



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
61/071,151	04/15/2008		105	1052-30		

CONFIRMATION NO. 1189

Alfred Leibovitz
11 Amal Street
Rosh HaAyn, 48092
ISRAEL

FILING RECEIPT



OC00000029527596

Date Mailed: 04/24/2008

Receipt is acknowledged of this provisional patent application. It will not be examined for patentability and will become abandoned not later than twelve months after its filing date. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please write to the Office of Initial Patent Examination's Filing Receipt Corrections. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Alfred Leibovitz, Petach Tikva, ISRAEL;

Power of Attorney: None

If Required, Foreign Filing License Granted: 04/22/2008

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/071,151**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

** SMALL ENTITY **

Title

Bridge synchronous rectifier

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international

patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and

Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

PTO/SB/16 (07-07)
Approved for use through 06/30/2010. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.
PROVISIONAL APPLICATION FOR PATENT COVER SHEET – Page 1 of 2
This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. _____

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Alfred	Leibovitz	Petach Tikva, Israel

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

TITLE OF THE INVENTION (500 characters max):

Bridge Synchronous Rectifier

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ The address corresponding to Customer Number:

OR

☒ Firm or Individual Name

Address 11, Amal Street

City Rosh HaAyin	State Israel	Zip 48092
Country Israel	Telephone +972 3 902 1057	Email morris@ipfactor.co.il

ENCLOSED APPLICATION PARTS (check all that apply)

☐ Application Data Sheet. See 37 CFR 1.76 ☐ CD(s). Number of CDs _____

☒ Drawing(s) Number of Sheets 4 ☐ Other (specify) _____

☒ Specification (e.g. description of the invention) Number of Pages 15

Fees Due: Filing Fee of \$200 (\$100 for small entity). If the specification and drawings exceed 100 sheets of paper, an application size fee is also due, which is \$250 (\$125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

METHOD OF PAYMENT OF THE FILING FEE AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT

☐ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fee and application size fee (if applicable). 105

☒ Payment by credit card. Form PTO-2038 is attached **TOTAL FEE AMOUNT (\$)**

☐ The Director is hereby authorized to charge the filing fee and application size fee (if applicable) or credit any overpayment to Deposit Account Number: _____ A duplicative copy of this form is enclosed for fee processing.

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. 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, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PROVISIONAL APPLICATION COVER SHEET
Page 2 of 2

PTO/SB/16 (07-07)

Approved for use through 06/30/2010. OMB 0651-0032

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

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: _____

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

SIGNATURE /Alfred Leibovitz/

Date 15th April 2008

TYPED or PRINTED NAME Alfred Leibovitz REGISTRATION NO. _____
(if appropriate)

TELEPHONE +972 3 902 1057 Docket Number: 1052-30

Bridge Synchronous Rectifier

Field of the Invention

The present invention is directed to providing a full-wave rectifier having low power loss characteristics.

5 Background

Power converters are used to interface between power sources and electrical devices. Because alternating current is preferred for efficient power transmission, power sources typically provide power at alternating current. On the other hand the operation of many electrical devices requires direct current. In order to provide direct
10 current for such devices from alternating current, the power sources, power converters need to convert the current supplied from alternating to direct, and use rectifiers for this purpose.

Bridge rectifiers are commonly used in power converters to provide full-wave rectification of alternating current. A typical bridge rectifier is the Graetz circuit or
15 diode bridge which consists of four diodes arranged in a bridge circuit as shown in Fig. 1a. It will be noted, however, that diodes are inherently inefficient conductors and this produces a number of well known problems.

One problem resulting from the inefficiency of diodes is that they produce a forward voltage drop. This is most noticeable in low-voltage power converters where
20 the voltage drop may be a significant proportion of the desired voltage output. Schottky diodes, which exhibit very low voltage drops, are often used to minimize the problem.

A further problem results from the heat dissipated by diodes, particularly in high frequency switching power supplies. Apart from reducing overall efficiency of
25 the power converter, resulting high temperatures also reduce the reliability of components. Much design effort is typically required to overcome this problem, and other factors such as the dimensions of the system may be compromised as a result.

MOSFETs (Metal Oxide Semiconductor Field-Effect Transistors) are electronic switches. A gate signal may be used to switch the MOSFET between an
30 OFF state and an ON state. In the OFF state, current is blocked whereas in the ON state, a current path is provided between the source and the drain terminals, having the characteristics of an ohmic resistor.

A prior art Power MOSFET 130 is shown in Fig. 1b. The Power MOSFET 130 consists of an electronic switch 131 having a source terminal 134, a drain terminal 136 and a gate terminal 138, and a diode 132 connected between the source 134 and drain 136 terminals in parallel to the electronic switch 131. When the MOSFET 130 is in the OFF state, current may pass only through the diode 132, however when the MOSFET 130 is in the ON state, an alternative low resistance current path is provided between the source 134 and the drain 136 terminals through the electronic switch 131. Because the closed electronic switch 131 of the MOSFET 130 behaves as an ohmic resistor, it produces less heat loss than the diode 132.

Additionally, it will be noted that MOSFETs have extremely fast switching speeds. This allows them to be used to replace diodes in a rectifier. Typically, the gate signals of the MOSFETs are synchronized with the frequency of the input voltage such that they are switched into their ON state whenever there is a voltage drop between the source 134 and the drain 138 terminals. Such rectifiers are known as synchronous rectifiers and may be used to improve the efficiency of power converters.

In bridge rectifiers, up to two of the diodes of the Graetz circuit may be replaced by MOSFETs, and their gate signal drawn directly from the input voltage. However, if the remaining two diodes are replaced by MOSFETs and also draw gate signals directly from the input voltage, it is difficult to avoid short circuiting between the input and/or the output terminals of the bridge rectifier.

There is a need therefore for a synchronous rectifier characterized by a low associated heat loss and the present invention addresses this need.

Summary of the Invention

In accordance with a first embodiment, the present invention is directed to providing a current-triggered synchro-rectifier comprising an electronic switch having an anode and a cathode, the electronic switch configured to be in its ON setting when
5 current flowing through the cathode exceeds a predetermined threshold.

Preferably, the electronic switch comprises a MOSFET device that comprises a source terminal, a drain terminal and a gate terminal; a half-wave rectifier in parallel with the MOSFET device, wired to the source terminal and the drain terminal of the MOSFET device, and a current monitor configured to monitor a drain-current flowing
10 through the drain terminal and to send a gate signal to the gate terminal, such that the MOSFET is switched to its ON state when the drain-current exceeds a first threshold current and the MOSFET is switched to its OFF state when the drain-current falls below a second threshold current. Optionally, the current monitor comprises a current transformer.

15 According to other embodiments of the present invention, a full-wave rectifier is disclosed, comprising:

- a first half-wave rectifier having one anode wired to a first output terminal and one cathode wired to a first input terminal;
- a second half-wave rectifier having one anode wired to the first output
20 terminal and one cathode wired to a second input terminal;
- a third half-wave rectifier having one anode wired to the first input terminal and one cathode wired to a second output terminal; and
- a fourth half-wave rectifier having one anode wired to the second input terminal and one cathode wired to the second output terminal;

25 the full-wave rectifier for providing an output of constant polarity from an input of variable polarity, wherein at least one half-wave rectifier comprises the current-triggered synchro-rectifier of the first embodiment.

Alternatively, a full-wave rectifier is disclosed comprising

- a first half-wave rectifier having one anode wired to a first output
30 terminal and one cathode wired to a first input terminal;
- a second half-wave rectifier having one anode wired to the first output terminal and one cathode wired to a second input terminal;

- a third half-wave rectifier having one anode wired to the first input terminal and one cathode wired to a second output terminal; and
 - a fourth half-wave rectifier having one anode wired to the second input terminal and one cathode wired to the second output terminal;
- 5 the full wave rectifier for providing an output of constant polarity from an input of variable polarity, wherein at least one half-wave rectifier comprises an electronic switch configured to be in its ON state when the current flowing through the cathode of the switch exceeds a predetermined threshold.

Preferably, the full-wave rectifier is provided wherein: the first half-wave
10 rectifiers comprises a first electronic switch configured to be in its ON setting when the current flowing through its cathode exceeds a first predetermined threshold, and the second half-wave rectifiers comprises a second electronic switch configured to be in its ON setting when the current flowing through its cathode exceeds a second predetermined threshold. Typically, at least one half-wave rectifier comprises an
15 electronic switch configured to be switched between its ON and OFF states in synchrony with the frequency of the input signal.

In certain embodiments, the full-wave rectifier is provided wherein:

- the first half-wave rectifier comprises a first electronic switch configured to be in its ON state when the current flowing through its
20 cathode exceeds a predetermined threshold;
- the second half-wave rectifiers comprises a second electronic switch configured to be in its ON state when the current flowing through its cathode exceeds a predetermined threshold;
- the third half-wave rectifiers comprises a third electronic switch configured to be switched between its ON and OFF states in phase
25 with the voltage signal at the second input terminal, and
- the fourth half-wave rectifiers comprises a third electronic switch configured to be switched between its ON and OFF states in phase with the voltage signal at the first input terminal.

30 Optionally, the electronic switch comprises a transistor. Preferably, the electronic switch comprises a MOSFET device.

Accordingly, a full-wave rectifier is disclosed wherein the electronic switch comprises:

- a MOSFET device comprising a source terminal, a drain terminal and a gate terminal;
- a half-wave rectifier wired to the source terminal and the drain terminal in parallel with the MOSFET device, and
- 5 ▪ a current monitor configured to monitor a drain-current flowing through the drain terminal and to send a gate signal to the gate terminal such that the MOSFET is switched to its ON state when the drain-current exceeds a first threshold current and the MOSFET is switched to its OFF state when the drain-current falls below a second threshold
- 10 current.

The current monitor may comprise a current transformer.

In a further embodiment the full-wave rectifier is incorporated into a power converter.

15 In an additional embodiment the present invention is directed to providing a power converter comprising a full-wave rectifier as described above.

Brief Description of the Figures

For a better understanding of the invention and to show how it may be carried into effect, reference will now be made, purely by way of example, to the accompanying drawings.

5 With specific reference now to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention Only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no
10 attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention; the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice. In the accompanying drawings:

Fig. 1a is a circuit diagram of a full-wave diode bridge rectifier of the prior art;

15 Fig. 1b is a diagram of a Power MOSFET of the prior art;

Fig. 2 is a block diagram of a first synchronous full-wave rectifier in which two of the diodes of the diode bridge of Fig. 1 have been replaced by electronic switches;

20 Fig. 3a is a block diagram of a second synchronous full-wave rectifier according to an exemplary embodiment of the invention in which all four diodes of the diode bridge of Fig. 1 have been replaced by electronic switches;

Fig. 3b is a schematic diagram showing a current triggered Power MOSFET which draws a gate signal from the current flowing through its drain terminal;

25 Fig. 3c is a graphical representation of the variations in drain-current and state of the MOSFET of Fig. 3b, over a single cycle of a sinusoidal input voltage, and

Fig. 4 is a circuit diagram representing a synchronous full-wave MOSFET bridge rectifier according to another embodiment of the invention.

Description of the Preferred Embodiments

Reference is now made to Fig. 1a showing a circuit diagram of a typical full-wave rectifier 100 of the prior art. The rectifier has two input terminals T_1 and T_2 and two output terminals T_3 and T_4 . When an alternating current source AC_{in} is wired to the two input terminals T_1 and T_2 , a direct current output DC_{out} may be drawn from the two output terminals T_3 and T_4 of the rectifier 100.

Four diodes D_{1-4} are arranged so that two diodes D_1 and D_2 form a first branch 110 of a Graetz circuit and the other two diodes D_3 and D_4 form a second branch 120 of the Graetz circuit. The anodes of two upstream diodes D_1 and D_3 are wired to the first output terminal T_3 and the cathodes of the two downstream diodes D_2 and D_4 are wired to the second output terminal T_4 . The cathode of the first upstream diode D_1 and the anode of first downstream diode D_2 are wired to the first input terminal T_1 and the cathode of the second upstream diode D_3 and the anode of second downstream diode D_4 are wired to the second input terminal T_2 .

When the polarity of the first input terminal T_1 is positive relative to the second input terminal T_2 , current flows through the first downstream diode D_2 and through the second upstream diode D_3 . When the polarity of the first input terminal T_1 is negative relative to the second input terminal T_2 , current flows through the second downstream diode D_4 and through the first upstream diode D_1 .

Diode bridge rectifiers, such as that shown in Fig. 1a, are used to produce an output with a fixed polarity that is independent of the polarity of the input. Such diode bridge rectifiers may be used in AC-to-DC power converters, for example. Optionally, the output is smoothed by a smoothing capacitor C .

It will be appreciated that power is lost from each diode with each reversal of polarity. In high frequency power converters, where the polarity of the input terminals T_1 and T_2 may oscillate at a frequencies of 100 kHz or more, such power losses may result in significant heating of the bridge circuit and its surrounding components, which may result in reduced reliability or failure.

Power loss may be reduced by replacing diodes with electronic switches, such as the Power MOSFETs shown in Fig. 1a, which have much lower associated power loss. Fig. 2 is a block diagram of one such synchronous full-wave rectifier 200 in which the first downstream diode D_2 and the second downstream diode D_4 of the diode bridge of Fig. 1a have been replaced by two electronic switches M_2 and M_4 .

The electronic switches M_2 and M_4 are controlled by switching signals G_2 and G_4 which switch them between the ON and OFF states. The switching signal G_2 controlling the electronic switch M_2 must be synchronized to switch to the ON state whenever the polarity of the first input terminal T_1 is positive relative to the second input terminal T_2 . The switching signal G_4 controlling the electronic switch M_4 must be synchronized to switch to the ON state whenever polarity of the first input terminal T_1 is negative relative to the second input terminal T_2 .

Typically, this synchronization is achieved by drawing the first switching signal G_2 from the voltage of the second input terminal T_2 and drawing the second switching signal G_4 from the voltage of the first input terminal T_1 .

The above described synchronous full-wave rectifier 200 in which two diodes are replaced by MOSFETs may reduce power loss from the rectifier by up to 50% as compared with the diode bridge rectifier 100 of the prior art. Where further reduction in power loss is required it would be desirable to replace the remaining two diodes D_1 and D_3 with electronic switches. However, it is much more difficult to synchronize four electronic switches without inadvertently causing short circuits between either the input or output terminals.

Fig. 3a is a block diagram of a second synchronous full-wave rectifier 300 in which all four diodes D_{1-4} of the diode bridge of Fig. 1a have been replaced by electronic switches M_{1-4} . In order to provide an output DC_{out} of constant polarity, the switching signals G_{1-4} need to be carefully controlled.

When the polarity of the first input terminal T_1 is positive relative to the polarity of the second input T_2 , the first upstream and second downstream electronic switches M_1 and M_4 must be switched to the OFF state and the first downstream and second upstream electronic switches M_2 and M_3 must be switched to the ON state. When the polarity of the first input terminal T_1 is negative relative to the polarity of the second input terminal T_2 , the first upstream and second downstream electronic switches M_1 and M_4 must be switched to the ON state and the electronic switches first downstream and second upstream electronic M_2 and M_3 must be switched to the OFF state.

Synchronization of the switching signals G_{1-4} , is complicated by an additional constraint. In order to prevent shorting across the output terminals, the upstream and

downstream electronic switches along a common branch 310, 320 must never be in the ON state at the same time. In practice, when both of the switching signals G_1 and G_2 controlling the two electronic switches M_1 and M_2 along the first branch 310 are each drawn from one of the input terminals T_1 and T_2 , the two switches M_1 and M_2 are periodically both in their ON states. Because the switches M_1 and M_2 are adjacent along the first branch 310 of the circuit, a short circuit is formed between the output terminals T_3 and T_4 . Similar shorting may occur along the second branch 320 when the switching signals G_3 and G_4 which control the other two electronic switches M_3 and M_4 are each drawn from one of the input terminals T_1 and T_2 .

According to preferred embodiments of the invention, only the switching signals G_2 and G_4 for the downstream electronic switches M_2 and M_4 are drawn directly from the voltage at the input terminals T_1 and T_2 whilst the switching signals G_1 and G_3 for the upstream switches M_1 and M_3 are controlled independently. Preferably, the switching signals G_1 and G_3 are responsive to changes in the cathode current of switches M_1 and M_3 respectively.

Fig. 3b shows a current-triggered synchro-rectifier 330 according to an exemplary embodiment of the invention, which may serve as an electronic switch M incorporated into a bridge synchro-rectifier 300. The current-triggered synchro-rectifier 330 includes a Power MOSFET 130, such as that shown in Fig. 1b, and a current monitor 332. The current monitor 332 is wired to the drain terminal 136 of the Power MOSFET 130 and is configured to send a current-based gate signal G_i to the gate terminal 138 of the Power MOSFET when the drain-current I_d exceeds a predetermined threshold I_{th} . Although in the above example the current-triggered synchro-rectifier 330 includes an n-channel MOSFET 130, it will be appreciated that in other embodiments current-triggered synchro-rectifiers may incorporate p-channel MOSFETs.

In order to understand the functioning of the current-triggered synchro-rectifier 330 consider the case where a sinusoidal alternating voltage is connected across the cathode 334 and the anode 336 terminals of the current-triggered synchro-rectifier 330. Fig. 3c shows three graphs showing variations in 1) the voltage drop V_d from the cathode 334 to the anode 336, 2) the drain-current I_d , and 3) the MOSFET state during one voltage cycle.

- For the first half of the sinusoidal cycle the voltage drop V_d between the cathode 334 and the anode 336 is negative, thus the polarity of the cathode 334 is negative relative to the anode 336. Consequently, no current flows through the drain-terminal 136 and the MOSFET remains in the OFF state.
- 5 ▪ At the beginning of the second half of the sinusoidal cycle, the voltage drop V_d between the cathode 334 and the anode 336 increases above zero. The polarity of the cathode 334 becomes positive relative to the anode.336 so a small drain-current I_d begins to flow through the diode 132. This current is measured by the current monitor 332.
- 10 ▪ During the third quarter of the cycle, the voltage drop V_d between the cathode 334 and the anode 336 continues to rise. The current monitor 332 measures an increasing drain-current I_d .
- When the drain-current I_d exceeds the predetermined threshold I_{th} , the current-based gate signal G_i triggers the MOSFET 130 to switch to the ON state.
- 15 ▪ As long as the MOSFET 130 is in the ON state, current flows through the ohmic conductive path of the electronic switch 131. Consequently, the drain-current I_d varies in proportion to the voltage drop V_d .
- During the last quarter of the cycle, the voltage drop V_d between the cathode 334 and the anode 336 decreases. The current monitor 332 measures a decreasing drain-current I_d .
- 20 ▪ When the drain-current falls below the predetermined threshold I_{th} , the current-based gate signal G_i triggers the MOSFET 130 to switch to the OFF state.

Fig. 4 is a circuit diagram representing a synchronous full-wave bridge rectifier 400 according to an exemplary embodiment of the invention.

- 25 The electronic switches M_{1-4} of the exemplary embodiment are all MOSFET transformers having three terminals: a source terminal, a drain terminal and a gate terminal. The upstream MOSFETs M_1 and M_3 are both n-channel MOSFETs and their source terminals are both wired to the first output terminal T_3 of the rectifier. The downstream MOSFETs M_2 and M_4 are both p-channel MOSFETs and their source terminals are both wired to the second output terminal T_4 of the rectifier. The drain terminals of the first upstream MOSFET M_1 and the first downstream MOSFET M_2
- 30

are both wired to the first input terminal T_1 of the rectifier and the drain terminals of the second upstream MOSFET M_3 and the second downstream MOSFET M_4 are both wired to the second input terminal T_3 of the rectifier.

5 The input terminals T_1 and T_2 are wired to a secondary coil L_2 of a power transformer which is inductively coupled to a primary coil (not shown). The secondary coil L_2 provides an alternating current input to the two input terminals T_1 and T_2 .

The gate terminals of the downstream MOSFETs M_2 and M_4 are wired to the input terminals T_2 and T_1 via smoothing circuits 420, 440 respectively. The switching
10 signals G_2 and G_4 , are therefore in out of phase with each other.

The gate terminals of the upstream MOSFETs M_1 and M_3 receive switching signals G_1 and G_3 driven by their own drain-currents I_{d1} and I_{d3} . The drain current I_{d1} of the first upstream MOSFET M_1 is monitored by a first current transformer 410, in which a primary current monitor coil CT_{1P} transfers the current signal to a secondary
15 current monitor CT_{2S} the output of which is rectified and relayed to a first input IN_1 of a driver 450 which amplifies the signal before outputting a signal from a first output OUT_1 . This first output signal from the driver is then fed back to the first upstream MOSFET M_1 such that when the drain current I_{d1} exceeds a threshold value the MOSFET M_1 switches itself to the ON state. This produces a switching signal G_1 at
20 the same frequency as the alternating current input AC_{in} .

Similarly the drain current I_{d3} of the second upstream MOSFET M_2 is monitored by a second current transformer 430, in which a primary current monitor coil CT_{2P} transfers the current signal to a secondary current monitor CT_{2S} the output of which is rectified and relayed to a second input IN_2 of the driver 450 which
25 amplifies the signal before outputting a signal from a second output OUT_2 . The second output signal from the driver is then fed back to the second upstream MOSFET M_3 such that when the drain current I_{d2} exceeds a threshold value the MOSFET M_3 switches itself to the ON state. This produces a switching signal G_3 at the same frequency as the alternating current input AC_{in} .

30 Although in the example hereabove, current transformers 410, 430 are used to monitor the drain-currents I_{d1} , I_{d2} , in alternative embodiments other current monitors such as ammeters, galvanometers, Hall effect sensors or the like may be preferred.

The scope of the present invention is defined by the appended claims and includes both combinations and sub combinations of the various features described hereinabove as well as variations and modifications thereof, which would occur to persons skilled in the art upon reading the foregoing description.

- 5 In the claims, the word “comprise”, and variations thereof such as “comprises”, “comprising” and the like indicate that the components listed are included, but not generally to the exclusion of other components.

Claims

1. A current-triggered synchro-rectifier comprising an electronic switch having an anode and a cathode, said electronic switch configured to be in its ON setting when current flowing through said cathode exceeds a predetermined threshold.
- 5 2. The current-triggered synchro-rectifier of claim 1 wherein said electronic switch comprises:
a MOSFET device that comprises a source terminal, a drain terminal and a gate terminal;
a half-wave rectifier in parallel with said MOSFET device, wired to the source
10 terminal and the drain terminal of the MOSFET device,
and a current monitor configured to monitor a drain-current flowing through the drain terminal and to send a gate signal to said gate terminal,
such that said MOSFET is switched to its ON state when said drain-current exceeds a first threshold current and said MOSFET is switched to its OFF state
15 when said drain-current falls below a second threshold current.
3. The current-triggered synchro-rectifier of claim 2 wherein said current monitor comprises a current transformer.
4. A full-wave rectifier, comprising:
 - a. a first half-wave rectifier having one anode wired to a first output terminal
20 and one cathode wired to a first input terminal;
 - b. a second half-wave rectifier having one anode wired to said first output terminal and one cathode wired to a second input terminal;
 - c. a third half-wave rectifier having one anode wired to said first input terminal and one cathode wired to a second output terminal; and
 - 25 d. a fourth half-wave rectifier having one anode wired to said second input terminal and one cathode wired to said second output terminal;the full-wave rectifier for providing an output of constant polarity from an input of variable polarity, wherein at least one half-wave rectifier comprises the current-triggered synchro-rectifier of claim 1.
- 30 5. A full-wave rectifier comprising

- a. a first half-wave rectifier having one anode wired to a first output terminal and one cathode wired to a first input terminal;
- b. a second half-wave rectifier having one anode wired to said first output terminal and one cathode wired to a second input terminal;
- 5 c. a third half-wave rectifier having one anode wired to said first input terminal and one cathode wired to a second output terminal; and
- d. a fourth half-wave rectifier having one anode wired to said second input terminal and one cathode wired to said second output terminal;

10 the full wave rectifier for providing an output of constant polarity from an input of variable polarity, wherein at least one half-wave rectifier comprises an electronic switch configured to be in its ON state when the current flowing through the cathode of said switch exceeds a predetermined threshold.

6. The full-wave rectifier of claim 5 wherein:

- 15 a. said first half-wave rectifiers comprises a first electronic switch configured to be in its ON setting when the current flowing through its cathode exceeds a first predetermined threshold, and
- b. said second half-wave rectifiers comprises a second electronic switch configured to be in its ON setting when the current flowing through its cathode exceeds a second predetermined threshold.

20 7. The full-wave rectifier of claim 5 wherein at least one half-wave rectifier comprises an electronic switch configured to be switched between its ON and OFF states in synchrony with the frequency of the input signal.

8. The full-wave rectifier of claim 5 wherein:

- 25 a. said first half-wave rectifier comprises a first electronic switch configured to be in its ON state when the current flowing through its cathode exceeds a predetermined threshold;
- b. said second half-wave rectifiers comprises a second electronic switch configured to be in its ON state when the current flowing through its cathode exceeds a predetermined threshold;

- c. said third half-wave rectifiers comprises a third electronic switch configured to be switched between its ON and OFF states in phase with the voltage signal at said second input terminal, and
- d. said fourth half-wave rectifiers comprises a third electronic switch
5 configured to be switched between its ON and OFF states in phase with the voltage signal at said first input terminal.
9. The full-wave rectifier of claim 5 wherein said electronic switch comprises a transistor.
10. The full-wave rectifier of claim 5 wherein said electronic switch comprises a
10 MOSFET device.
11. The full-wave rectifier of claim 5 wherein said electronic switch comprises:
a MOSFET device comprising a source terminal, a drain terminal and a gate terminal;
a half-wave rectifier wired to said source terminal and said drain terminal in
15 parallel with said MOSFET device, and
a current monitor configured to monitor a drain-current flowing through said drain terminal and to send a gate signal to said gate terminal such that said MOSFET is switched to its ON state when said drain-current exceeds a first threshold current and said MOSFET is switched to its OFF state when said drain-
20 current falls below a second threshold current.
12. The full-wave rectifier of claim 11 wherein said current monitor comprises a current transformer.
13. The full-wave rectifier of claim 5 incorporated into a power converter.
14. A power converter comprising a full-wave rectifier of claim 5.

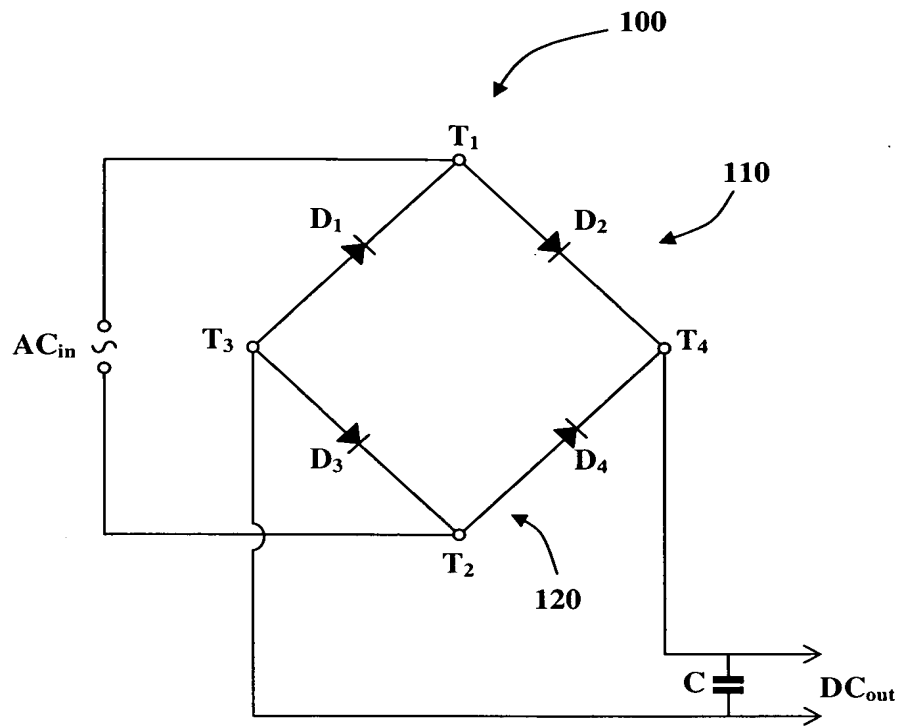


Fig. 1a

PRIOR ART

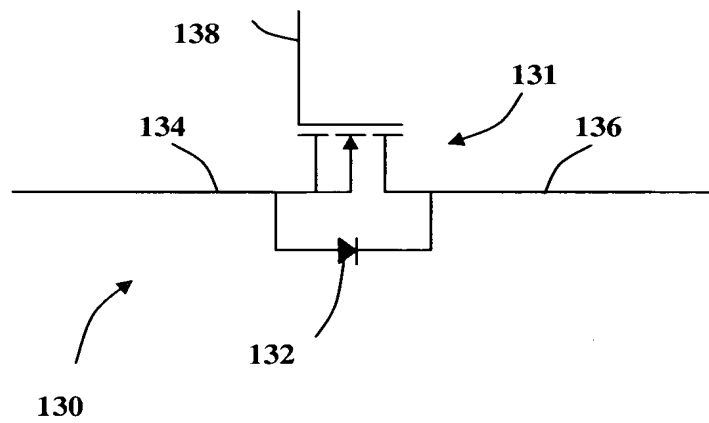


Fig. 1b

PRIOR ART

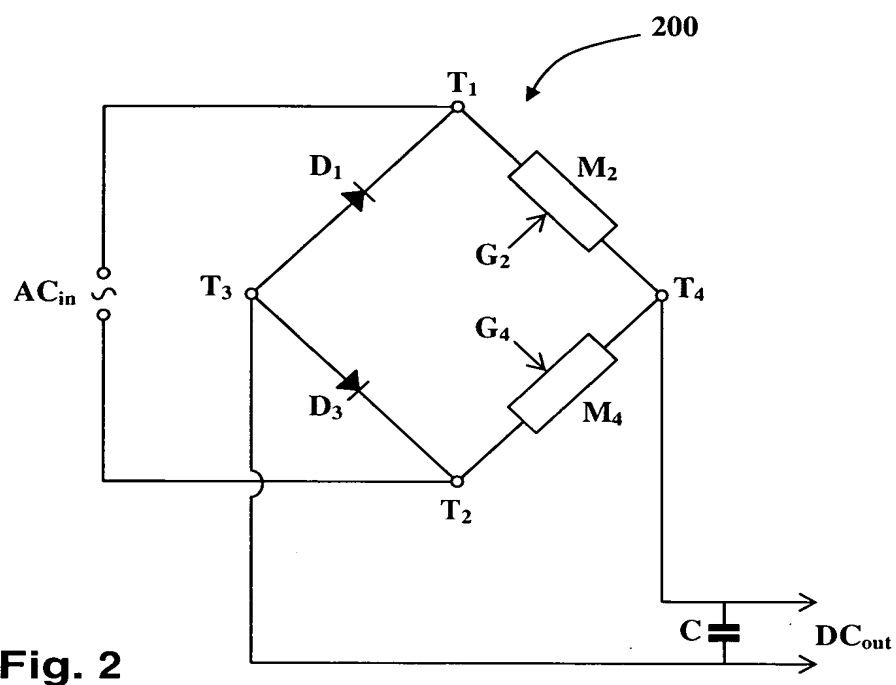


Fig. 2

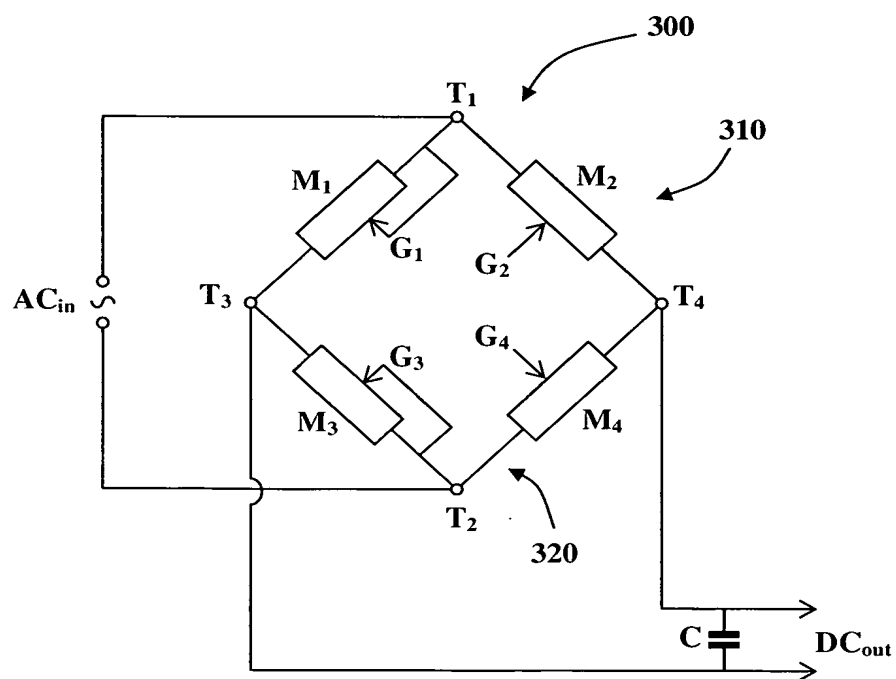


Fig. 3a

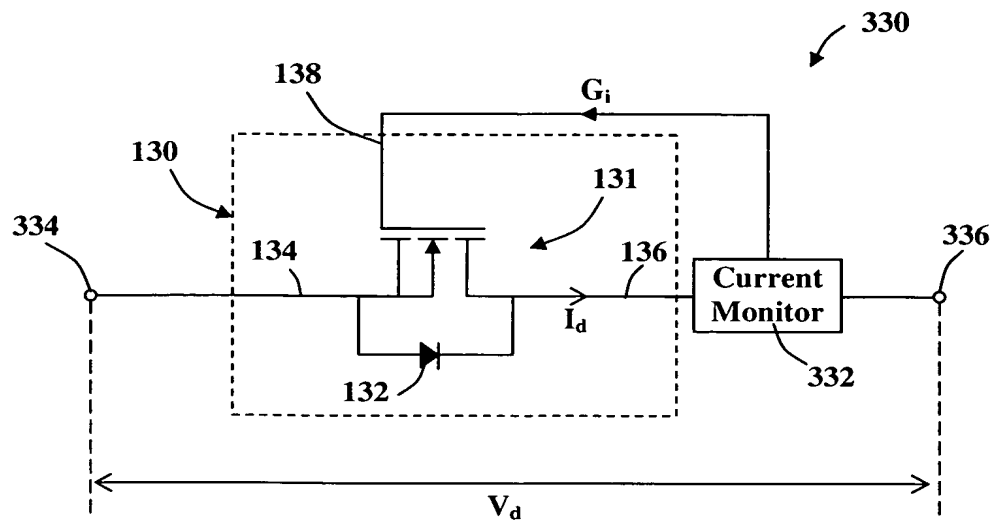


Fig. 3b

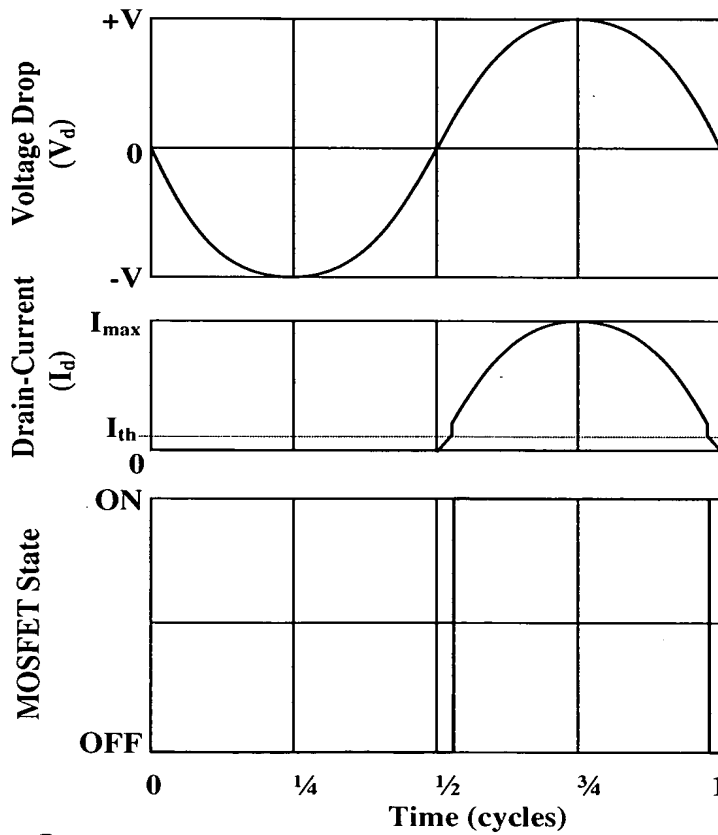


Fig. 3c

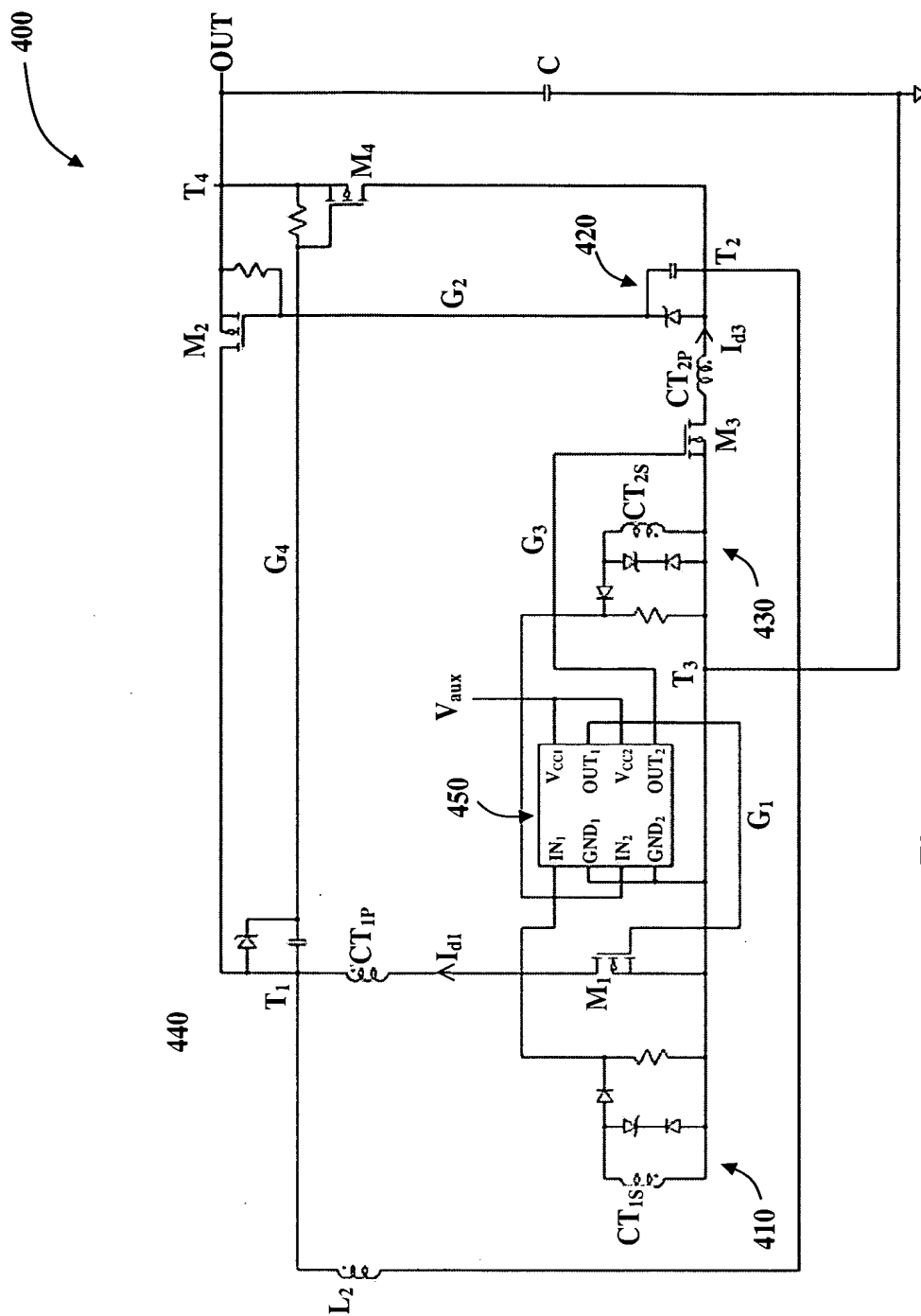


Fig. 4

PATENT APPLICATION SERIAL NO. _____

**U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET**

04/16/2008 SZEWDIE1 00000120 61071151

01 FC:2005

105.00 OP

**PTO-1556
(5/87)**