility of duty-ratio control. The switch can be turned on to result in a desired duty ratio with negligible switching losses. Typical simulated capacitor voltage and current waveforms for the resonant control circuit are shown in FIG. 2. The voltage across the capacitor periodically rises towards twice the supply voltage of the control circuit and returns to zero at a pre-determined duty-ratio.

The circuit can be integrated monolithically by choosing a sufficiently high switching frequency to ensure low values of passive components. A typical switching frequency of 100 MHz will result in inductor values less than 100 nH and capacitance around 1 nF. Such values can be provided on-chip. However, presently available on-chip inductors have poor quality factor, typically restricted to less than 15. Using such practical components, an efficiency improvement up to 10% is expected from the use of this topology over the conventional synchronous rectifier. The predicted efficiency of a monolithic synchronous rectifier with

resonant gate drive for various values of inductor Q and load is depicted in FIG. 3. This justifies the advantages of this invention.

A specific embodiment of a method and apparatus of dc voltage conversion according to the present invention has been described for the purpose of illustrating the manner in which the invention is made and used. It should be understood that the implementation of other variations and modifications of the invention is not limited by the specific embodiments described. Therefore it is contemplated to cover the present invention any and all modifications, variations, or equivalents that fall within the true spirit and scope of the basic underlying principles disclosed and claimed herein.

CLAIMS

We claim:

1. A dc-dc voltage converter comprising:

a series synchronous rectifier connection of two main switches that operate as a voltage step-down device,

an inductor connected to the common point of the series switch configuration, which provides an output of the dc-dc voltage converter;

a step-down switch configuration operating at a load-dependent switching frequency,

a control circuit that monitors the output voltage of the voltage step-down device and triggers the switches each time the output of the dc-dc converter falls below a threshold voltage,

an auxiliary switch connected to the output of the control circuit, and

an inductor connected between the output of the auxiliary switch and the input of the main switch.

2. The dc-dc converter as in claim 1 further wherein the voltage step-down device further comprises a power supply connected in series with the synchronous rectifier configuration.

3. The dc-dc converter as in claim 1 further comprising a capacitor coupled across an output of the dc-dc step-down converter.

4. The dc-dc converter as in claim 1 wherein both the switch comprising the synchronous rectifier are implemented using MOSFET devices.

5. The dc-dc converter as in claim 1 further comprising a feedback and startup circuit, the output of which controls the switching of the synchronous rectifier switches.

6. The dc-dc converter as in claim 5 further comprising of an auxiliary resonant network that gets the input signal from the feedback circuit to provide a lossless switching waveform at the control terminal of the main switch

7. The dc-dc converter as in claim 6, with the auxiliary network comprising of an auxiliary switch, resonant inductor and resonant capacitor.

8. The dc-dc converter as in claim 6 further comprising the network of auxiliary switch, resonant inductor and resonant capacitor to the control terminal of each of the main switches in the converter.

9. The dc-dc converter in claim 8, with the control signal for the two main switches being out of phase with each other.

10. The dc-dc converter as in claim 9, with the control signal being generated from the same feedback circuit with the use of an inverter.

11. The dc-dc converter as in claim 7 wherein the voltage regulator further comprises an LC filter providing the regulated output voltage at the output of the LC filter.

12. A monolithic step-down dc-dc converter with resonant gate voltage control for improved performance comprising:

a series switch with the first end of the switch connected in series with a positive side of a power supply, the power supply also having a negative side,

another series switch with the first end of the switch connected in series with the first switch, the second end being connected to the negative side of the power supply,

an inductor, with the first end of the inductor connected to the common connection point of the two switches,

a capacitor with a first end of the capacitor connected between a second end of the inductor and the negative side of the power supply and the voltage across the capacitor defining an output of the monolithic dc-dc converter,

a control feedback and startup circuit receiving an output of the dc-dc converter, and a reference voltage as input, generating the required switching signals for the step-up switch,

an auxiliary switch, with the first end connected to the output point of the control feedback,

a resonant inductor, with the first end of the inductor connected to the second end of the auxiliary switch, the second end being connected to the control terminal of the aforementioned switch,

an auxiliary switch, resonant inductor and resonant capacitor arrangement for each of the main switches,

with the two main switches, one auxiliary switch, control feedback and start-up circuit, filter inductor, filter capacitor, resonant inductor and resonant capacitor all being fabricated within a substrate of an integrated circuit forming the monolithic dc-dc voltage step-up converter.

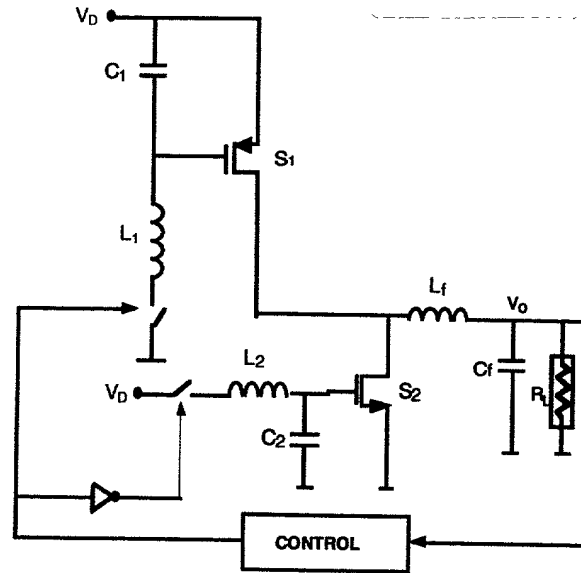


FIGURE 1

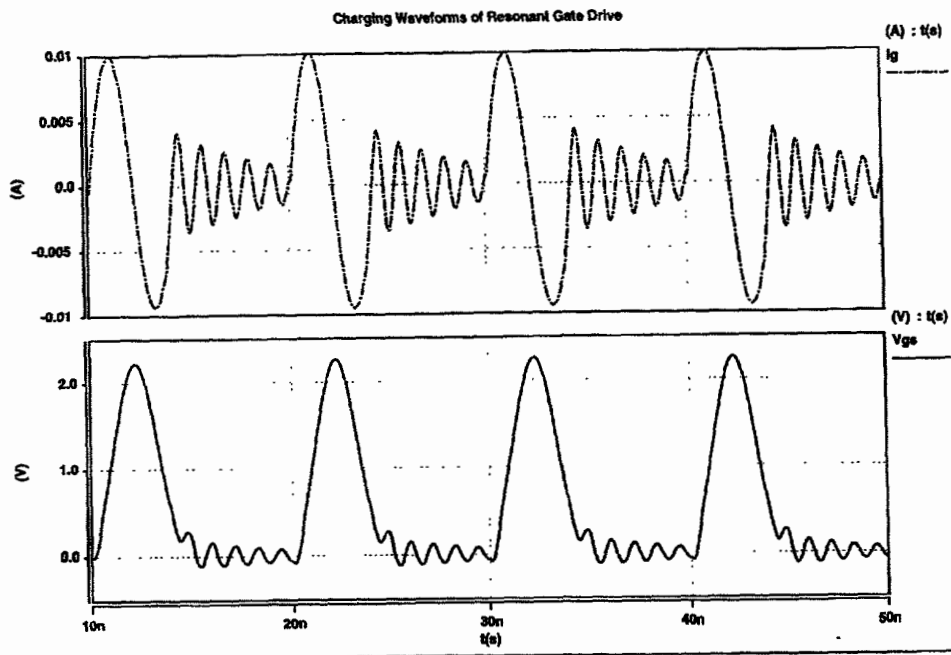


FIGURE 2

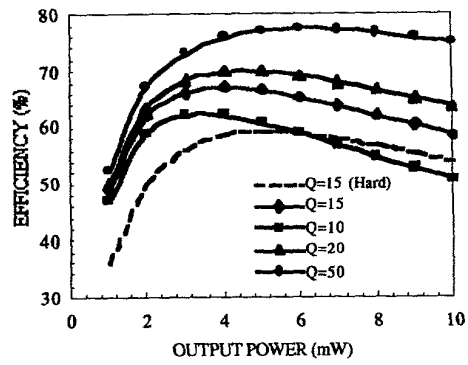


FIGURE 3