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(12) **Reissued Patent**  
**Kirn**

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(54) **METHOD OF DETECTING SWITCHING POWER SUPPLY OUTPUT CURRENT**

FOREIGN PATENT DOCUMENTS

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*Primary Examiner* — Matthew Nguyen

**Related U.S. Patent Documents**

(74) *Attorney, Agent, or Firm* — Dorsey & Whitney LLP

Reissue of:

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(57) **ABSTRACT**

U.S. Applications:

(60) Provisional application No. 60/444,568, filed on Feb. 3, 2003.

A method and apparatus for detecting output current in switching power supplies forgoes the need for any resistor or other components in series with the load. A method according to the invention includes the steps of inferring the peak current through the inductor as a function of input voltage and inductor charge time, and deriving the current available to the load based upon the flyback voltage during discharge of the inductor. Although a disclosed example is based upon a buck/boost topology, other converter topologies are anticipated. In terms of apparatus, in a switching power supply of the type wherein a switching device is used to charge an inductor that discharges to a load, the invention provides devices arranged for detecting output current without the need for a resistor or other component in series with the load. In the preferred embodiment, these devices include electrical components operative to generate a signal indicative of peak inductor current, and a switch for switching the signal to provide a waveform, the integral of which is proportional to peak inductor current multiplied by the duty cycle of the discharge of the inductor. Circuitry is further used for comparing the waveform to a fixed reference so as to output a signal indicative of load current.

(51) **Int. Cl.**  
**G05F 1/652** (2006.01)  
**G05F 1/656** (2006.01)

(52) **U.S. Cl.**  
USPC ..... **323/222; 323/284; 323/351**

(58) **Field of Classification Search**  
USPC ..... 323/222, 282, 284–286, 351  
See application file for complete search history.

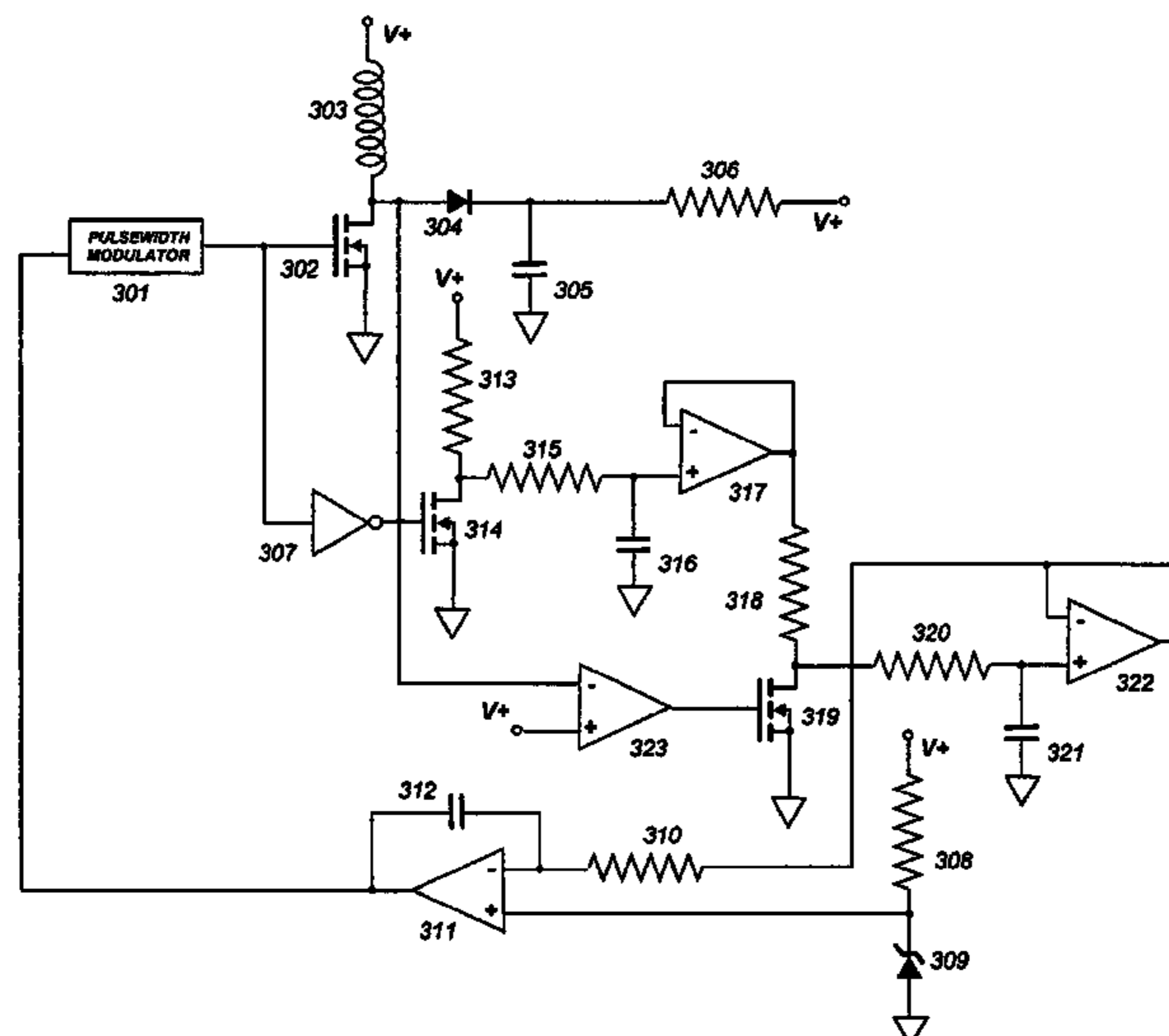
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**10 Claims, 2 Drawing Sheets**

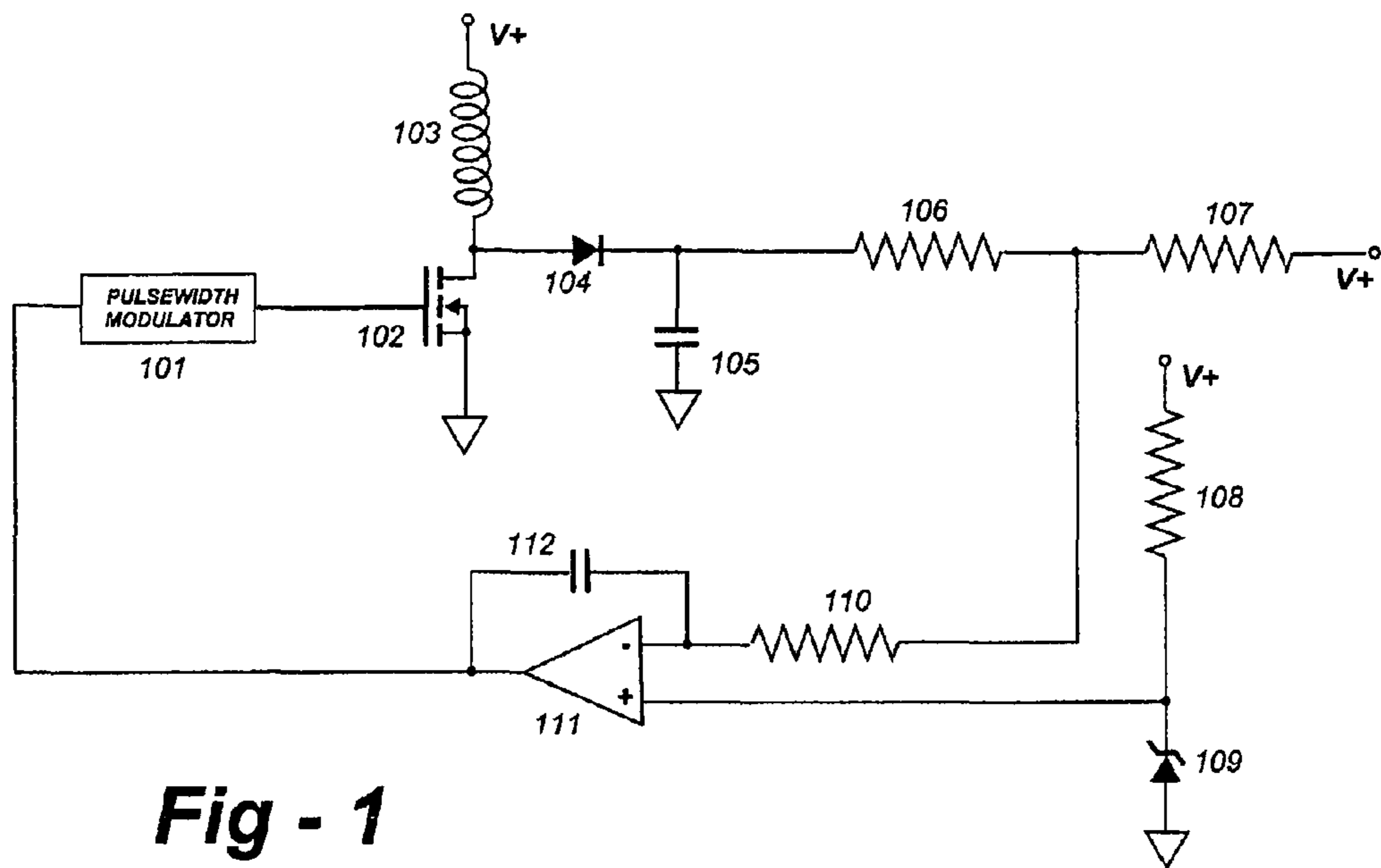


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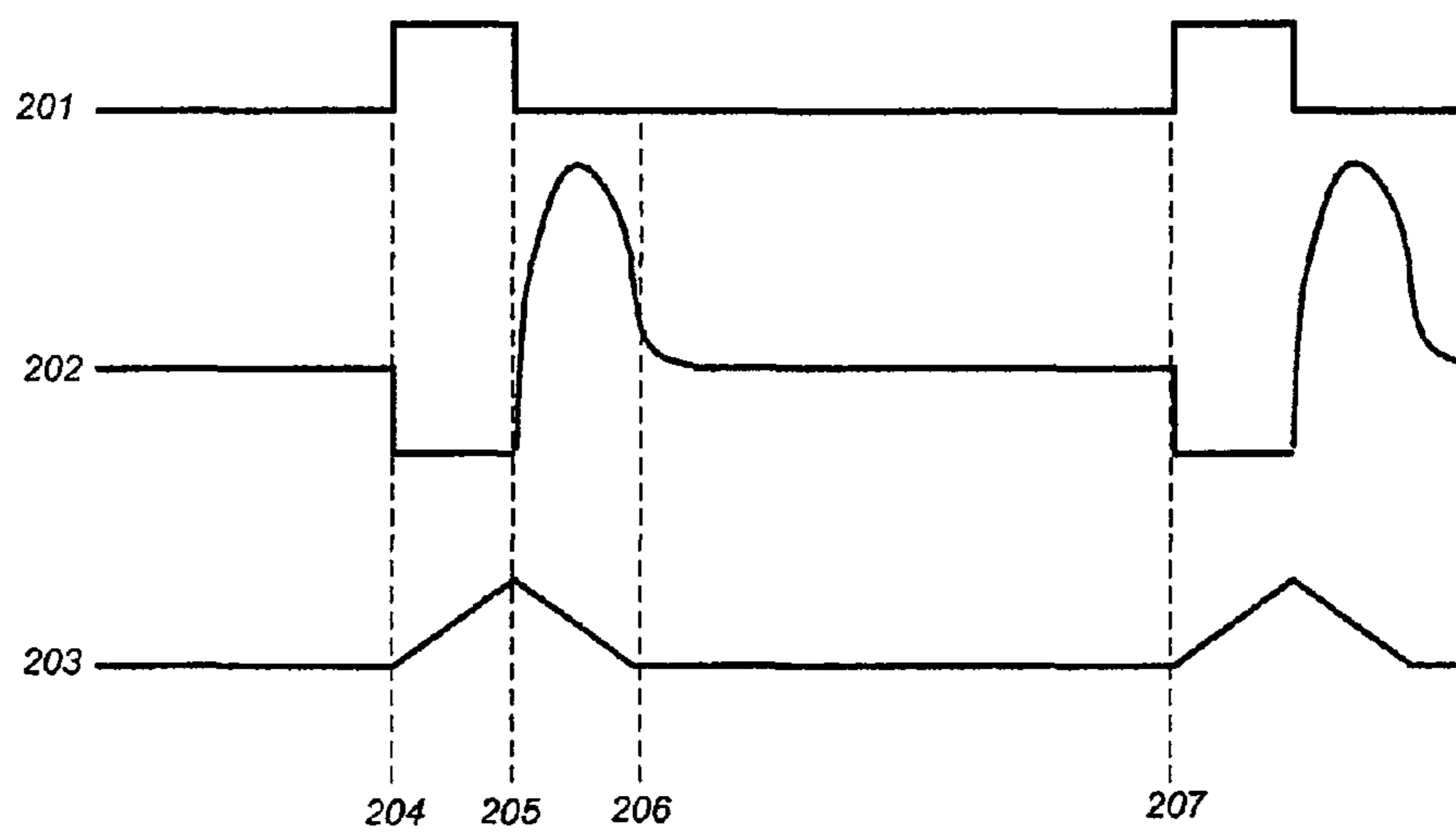
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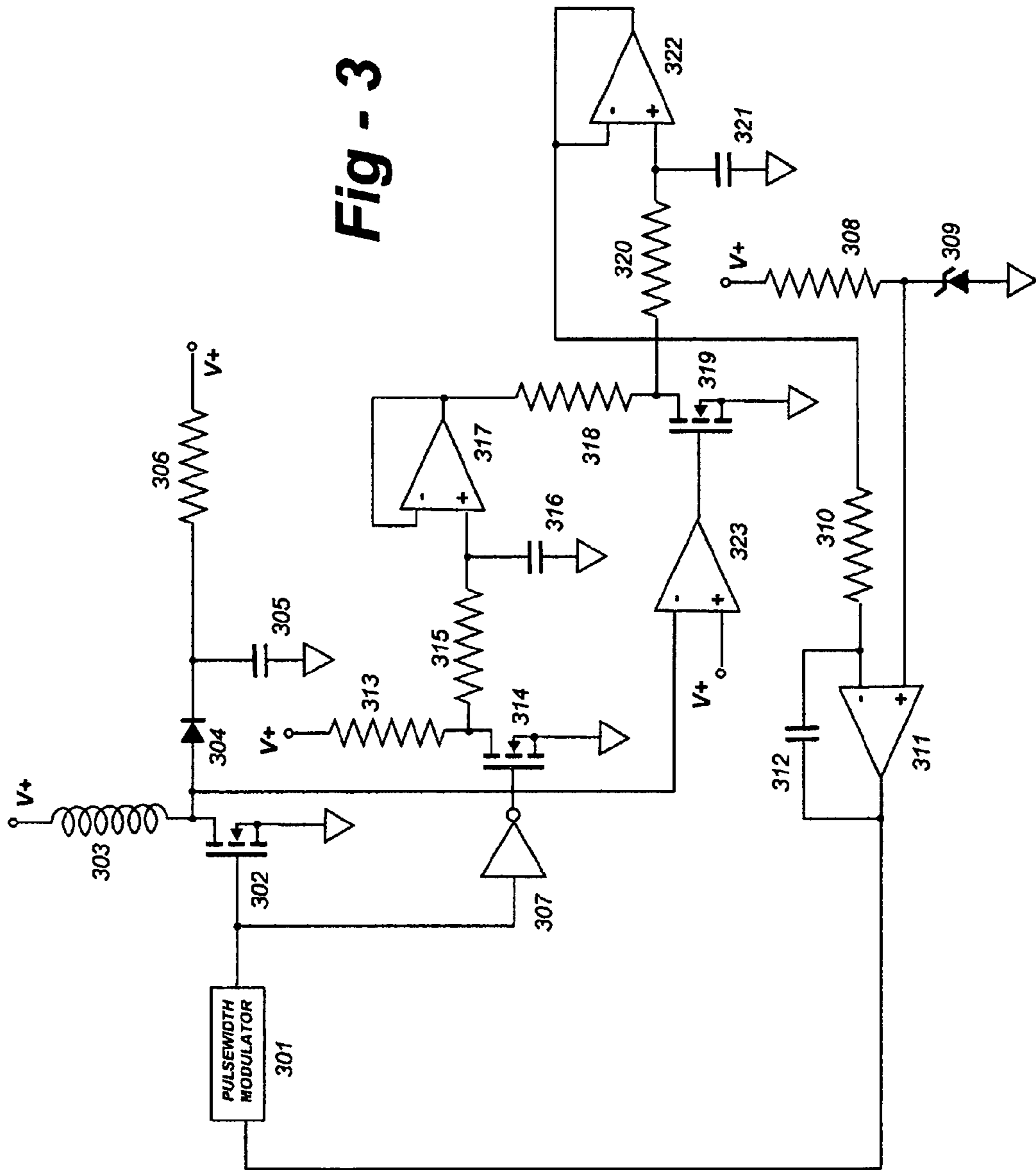


**Fig - 1**



**Fig - 2**

Fig - 3



## METHOD OF DETECTING SWITCHING POWER SUPPLY OUTPUT CURRENT

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

### REFERENCE TO RELATED APPLICATION

This application claims priority from U.S. Provisional Patent Application Ser. No. 60/444,568, filed Feb. 3, 2003, the content of which is incorporated herein by reference.

### FIELD OF THE INVENTION

This invention relates generally to switching power supplies and, in particular, to a method of detecting output current in such supplies which uses fewer components.

### BACKGROUND OF THE INVENTION

Switching power supplies employing inductive components have been in use for some time. Although most applications require constant output voltage (usually implemented through voltage feedback), some applications require a constant output current.

Standard practice for constant current outputs involves adding a resistor in series with the load to convert the output current into a voltage which can then be used as feedback. This approach, however, imposes a tradeoff between series resistor loss and feedback voltage magnitude, or dynamic range. A need exists for a method of detecting output current in switching power supplies which uses no series components.

### SUMMARY OF THE INVENTION

This invention resides in a method and apparatus for detecting output current in switching power supplies without the need for any resistor or other components in series with the load. In broad and general terms, the technique derives the peak inductor current of a switching converter through input voltage and inductor charge time, and calculates the current integral of that peak current available to the load through the use of the flyback voltage during discharge of the inductor.

A method according to the invention more particularly includes the steps of inferring the peak current through the inductor as a function of input voltage and inductor charge time, and deriving the current available to the load based upon the flyback voltage during discharge of the inductor. Although a disclosed example is based upon a buck/boost topology, other converter topologies are anticipated.

In terms of apparatus, in a switching power supply of the type wherein a switching device is used to charge an inductor that discharges to a load, the invention provides devices arranged for detecting output current without the need for a resistor or other component in series with the load. In the preferred embodiment, these devices include electrical components operative to generate a signal indicative of peak inductor current, and a switch for switching the signal to provide a waveform, the integral of which is proportional to peak inductor current multiplied by the duty cycle of the discharge of the inductor. Circuitry is further used for com-

paring the waveform to a fixed reference so as to output a signal indicative of load current.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a typical, fixed-frequency buck/boost converter known in the art;

FIG. 2 shows operational voltage and current waveforms of the circuit of FIG. 1; and

FIG. 3 is a schematic of a preferred embodiment of the current invention.

### DETAILED DESCRIPTION OF THE INVENTION

Turning now to the drawings, FIG. 1 is a schematic diagram of a typical, fixed-frequency buck/boost converter known in the art. Pulsewidth modulator **101** outputs a duty cycle to switching device **103** proportional to its control voltage input. Switching device **103** alternately charges inductor **103** and allows its discharge through diode **104** to load **106**. Capacitor **105** serves to filter the resultant voltage supplied to load **106**. Resistor **107** converts the resultant current in load **106** to a voltage useable as feedback. The feedback voltage is supplied to an integrator comprised of resistor **110**, capacitor **112**, and operational amplifier **111**, wherein it is compared to a fixed voltage reference comprised of resistor **108** and zener diode **109**. The integrator then provides the control voltage for pulsewidth modulator **101**, closing the loop.

Referring now to FIG. 2, trace **201** shows the switching output of pulsewidth modulator **101** which drives switching device **102**, trace **202** shows resultant inductor voltage at the anode of diode **104**, and trace **203** shows resultant current in inductor **103**. At time marker **204**, switching device **102** is activated, causing a resultant linear increase in inductor **103** current, shown in trace **203**. At time marker **205**, switching device **102** is deactivated, which results in inductor **103** flyback voltage seen in trace **202**, and a linear decrease in inductor **103** current seen in trace **203**. At time marker **206**, the energy of inductor **103** is depleted, resulting in zero current and zero voltage differential in inductor **103**, as seen in traces **202** and **203**, respectively. At time marker **207**, the entire cycle repeats.

Note that peak current in inductor **103** is a linear function of both supply voltage and switching device **102** assertion time. Note as well that this peak current linearly decreases to depletion during inductor **103** discharge. The average current delivered to load **106** is therefore half the peak inductor **103** current multiplied by the ratio of discharge time to total cycle period. Expressed mathematically, average output current can be expressed as  $((V \cdot (T_{205} - T_{204})) / 2) \cdot ((T_{206} - T_{205}) / (T_{207} - T_{205}))$ , where V denotes supply voltage, and T<sub>nm</sub> indicates absolute time at the indicated FIG. 2 marker. Note that depletion of inductor **103** current at time marker **206** is clearly indicated by inductor **103** voltage in trace **202**. Discharge time of inductor **103** can thereby be monitored.

Referring now to FIG. 3, note that the circuitry depicted deviates from that of FIG. 1 by the omission of resistor **107**, and the additional circuitry driving the integrator formed by resistor **110**, capacitor **112**, and operational amplifier **111** of FIG. 1. Components **301-306**, and **308-312** of FIG. 3 thus operate similarly to their counterparts of FIG. 1, but with the lack of current sense resistor **107** and feedback voltage derivation.

Inverter **307** de-asserts switching device **314** whenever switching **302** is charging inductor **303**, and asserts switching device **314** otherwise. In conjunction with resistor **313**, switching device **314** then outputs a switched waveform, the

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integral of which is the supply voltage times the duty cycle of inductor 303 charge time. This switched waveform, being directly proportional to peak inductor charge current, is filtered by resistor 315 and capacitor 316, and buffered by voltage follower 317.

Voltage follower 317 thus outputs a filtered voltage indicative of peak inductor 303 current. This filtered voltage is then switched through resistor 318 by switching device 319 under control of comparator 323. Connected as shown, comparator 323 yields a low-switched output whenever the output of inductor 303 (at the anode of diode 304) exceeds the incoming supply voltage, and yields a high switched output otherwise. Controlled in this fashion, switching device 319 and resistor 318 then output a switched waveform, the integral of which is directly proportional to inductor 303 peak current multiplied by the duty cycle of inductor 303 discharge.

After filtering and buffering by resistor 320, capacitor 321, and voltage follower 322, this voltage, being directly indicative of output load current, is supplied to the integrator formed by resistor 310, capacitor 312, and operational amplifier 311, for comparison with the fixed reference voltage supplied by resistor 308 and zener diode 309. By the above method, power supply loop closure on output current is affected without use of any load series resistance.

Although use is shown in a buck/boost topology, it will be apparent to those of skill in the art that other converter topologies are anticipated.

I claim:

1. In a switching power supply of the type wherein a switching device is used to charge an inductor that discharges to a load, a method of [detecting] *determining a magnitude of an output current* [without the need for a resistor or other component in series with the load], [the] *said* method comprising [the steps of]:

inferring [the] *a* peak current through [the] *said* inductor as a function of input voltage and inductor charge time; and deriving [the] *a* current available to [the] *said* load based upon [the] *a* flyback voltage *produced by said inductor* during discharge of [the] *said* inductor.

2. The method of claim 1, wherein *said* inductor forms part of a buck/boost topology.

3. In a switching power supply of the type wherein a switching device is used to charge an inductor that discharges to a load, *an apparatus for [detecting] determining the magnitude of an output current* [without the need for a resistor or other component in series with the load], comprising:

electrical components operative to generate a signal indicative of peak inductor current;

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a switch for switching the signal to provide a waveform, the integral of which is proportional to peak inductor current multiplied by the duty cycle of the discharge of the inductor; and

circuitry for comparing the waveform to a fixed reference so as to output a signal indicative of load current.

4. [Apparatus] *An apparatus* for [detecting] *determining the magnitude of an output current of a switching power supply* [without the need for a resistor or other component in series with the load], comprising:

a switching device used to charge an inductor that discharges to a load in accordance with an input signal; electrical components operative to generate a signal indicative of peak inductor current;

a switch for switching the signal to provide a waveform, the integral of which is proportional to peak inductor current multiplied by the duty cycle of the discharge of the inductor; and

circuitry for comparing the waveform to a fixed reference so as to output a signal indicative of load current.

5. The apparatus of claim 4, wherein the switching device and inductor form part of a buck/boost topology.

6. *An apparatus for determining a magnitude of an output current through a load driven by a power supply, comprising:*

*an inductive element included in the power supply;*

*a first circuit coupled to the inductive element and operable to determine a peak current through the inductive element as a function of a voltage across the inductive element and charge time of the inductive element; and*

*a second circuit coupled to the first circuit and operable to determine the magnitude of the output current based upon the peak current.*

7. *The apparatus of claim 6, wherein the inductive element comprises an inductor that forms part of a buck/boost topology.*

8. *The apparatus of claim 6, wherein the first circuit is operable to provide a signal indicative of the peak current through the inductive element.*

9. *The apparatus of claim 6, wherein the first circuit is further operable to switch the signal to provide a waveform the integral of which is proportional to the peak current multiplied by a duty cycle of a discharge time of the inductive element.*

10. *The apparatus of claim 6, wherein the second circuit is operable to compare the waveform to a fixed reference voltage to provide a signal indicative of the magnitude of the output current.*

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : RE44,406 E  
APPLICATION NO. : 12/019623  
DATED : August 6, 2013  
INVENTOR(S) : Kirn

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It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specifications:

In Column 2, Line 18, delete "device 103" and insert -- device 102 --, therefor.

In Column 2, Line 19, delete "device 103" and insert -- device 102 --, therefor.

In Column 2, Line 51, delete "Tnnn" and insert -- Tn --, therefor.

In the Claims:

In Column 4, Line 39, in Claim 9, delete "claim 6," and insert -- claim 8, --, therefor.

In Column 4, Line 44, in Claim 10, delete "claim 6," and insert -- claim 8, --, therefor.

Signed and Sealed this  
Twenty-second Day of April, 2014



Michelle K. Lee  
*Deputy Director of the United States Patent and Trademark Office*