January 28, 2016

Patent Office Commissioner

1. Presentation of Case

Patent Application H9-129403

2. Claimant

Postal code	163-0434
Address	Sonoda & Kobayashi Patent Office Shinjuku Mitsui Building 34th Floor 2-1-1 Nishishinjuku, Shinjuku-ku, Tokyo
Name	SONODA, Yoshitaka

3. Name of Document Related to Evidence

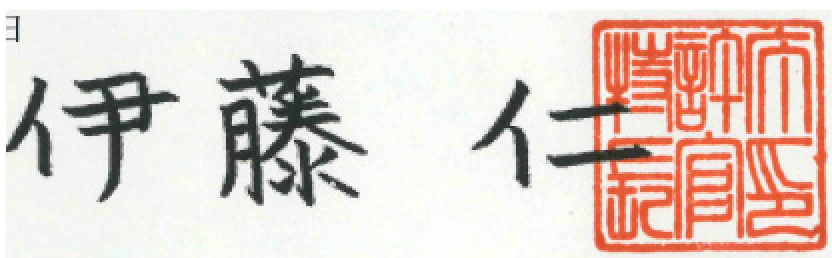
Japanese Unexamined Patent Application H10-323028

Please attest that the items shown in Name of Document Related to Evidence are true and correct.

I attest that the Name of Document Related to Evidence is true and correct.

February 5, 2016

Patent Office Commissioner ITO, Hitoshi



2016 Proof of Application 600071

(19) Japanese Patent Office (12) Publication of Unexamined Patent Application (A)
(11) *Kokai* number
Kokai number H10(1998)-323028
(43) Date of Publication of Unexamined Patent Application: December 4, 1998

(51) Int. Cl.^{6}	Identification Symbol	FI	
H02M 3/155		H02M 3/155	P
			H

Request for Examination: Not Requested. Number of Claims: 3. OL (8 Pages Total)

(21) Application Number: Application Number H9(1997)-129403
(22) Filing Date: May 20, 1997

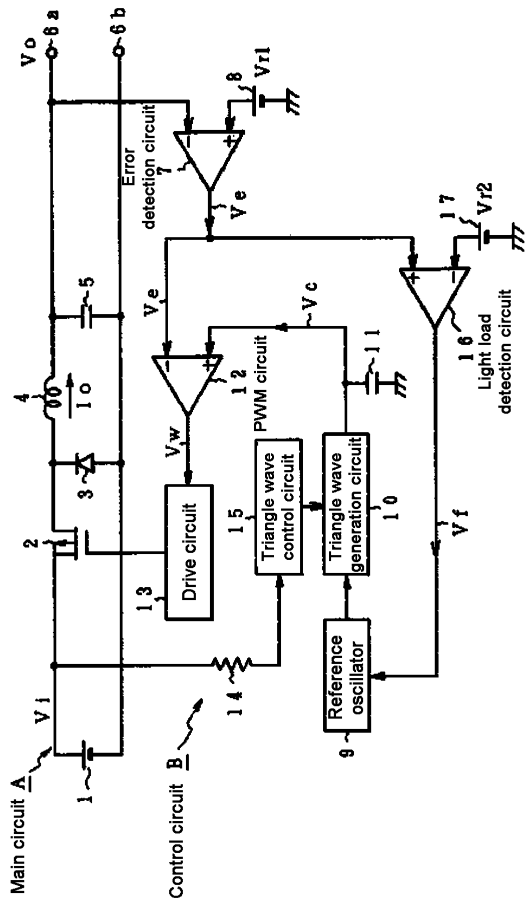
(71) Applicant 000103208
Cosel Co., Ltd.
1-6-43 Kamiakae-machi, Toyama
(71) Applicant 000005821
Matsushita Electric Industrial Co., Ltd.
1006, Oaza Kadoma, Kadoma-city, Osaka
(72) Inventor Seiji Oda
c/o Cosel Co., Ltd.
1-6-43 Kamiakae-machi, Toyama
(72) Inventor Mikio Motomori
c/o Matsushita Electric Industrial Co., Ltd.
1006, Oaza Kadoma, Kadoma-city, Osaka
(74) Agent Susumu Takeuchi, Patent Attorney (*et al* 1 person)

(54) Title of the Invention: DC-DC CONVERTER

(57) ABSTRACT

Problem: To reduce a switching frequency by accurately detecting, based on an error voltage, light load conditions characterized by small load currents.

Resolution means:Using a triangle wave control circuit 15, change the voltage gradient (dV/dt) of the triangle wave voltage Vc generated by the triangle wave generation circuit 10 so as to be nearly proportional to input voltage Vi, and at a load state where a current flows continuously through a choke coil 4, change the voltage gradient of the triangle wave voltage Vc proportionally to the input voltage Vi to maintain a constant error voltage Ve. In a light load state where the current flowing through the choke becomes discontinuous, a decrease in error voltage Ve accompanying a decrease in output current Io is tolerated. At this time, a light load detection circuit 21 can detect when the error voltage Ve falls below a second reference voltage Vr2, and then the oscillation frequency of a reference circuit oscillator 9 is reduced.



What Is Claimed Is:

1. In a DC-DC converter comprising:

a main circuit which converts an input voltage into a pulsed voltage by driving a switching element on and off and then rectifies and smoothes out the voltage, and supplies a predetermined step-down output voltage to the load;

an error detection circuit that detects an error between said output voltage and a predetermined 1st reference voltage to output an error voltage;

a reference oscillator that produces a reference pulse signal with a constant period;

a triangle wave generation circuit that generates a triangle wave voltage synchronized to said reference pulse signal;

a pulse-width modulation circuit that compares said error voltage to said triangle wave voltage and generates a pulse-width modulation signal with a corresponding width based on the comparison result; and

a drive circuit for driving said switching element using said pulse-width modulation signal;

the DC-DC converter characterized by:

a triangle wave control circuit that changes the voltage gradient of the triangle wave voltage generated by said triangle wave generation circuit so as to be nearly proportional to said input voltage; and

a light load detection circuit that detects when the error voltage of said error detection circuit falls below a predetermined 2nd reference voltage due to a decrease in output current relative to the load, and then decreases the oscillation frequency of said reference oscillator.

2. The DC-DC converter according Claim 1, wherein said DC-DC converter is characterized in that:

in a state where the current flowing through the choke coil of said main circuit is continuous, said triangle wave control circuit changes the voltage gradient of said triangle wave voltage proportionally to the input voltage to keep said error voltage constant, and in a light load state where said current flowing to said choke becomes discontinuous, the error voltage is allowed to fall commensurately with a reduction in the output current.

3. The DC-DC converter according to Claim 1, wherein said DC-DC converter is characterized in that:

said light load detection circuit, upon detecting that the error voltage falls at or below the 2nd reference voltage, reduces the reference oscillation frequency of said reference oscillator to a range of between 1/5 to 1/100.

DETAILED EXPLANATION OF THE INVENTION

Field of the Invention

[0001]

The present invention relates to a step-down type DC-DC converter, and more particularly to a DC-DC converter that implements control so as to reduce losses by decreasing the switching frequency during light loads when the output current is low.

DESCRIPTION OF THE RELATED ART

[0002]

Conventionally, DC-DC converter control circuits of the type described herein were as shown in, for example, FIG. 9 and FIG. 10. In FIG. 9, a main circuit A that performs step-down type DC-DC conversion converts input voltage Vi coming from a battery or other input voltage source 1 into a pulsed voltage by driving a FET 2 on and off, rectifies the pulsed voltage with a diode 3, smoothes out the rectified voltage with a choke coil 4 and capacitor 5, and then supplies a specified stepped down output voltage Vo from output terminals 6a and 6b to the load.

[0003]

A control circuit B uses an error detection circuit 7 to generate an error voltage Ve that indicates the error between the output voltage Vo and a 1st reference voltage Vr1 of a reference voltage power source 8 that has been preset in order to acquire the specified output voltage. A reference oscillator 9 is provided to generate a periodic reference pulse signal determined by a reference oscillation frequency fo, and a triangle wave generation circuit 10 uses the discharging and charging of a capacitor 11 to generate a triangle wave voltage Vc.

[0004]

The error voltage Ve and the triangle wave voltage Vc are input into a pulse-width modulation control circuit 12 comprising a comparator, and are converted into a pulse-width modulation signal as a pulse having a width corresponding to the error voltage. A drive circuit 13 then correspondingly drives the FET 2, which is a switching element of the main circuit A, controlling the output voltage Vo to a specific constant voltage determined by the 1st reference voltage. Moreover, a light load detection circuit 23 is provided in order to reduce losses by reducing the switching frequency at light loads when the output load current is small. The main circuit A choke coil 4 is connected in series to a current detection resistor 25, which provides a current detection voltage Vs proportional to the load current to the light load detection circuit 23. The light load detection circuit 23 includes a comparator to reduce the oscillating frequency of the reference oscillator 9 through its comparison output when the current detecting voltage Vs is less than or equal to a reference voltage Vr3 from a reference voltage source 24, whose value is set to detect light loads.

[0005]

The DC-DC convertor in FIG. 10 has basically the same main circuit A and control circuit B as FIG. 9. However, in FIG. 10, the light load detection circuit 26 helps reduce losses by decreasing the switching frequency during a light load state when the output current is small, and reduces the oscillating frequency of the reference oscillator 9 through a comparative output from when the error voltage Ve of the error detection circuit 7 is input and is less than or equal to a reference voltage Vr4 from a reference voltage supply 27 used for detecting light loads.

PROBLEMS THAT THE INVENTION IS TO SOLVE

[0006]

However, conventional DC-DC converters such as the above which decrease the switching frequency during a light load state when the output current is small relative to the load in order to reduce loss have the following problems. First, in the DC-DC converter in FIG. 9, the method for detecting the output current involves detecting a voltage drop by inserting a current detection resistor 25 in the line through which the output current flows, but this produces a loss, due to the current detection resistor 25, which worsens the efficiency of the DC-DC converter.
[0007]
In the DC-DC converter in FIG. 10, the output current during a light load state is detected through a reduction in the error voltage Ve of the error detection circuit 7, but because the error voltage Ve of the error detection circuit 7 is also changed significantly by variations in the input voltage Vi, there is a problem because a decrease in output current due to light load may not be accurately detected using this error voltage Ve. The present invention was created in contemplation of the conventional problems described above, and the object of the present invention is to provide a DC-DC converter that can decrease the switching frequency based on an accurate detection, through the error voltage, of light loads characterized by small load currents.

MEANS OF SOLVING THE PROBLEMS

[0008]
The DC-DC converter in the present invention is comprised as described below to achieve this object. First, an object of the present invention is to provide a step-down type DC-DC converter comprising: a main circuit which uses on and off driving of a switching element to convert input voltage into a pulsed voltage then rectifies and smoothes out the voltage, and supplies a predetermined step-down output voltage Vo to the load; an error detection circuit that detects an error between the output voltage Vo and a predetermined 1st reference voltage Vr1 and generates a corresponding error voltage Ve; a reference oscillator for generating a reference pulse signal having a constant period (reference frequency fo); a triangle wave generation circuit that generates a triangle wave voltage Vc synchronized to the reference pulses; a pulse-width modulation circuit that generates a pulse-width modulation signal as a result of comparing the error voltage Ve to the triangle wave voltage Vc; and a drive circuit for driving the switching element using the pulse-width modulation signal.
[0009]
The step-down type converter in the present invention is characterized in that it comprises: a triangle wave control circuit that changes the voltage gradient (dV/dt) of the triangle wave voltage Vc generated by the triangle wave generation circuit so as to be nearly proportional to the input voltage Vi; and a light load detection circuit that detects when the error voltage Ve of the error detection circuit falls below a predetermined 2nd reference voltage Vr2 due to a decrease in output load current, and decreases the oscillation frequency of the reference oscillator in response thereto.
[0010]
In a state where the current flowing through the choke coil of the main circuit is continuous, the triangle wave control circuit maintains the error voltage Ve at a constant value by changing the voltage gradient of the triangle wave voltage Vc in proportion to the input voltage Vi. However, for lighter loads where the current flowing through the choke becomes discontinuous, the error voltage Ve is allowed to fall in proportion to a decrease in output current Io, which enables the detection of a light load by the light load detection circuit based on the error voltage Ve .
[0011]

When the light load detection circuit detects that the error voltage has fallen to be at or below the 2nd reference voltage Vr2, the reference oscillation frequency of the reference oscillator is reduced by a factor of 1/5 to 1/100. In this way, in a load state where the current flowing through the choke coil is continuous, the step-down DC-DC converter of the present invention is able to maintain the error voltage Ve at a constant value despite variation in the input voltage Vi by changing the voltage gradient (dV/dt) of the triangle wave voltage Vc using pulse width modulation proportionally to the input voltage Vi so that there will be no false detection of light load.

[0012]

For lighter loads, however, the current flowing through the choke coil becomes discontinuous and the output current Io decreases as a result. Because of this, the voltage Ve will also fall in proportion to the reduction in the output current Io, and if this voltage falls to be at or below the 2nd preset reference voltage AVr2, a light load state may be accurately detected so that the oscillation frequency of the reference oscillator can be reduced.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013]

FIG. 1 is a circuit block diagram of a preferred embodiment of a step-down type DC-DC converter according to the present invention. In FIG. 1, the DC-DC converter of the present invention comprises a main circuit A and a control circuit B. The main circuit A provides an input voltage Vi supplied from an input voltage source 1, such as a battery, to the FET 2 switching element, converts the input voltage Vi into a pulsed voltage by driving the FET 2 on and off, rectifies the voltage with a diode 3, ultimately smoothes out the voltage with the choke coil 4 and capacitor 5, thus converting the input voltage Vi into a stepped down specified output voltage Vo, which is supplied to the load.

[0014]

On the other hand, the error detection circuit 7 of the control circuit B generates an error voltage Ve by comparing the output voltage Vo of the main circuit A with a 1st reference voltage Vr1 set by the reference voltage supply 8. Also, a reference oscillator 9 provides a reference pulse signal having a reference period (reference oscillation frequency fo) to the triangle wave generation circuit 10, in which the triangle wave voltage Vc is generated by discharging and charging the capacitor 11 in the output stage of the triangle wave generation circuit 10 using the reference pulse signal.

[0015]

The error voltage Ve from the error detection circuit 7 and the triangle wave voltage Vc from the triangle wave generation circuit 10 are input to a PWM circuit (pulse-width modulation circuit) 12, and are converted into pulse-width modulation signal Vw, which is the pulse width that becomes the ON duty corresponding to the error voltage Ve. The PWM circuit 12 provides the pulse-width modulation signal Vw to a drive circuit 13, which then turns the FET 2 in the main circuit A off and on.

[0016]

In the control circuit B of the present invention, a triangle wave control circuit 15 is provided for the triangle wave generation circuit 10. The triangle wave control circuit 15 receives at its input the input voltage Vi from the main circuit A via a resistor 14, and changes the time gradient (dV/dt) of the triangle wave voltage generated by the triangle wave generation circuit 10 proportionally to the input voltage Vi, thereby preventing the output voltage Vo from being affected even if the input voltage Vi fluctuates.

[0017]

FIG. 2 is a schematic of the PWM circuit 12 and drive circuit 13 of the preferred embodiment together with the triangle wave generation circuit 10 and the triangle wave control circuit 15 from FIG. 1. FIG. 3 shows the signal waveforms of each portion shown in FIG. 2. As shown in FIG. 3 (A), the reference oscillator 9 outputs a reference pulse signal with a period T at its Q output. The triangle wave generation circuit 10 receives the reference pulse signal from the Q output of the reference oscillator 16 at the base of a transistor 19 to generate the triangle wave voltage Vc by discharging and charging the capacitor 11 through driving the transistor 19.

[0018]

Namely, when the Q output of the reference oscillator 9 is at the L level, the transistor 19 is off and the capacitor 11 will be charged by the charging current Ic flowing from a constant current source 18 provided in the triangle wave control circuit 15. During this charging, the upper limit value Vmax of the charging voltage is limited by a zener diode 21. When the Q output of the reference oscillator 9 is at the H level, the transistor 19 turns on thus carrying out the discharging of the capacitor 11. During this discharging, the lower limit Vmin of the discharging voltage of the capacitor 11 is limited by a reference voltage source 20.

[0019]

The triangle wave voltage Vc from the triangle wave generation circuit 10 is compared with the error voltage Ve by the PWM circuit 12, and is then converted into a pulse-width modulation signal Vw that has a pulse width corresponding to the error voltage Ve in FIG. 3 (D). The pulse-width modulation signal Vw is input to a NAND circuit 22 of the drive circuit 13, and the inverted logical product of the inverted Q output of the reference oscillator 9 in FIG. 3 (B) is taken in order to drive the FET 2 using the drive signal Vd that has a ON time t as in FIG. 3 (E).

[0020]

Thus, as shown in FIG. 3 (C), the triangle wave generation circuit 10 generates a triangle wave voltage Vc that changes between the lower limit Vmin and the upper limit Vmax synchronously to the Q output of the reference oscillator 9. The voltage gradient (dV/dt) of the triangle wave voltage Vc at this time is controlled by the triangle wave control circuit 15. The triangle wave control circuit 15 causes the charging current Ic flowing to the capacitor 11 to be proportional to the input voltage Vi by controlling the current source 18 so that

$$Ic = K \cdot Vi .$$

That is, when the input voltage Vi increases, the charging current Ic increases and the voltage gradient (dV/dt) of the triangle wave voltage Vc gets larger. When the input voltage Vi decreases, the charging current Ic decreases and the voltage gradient (dV/dt) of the triangle voltage Vc gets smaller.

[0021]

FIG. 4 shows the error voltage Ve and the triangle wave voltage Vc input to the PWM circuit 12 in FIG. 1 and the pulse width modulation signal that is extracted therefrom. In FIG. 4, T is the reference period for the oscillation pulse of the reference oscillator 9, and the triangle wave voltage Vc1 that is determined by the input voltage Vi is assumed to be the solid line voltage gradient (dV/dt) as shown. The PWM circuit 12 compares the error voltage Ve at that time to the triangle wave voltage Vc1, which changes with the voltage gradient (dc/dt) starting from the start timing of the reference period T. During on time t1, when the triangle wave voltage Vc1 is less than or equal to the error voltage Ve, a L level output is provided to the drive circuit 13 as shown in FIG. 3 (D) to cause the FET 2 to remain on during this on time t1 as shown in FIG. 3 (E).

[0022]

When the on time t1 passes and the triangle wave voltage Vc1 exceeds the error voltage Ve, then the PWM circuit 12 output changes from the L level to the H level, causing the FET 2 to be off during the remaining (T – t1) time. Thereafter, the FET 2 being on during time t1 and the FET 2 being off during time (T – t1) is repeated with each reference period T. If the input voltage Vi is increased, however, then the triangle wave control circuit 15 in FIG. 2 increases the charging current Ic sent from the constant current source 18 to the capacitor 11 in proportion to the increase in the input voltage Vi . Because of this, the voltage slope (dV/dt) increases as shown by the dotted line in FIG. 4 representing the triangle wave voltage Vc2, and the on-time is shortened to t1'.

[0023]

In this manner, by shortening the on time of the FET 2 in response to the increase of the input voltage Vi, the electric power supplied to the output side will be kept constant. Because of this, even if the input voltage Vi fluctuates, the control that the triangle wave control circuit 15 performs on the voltage gradient (dV/dt) of the triangle wave voltage Vc keeps the output voltage Vo constant, which in turn also causes the error voltage Ve from the error detection circuit 7 to be kept constant.

[0024]

This preservation of the error voltage Ve by using the triangle wave control circuit 15 to control the time gradient of the triangle wave voltage Vc in response to fluctuations in the input voltage Vi is only achieved when the current I flowing through the choke coil 4 flows continuously, even as the current I fluctuates as shown in FIG. 5 when the FET 2 is turned on and off with switching period T. FIG. 5 shows the current I that flows through the choke coil 4 corresponding to large, medium, and small output current Io load states, in which current flows continuously through the choke coil 4, until the lowest value of the output current Io becomes I=0 at the boundary of each period T. When the load becomes light, however, and the output current Io falls further, the current I that flows in the choke coil 4 goes into a discontinuous state wherein no current flows in the later portion of the reference period T, as shown in FIG. 6.

[0025]

When the current that flows through the choke coil 4 goes into a discontinuous state, as shown in FIG. 6, the error voltage Ve from the error detection circuit 7 also falls in accordance with the output current Io. That is, when the current flowing through choke coil 4 is discontinuous, a reduction in output current Io causes the output voltage Vo to increase, and, as a result, the error voltage Ve starts to decrease and the PWM circuit 12 executes control so as to shorten the on time of the pulse-width modulation signal Vw. Thus, the error voltage Ve decreases in accordance with the output current Io.

[0026]

In the embodiment shown in FIG. 1, the error voltage Ve from the error detection circuit 7 is input to a light load detection circuit 16, which comprises an amplifier, and in which the error voltage is compared to a 2nd reference Vr2, preset by reference voltage source 17, for detecting a light load. The oscillation frequency of the reference oscillator 9 is then decreased in accordance with the light load detection voltage Vf that is output from the light load detection circuit 16 when the error voltage Ve falls to be less than or equal to the 2nd reference voltage Vr2.

[0027]

FIG. 7 is a characteristic diagram of the output current Io and the error voltage Ve in the embodiment shown in FIG. 1. For the output current Io, shown on the horizontal axis, when the output current Io is greater than the choke critical current Io1 (at which point the even current from the choke 4 becomes discontinuous), including for the small Io output current in FIG. 5, the error voltage Ve will be constant. However, when the output current Io falls below the choke critical current Io1, the error detection voltage Ve will begin to fall.

[0028]

The 2nd reference voltage Vr2 that is to be compared to the error voltage Ve for starting the reduction of the switching frequency is set to correspond to a frequency switching current Io2. When the output current Io falls below this frequency switching current Io2, the light load detection voltage Vf from the light load detection circuit 16 in FIG. 1 is increased in accordance with the decrease in the error voltage Ve. Reference oscillator 9 is voltage-controlled so as to decrease the reference frequency proportionally to the increase in the detection voltage Vf from the light load detection circuit 16.

[0029]

FIG. 8 shows the controllability of the oscillation frequency of the reference oscillator 9 relative to the error voltage Ve. The vertical axis shows the oscillation frequency normalized to the reference oscillation frequency fo (frequency ratio f/fo), the reference oscillation frequency fo having a normalized value of 1.0 and corresponding to the steady state when the output current Io is greater than or equal to the choke critical current Io1. In FIG. 8, when the error voltage Ve becomes less than or equal to the 2nd reference voltage Vr2 corresponding to the choke critical current Io1[1], the light load detection circuit 16 in FIG. 1 increases the light load detection voltage Vf provided to the reference oscillator 9 in accordance with the decrease of the error voltage Ve, and thus the reference oscillator 9 linearly decreases the oscillation frequency in accordance with the increase of the light load detection voltage Vf.

[0030]

The reduction in the oscillation frequency of the reference oscillator 9 is limited to a range of between about 1/5 to 1/100 relative to the reference oscillation frequency having a 1.0 value. In FIG. 8, reduction is limited to 1/10 and the oscillation frequency remains constant after it decreases to 1/10. In this manner, the error detection voltage Ve in FIG. 7 gradually falls at a constant rate while the oscillation frequency in FIG. 8 is linearly reduced in accordance with the error voltage Ve. However, if output current falls further once the oscillation frequency has been reduced down to the minimum frequency, the error voltage Ve will drop more rapidly and will approach the PWM triangle wave lower limit value min. In this manner, by executing control so as to reduce the switching frequency when a light load state is detected based on the error voltage Ve, it is possible to reduce losses by lengthening the switching period of the FET 2.

[0031]

The present invention is not limited to the embodiments described above and may be modified as long as such modification does not deviate from the object of the present invention.

EFFECT OF THE INVENTION

[0032]

According to the present invention as described above, in a load state where the current flowing through the choke coil is in a continuous state, the voltage gradient of the triangle wave voltage used in pulse-width modulation is changed proportionally to the input voltage so that the error voltage becomes constant and is not affected by fluctuations in the input voltage. This enables the reliable prevention of malfunctions such as misdetection of light load states (and the corresponding reduction in the switching frequency) due to input voltage fluctuations.

[1] This is a typo and should say “frequency switching current Io2”

[0033]

On the other hand, when the current flowing through the choke coil becomes discontinuous during light loads, the error voltage will decrease in accordance with the output current reduction. By using this characteristic of detecting a light load when the error voltage is less than or equal to a predetermined reference voltage and decreasing the switching frequency in response thereto, it is possible to accurately detect a light load state and accurately control the reduction in the switching frequency.

[0034]

Thus, by decreasing the switching frequency it is possible to reduce losses during light loads, reduce the power consumption of battery driven devices during light loads, and extend the operating time of battery driven devices.

BRIEF EXPLANATION OF DRAWINGS

FIG. 1 Circuit block diagram of an embodiment of the present invention

FIG. 2 Schematic of triangle wave generation circuit and triangle wave control circuit according to FIG. 1

FIG. 3 Signal waveform diagram of each portion of FIG. 2

FIG. 4 Explanatory diagram of pulse-width modulation wherein the voltage gradient of the triangle wave voltage is changed in response to the input voltage

FIG. 5 Explanatory diagram of the load state when current continuously flows through the choke coil

FIG. 6 Explanatory diagram of the light load state when the current flowing through the choke coil becomes discontinuous

FIG. 7 Characteristic diagram of output current relative to error voltage according to the present invention

FIG. 8 Explanatory diagram showing a reduction in oscillation frequency when a light load is detected by the error voltage according to the present invention

FIG. 9 Circuit block diagram for the conventional detection of a light load state using a current detection resistance

FIG. 10 Circuit block diagram for the conventional detection of a light load state using an error voltage

[Description of the Reference Numerals]

A: Main circuit
B: Control circuit
1: Input voltage source
2: FET (switching element)
3: Diode (rectifying device)
4: Choke coil
5: Smoothing capacitor
6a, 6b: Output terminal
7: Error detection circuit
8, 17, 20: Reference voltage source
9: Reference oscillator
10: Triangle wave generation circuit
11: Capacitor

12: Pulse-width modulation circuit (PWM circuit)
13: Drive circuit
14: Resistor
15: Triangle wave control circuit
16: Light load detection circuit
18: Current source
19: Transistor
21: Zener diode

FIG. 1

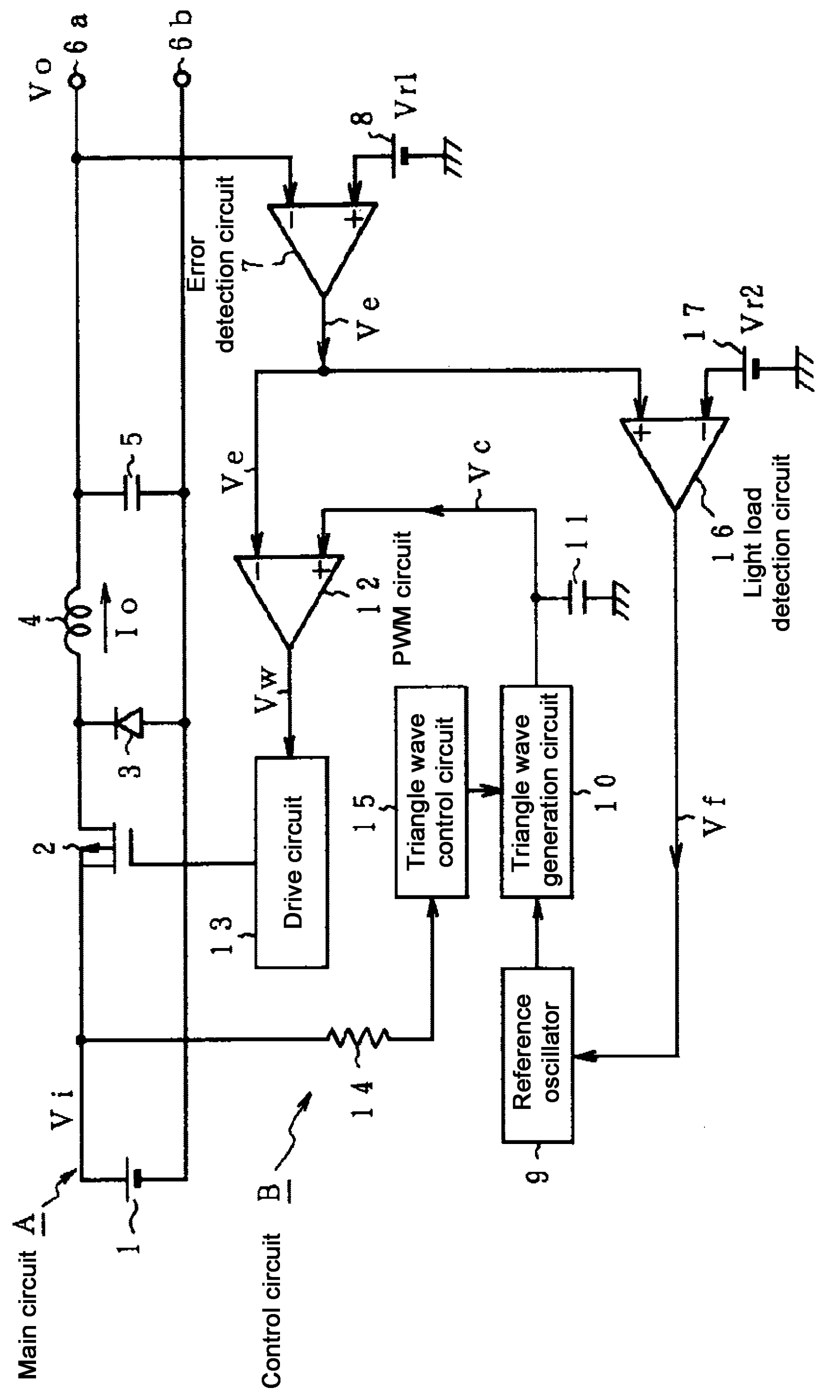

Main circuit
A
Control circuit
B
1
Vi
2
3
4
Io
5
Vo
6a
6b
Error detection circuit
7
8
Vr1
Ve
Vc
Vw
12
PWM circuit
Drive circuit
13
14
Triangle wave control circuit
15
Triangle wave generation circuit
10
11
Reference oscillator
9
Vf
16
Light load detection circuit
17
Vr2

FIG. 2

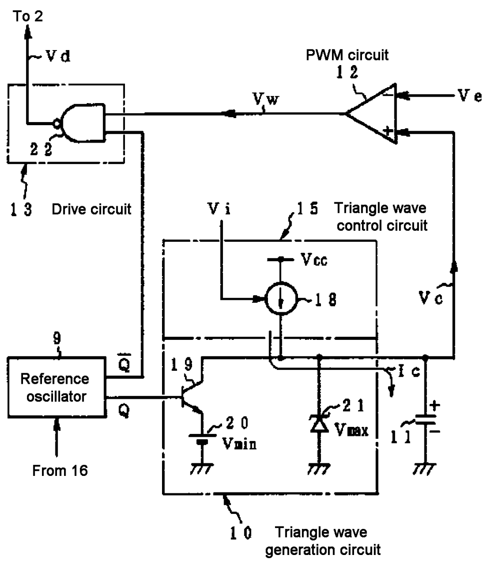


FIG. 3

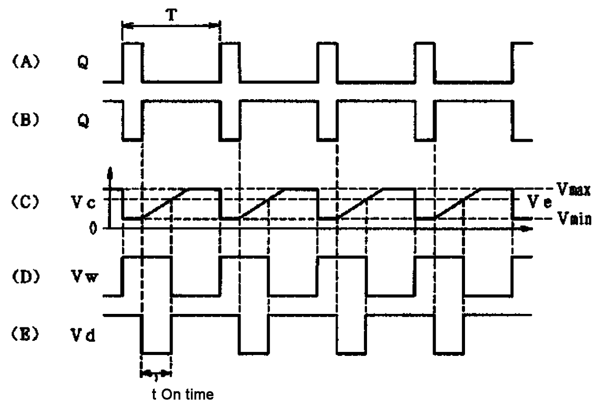


FIG. 4

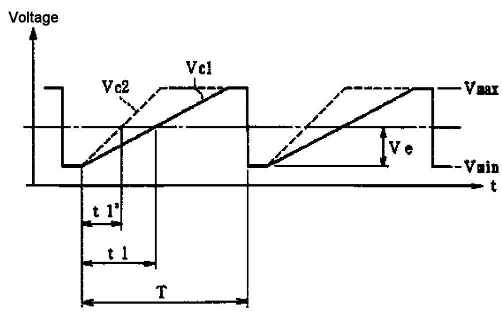


FIG. 5

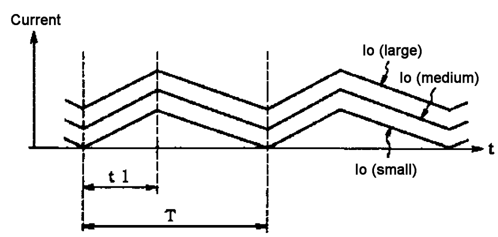


FIG. 6

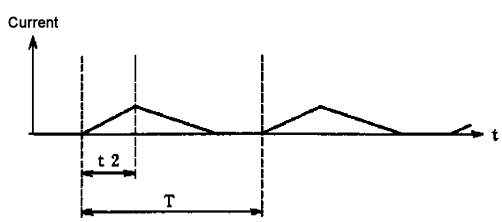


FIG. 7

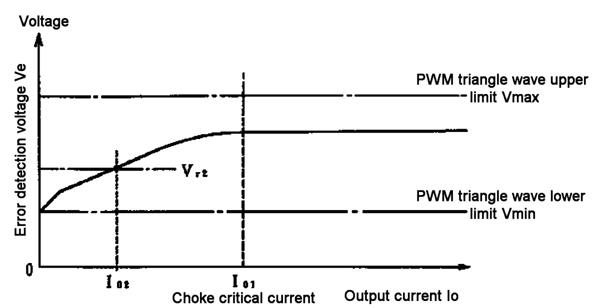


FIG. 8

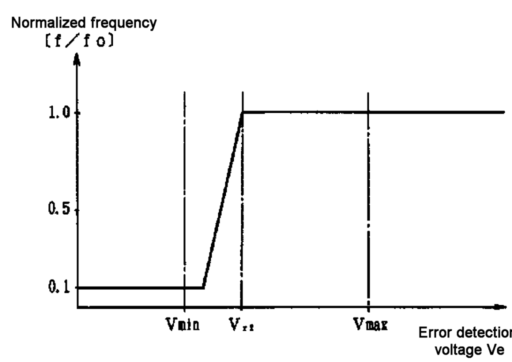


FIG. 9

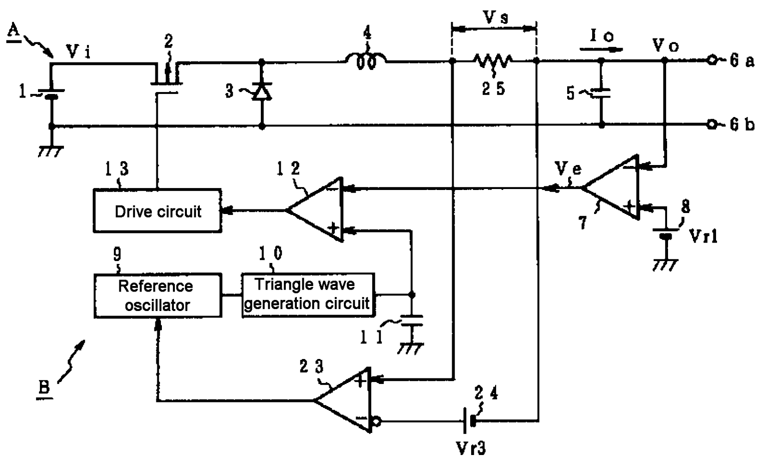
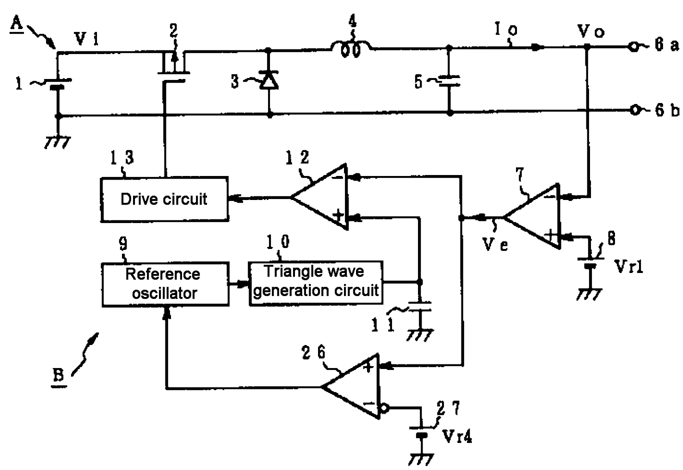

A
Vi
2
3
4
Vs
25
Io
Vo
5
6a
6b
1
13
Drive circuit
12
Ve
7
8
Vr1
9
Reference oscillator
10
Triangle wave generation circuit
11
B
23
24
Vr3

FIG. 10


A
Vi
2
3
4
Io
Vo
5
6a
6b
1
13
Drive circuit
12
7
Ve
8
Vr1
9
Reference oscillator
10
Triangle wave generation circuit
11
B
26
27
Vr4