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(54) A circuit and method for regulating voltage

(57) A circuit and method for providing an efficient voltage regulator is disclosed. The voltage regulator uses a switching mode power supply, a linear regulator, and a feedback loop having an output connected to the feedback input of the switching mode power supply so that the switching mode power supply provides an output voltage responsive to the voltage drop across the voltage regulator.

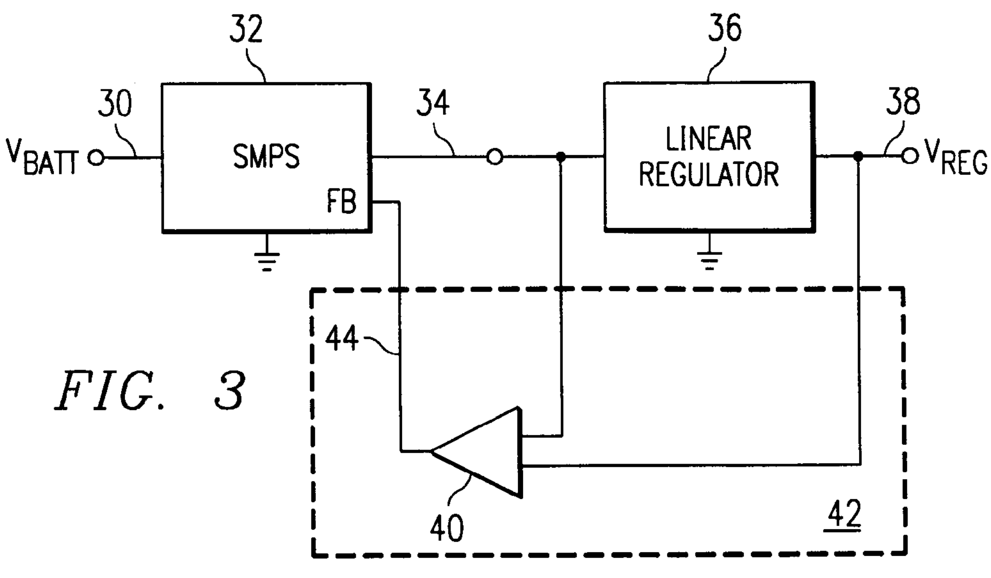

FIG. 3

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Description

This invention relates to electronic circuits used to regulate voltages and more specifically to high efficiency voltage regulators used in the automotive industry.

The problem addressed by this invention is encountered in the automobile industry, where automobile engines are now controlled by sophisticated process controllers. Automobile performance requirements have increased with tighter government emission requirements and fuel economy regulations, while customer expectations have required increased reliability. Automobile manufacturers have responded to the increasing demands by using more microcomputers and electronics. Consequently, automobile manufacturers are requiring electronics manufacturers to provide circuits capable of operating in harsh operating conditions of an automobile and yet have smaller packages, higher degrees of integration, lower power consumption, and higher reliability, at a low cost.

To meet these demands, it is desirable to have a highly efficient method for providing a regulated voltage to the sophisticated electronics in an automobile. Figure 1 shows a voltage regulator in the prior art. The linear voltage regulator 10 would receive an unregulated battery voltage Vbatt to provide a regulated output voltage Vout. The unregulated battery voltage Vbatt 12 varies from around 12 volts to around 14.5 volts. The regulated output voltage is typically 5 volts, providing around 1 amp of current. The problem with this approach is that the linear voltage regulator is very inefficient. In this example, the linear voltage regulator would be dissipating at least

(12v-5v) (1amp)= 7 watts

of power. It is generally known that dissipating 7 watts in an integrated circuit requires significant packaging and heat sinking considerations. Even with the appropriate packaging, reliability may still be an issue because of the wide temperature ranges of an automotive environment.

Figure 2 shows a conventional approach for improving the efficiency of the circuit in figure 1. Figure 2 shows a battery voltage Vbatt powering a switching mode power supply 22 (SMPS). Switching mode power supplies of the type shown are taught in such text books as High Frequency Switching Power Supplies...Theory and Design by George Chryssis and is fully incorporated into this specification by reference. The SMPS 22 typically provides an 8 volt output 24 at about a 90% efficiency. The linear regulator uses the 8 volt output 24 and provides the same 5 volt 1 amp output as in figure 1. The power dissipated by this circuit is at least

(12v-8v)(1amp)(10%)+(8v-5v)(1amp)=3.4 watts

of power. Although this is a significant improvement, 3.4 watts of power dissipation will still require significant packaging and heat sinking considerations.

In light of the above, it is therefore an object of the invention to provide a more efficient circuit for regulating voltages.

It is another object of the invention to minimize the packaging and heat sinking considerations for a circuit for regulating voltage.

It is yet another object of this invention to improve the reliability of a voltage regulator.

These and other objects, features, and advantages of the invention will be apparent to those skilled in the art from the following detailed description of the invention, when read with the drawings appended claims.

The invention can be summarized as a circuit and method for providing an efficient voltage regulator. The improved voltage regulator uses a switching mode power supply, a linear regulator, and a feedback loop having an output connected to the feedback input of the switching mode power supply so that the switching mode power supply provides an output voltage responsive to the voltage drop across the voltage regulator.

Fig. 1 is an electrical schematic of a voltage regulator as known in the prior art.

Fig. 2 is an electrical schematic of a SMPS in series with a linear regulator as known in the prior art.

Fig. 3 is electrical schematic of an embodiment of an efficient voltage regulator.

Fig. 4 is electrical schematic of the preferred embodiment of an efficient voltage regulator.

Fig. 5 is an electrical schematic of an efficient voltage regulator in an automobile system.

An efficient voltage regulator constructed according to an embodiment of the invention will be described.

Referring now to figure 3, a switching mode power supply (SMPS)32 receives an unregulated voltage Vbatt 30. The lowered voltage output of the SMPS 32 at node 34 is connected to a conventional linear regulator 36 which presents a regulated voltage Vreg. A differential amplifier 40 has a first input connected to the lowered voltage at node 34 and has a second input connected to the regulated output Vreg 38. The first input can be the inverted input or the non-inverted input as the choice is matter of the designers preference. The differential amplifier generates an error signal 44 which is connected to the feed back input of the SMPS 32.

In operation, the switching mode power supply 30 is powered by Vbatt 30 and generates a lowered voltage at node 34. The linear regulator 36 is powered by the lowered voltage at node 34 and produces a regulated voltage Vreg at node 38. The feed back loop circuit 42 operates by the differential amplifier 40 sensing the voltage drop (Vreg-V_{34}) across the linear regulator and generating an error signal 44 proportional to this voltage drop. The error signal 44 is fed back to the SMPS 32 so that the SMPS 32 can provide a lowered voltage at node 34 which optimizes the voltage drop across the linear regulator.

Figure 4 shows a detailed description of the embodiment in figure 3. More specifically, the linear regulator 36 in figure 3 is described in detail in figure 4.

In figure 4, the SMPS 52 is connected to Vbatt at node 50 and provides a lowered voltage at node 54. The linear regulator 72 includes a pnp bipolar transistor 56, a differential amplifier 62, a resistor 58, a resistor 60, and a band gap voltage reference 64. The emitter of transistor 56 is connected to SMPS 52 at node 54 and to a first input of differential amplifier 68. The collector of transistor 56 is connected to the second input of differential amplifier 68 and resistor 58. The other end of resistor 58 is connected to resistor 60 and the inverting input of differential amplifier 62. The non-inverting input of differential amplifier 62 is connected to a band gap voltage reference 64. The output of differential amplifier 62 is connected to the base of transistor 56. The output to differential amplifier 68 is connected to the feedback input of the SMPS 52.

In operation, the SMPS 52 is powered by Vbatt at node 50 and generates a lowered voltage at node 54 which is used to power linear regulator 72. The linear regulator operates by controlling the conductivity of transistor 56 based on the comparison of a band gap reference voltage 64 to a scaled voltage. The scaled voltage is generated by resistors 58 and 60 placed in series across the output of linear regulator 72. The output voltage is controlled by adjusting the ratio of resistors 58 and 60 and/or adjusting the band gap reference voltage 64, as is well known in the art. The differential amplifier generates an error signal 70 proportional to the voltage drop across the pass element (transistor 56). The error signal is fed back to SMPS 52 so that the SMPS 52 can provide the optimal lowered voltage at node 54 to maintain the optimum voltage drop across transistor 56.

In this preferred embodiment, a 1 volt voltage drop across transistor 56 results in an efficiency of the power used by the SMPS 52 + the power used by the linear regulator 72 which is

$$(12v\text{-}6v)\ (1a)\ (10\%)+(6v\text{-}5v)\ (1a)= 1.6\ \text{watts}$$

of power. Therefore, the preferred embodiment offers the advantages of providing a more efficient circuit for regulating voltages. Consequently, the invention decreases the packaging and heat sinking considerations and improves the reliability of a voltage regulator by dissipating less power.

Figure 5 describes the use of the efficient voltage regulator in an automobile. In figure 5, the battery has a negative terminal connected to chassis ground and a positive terminal connected to an alternator 82 and an efficient voltage regulator 84 (such as the one described in figure 4). The efficient voltage regulator 84 supplies a regulated voltage Vreg to the on board electronics of an automobile. The on board electronics 86 of an automobile may be an ignition control system, climate control system, on board diagnostics, and the like.

In operation, the alternator converts the mechanical energy of an automobile motor into electrical energy, which is stored in the battery 80. The efficient voltage regulator 84 regulates the battery voltage for the on board electronics 86. The on board electronics 86 are used to increase the gas milage, lower emissions, and/or provide consumer features such as climate control.

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

Claims

1. A voltage regulator comprising:

a switching mode power supply having an input for receiving a power source, having an output, and having a feedback input;

a linear regulator having an input connected to the output of said switching mode power supply, and having an output for providing a regulated voltage; and

a feedback loop having a first input connected to the input of said linear regulator, having a second input connected to the output of said linear regulator, for sensing the voltage drop across said linear regulator, and having an output connected to the feedback input of said switching mode power supply so that the switching mode power supply provides an output voltage responsive to the voltage drop across said voltage regulator.

2. An automobile system comprising a body, a drive train, an engine, electronic engine controllers, and a voltage regulator to provide the voltage for the electronic engine controllers wherein said voltage regulator comprises:

a switching mode power supply having an input for receiving a power source, having an output, and having a feedback input;

a linear regulator having an input connected to the output of said switching mode power supply, and having an output for providing a regulated voltage; and

a feedback loop having a first input connected to the input of the input of said linear regulator, having a second input connected to the output of said linear regulator, and having an output connected to the feedback input of said switching mode power supply so that the switching mode power supply provides an output voltage responsive to the voltage drop across said voltage regulator.

3. The voltage regulator of claim 1 or claim 2 wherein said feedback loop comprises an amplifier.

4. The voltage regulator of claim 1 or claim 2 wherein said linear regulator comprises a pass element, a band gap reference voltage, and an amplifier.

5. The voltage regulator of claim 4 wherein said pass element comprises a transistor.

6. The voltage regulator of claim 5 wherein said transistor comprises a bipolar transistor.

7. The voltage regulator of claim 3 or claim 4 wherein said amplifier comprises a differential amplifer.

8. The voltage regulator of claim 1 or claim 2 wherein said switching mode power supply, linear regulator, and feedback loop are integrated into a single integrated circuit.

9. A method for regulating voltage comprising the steps of:

converting an unregulated voltage to a lowered voltage by using a switching mode power supply;

regulating the lowered voltage with a linear regulator;

sensing the voltage drop across the linear regulator;

controlling the switching mode power supply responsive to the voltage drop across the linear regulator.

10. The method of claim 9 wherein the step of sensing the voltage is performed using an amplifier.

11. The method of claim 9 wherein the step of sensing the voltage is performed using a differential amplifier.

12. The method of claim 9 wherein the step of regulating the lowered voltage further comprises the step of controlling the conductivity of a pass element.

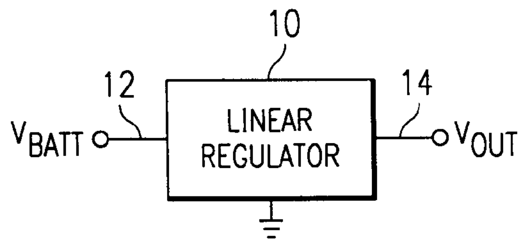


FIG. 1
(PRIOR ART)

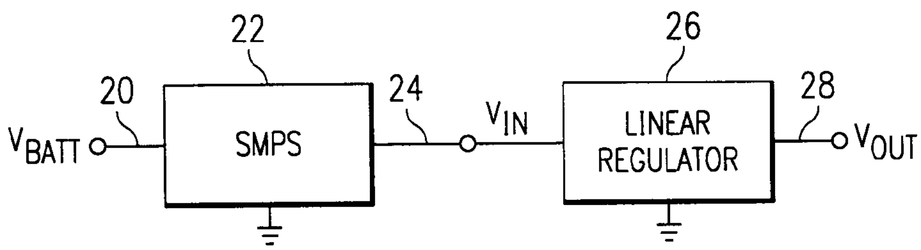


FIG. 2
(PRIOR ART)

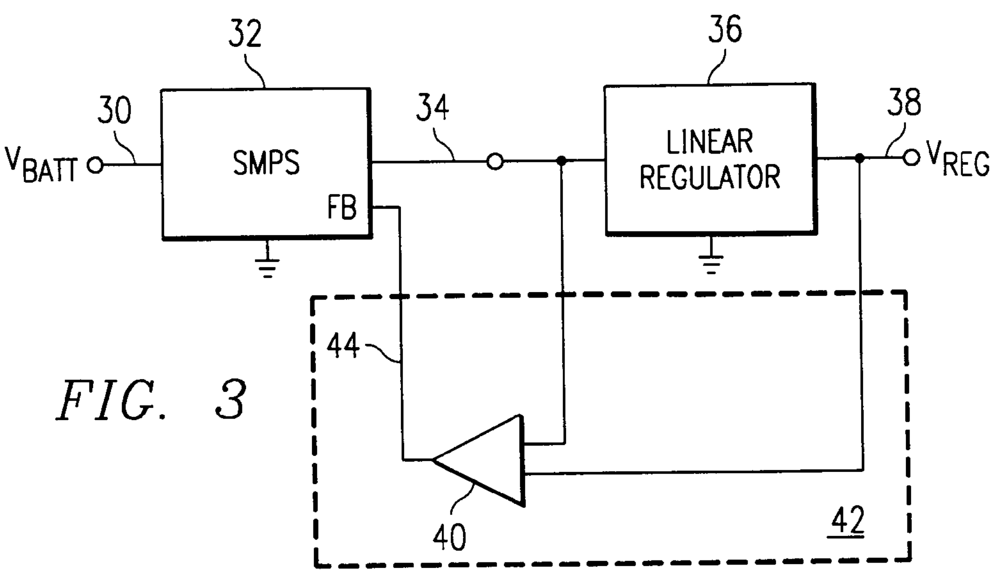


FIG. 3

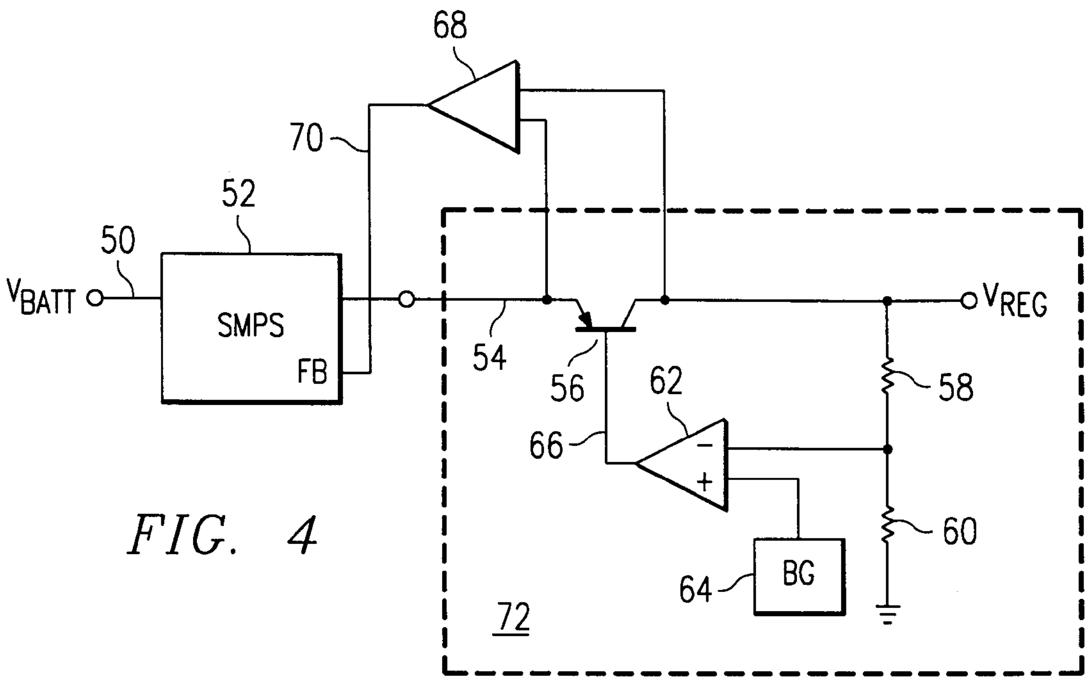
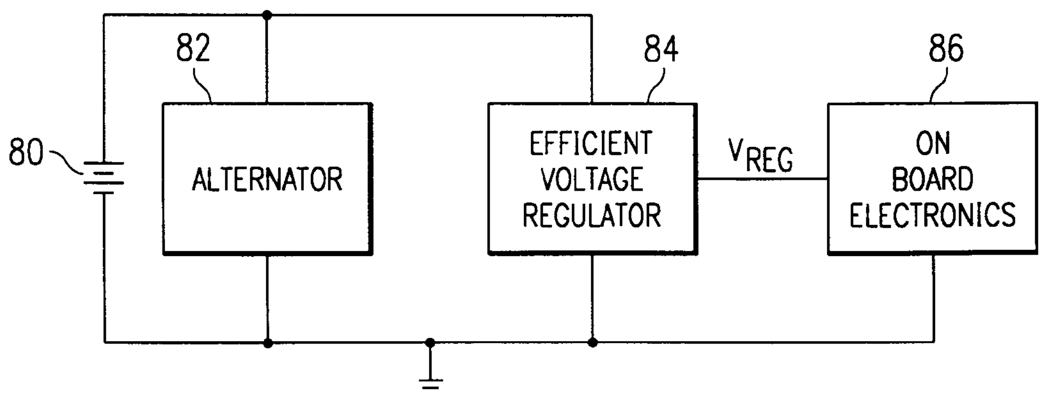

68
70
52
50
V_{BATT}
SMPS
FB
54
56
62
V_{REG}
58
66
60
BG
64
72

FIG. 4

FIG. 5


82
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ALTERNATOR
EFFICIENT VOLTAGE REGULATOR
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ON BOARD ELECTRONICS