United States Patent [19]

Trilling

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[54] **FOLDBACK CURRENT LIMITER**

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[52] **U.S. Cl.** .... **323/4,** 317/33 VR, 323/9, 323/17, 323/22 T

[51] **Int. Cl.** **G05f 1/58**

[58] **Field of Search** .... 323/4, 9, 17, 22 T; 317/31, 33 VR, 20

[56] **References Cited**

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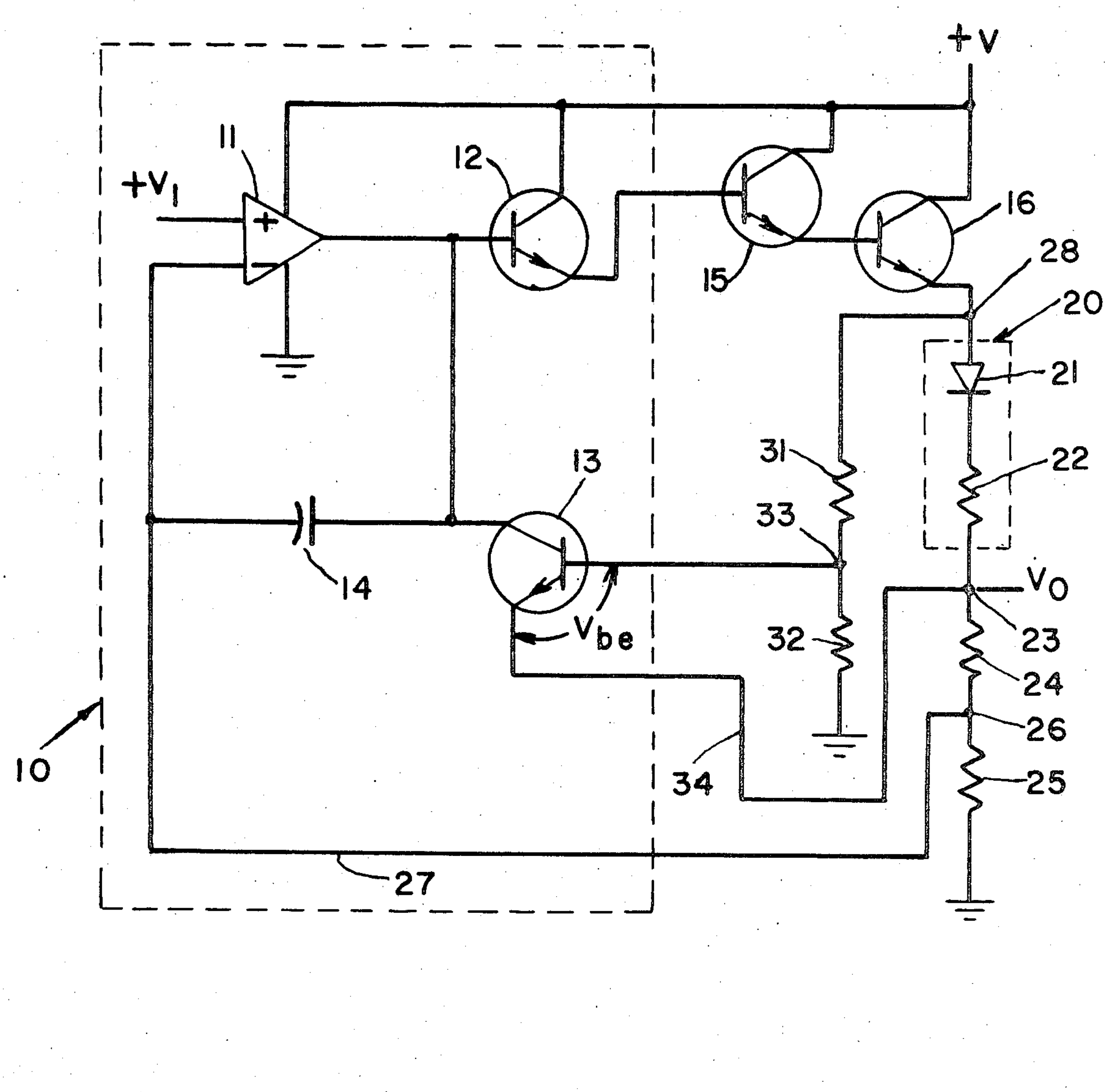
[57] **ABSTRACT**

A diode providing a current that is an exponential function of the voltage applied across it is inserted in a series circuit carrying the output current of a current limiting device in which the voltage across the diode is reduced upon a short circuit taking place at an output terminal. This reduction in voltage severely limits the current through the diode at an exponential rate thereby affecting a sharp reduction in the short circuit current.

8 Claims, 3 Drawing Figures



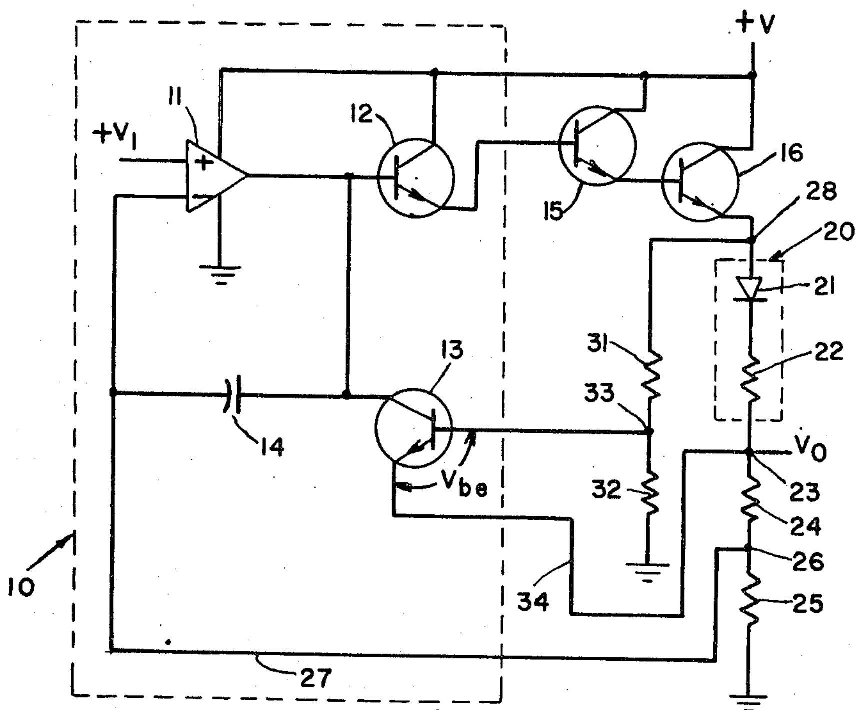


Fig.1.

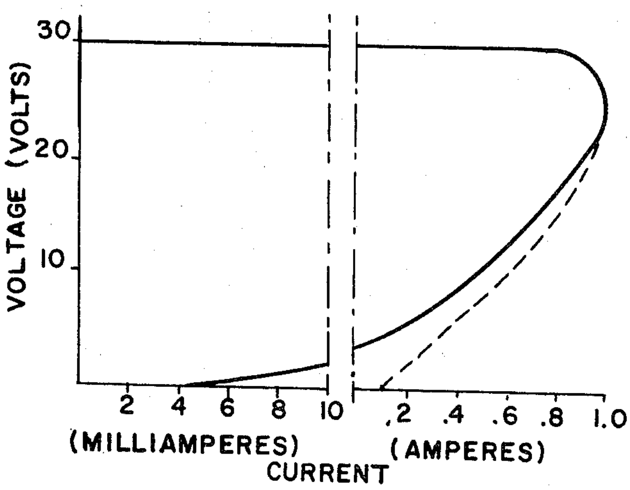


Fig. 2.

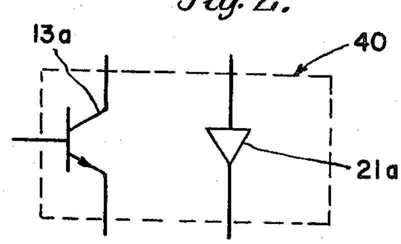


Fig.3.

FOLDBACK CURRENT LIMITER

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

The present invention generally relates to power supplies and more particularly protective circuitry to prevent an excess of current from being drawn from a voltage regulator upon a low impedance appearing at an output terminal of the regulator.

In voltage regulators a common form of current control is constant current limiting. As the name implies the current supply from such a device has a predetermined maximum which is unaffected by short circuits or other loads that require excessive current. The constant current limiting power supply has a major disadvantage in that it normally requires a transistor serving as the main regulating element to dissipate the full power of the supply unit if the output terminal should become grounded.

Foldback current limiting is a second type of current control that is available and in voltage regulators has the advantage of reducing a short circuit current to considerably less than a predetermined maximum current that can be supplied. In such a device both voltage and current are reduced when the current drawn from the regulator exceeds a predetermined maximum. This has the advantage of not only reducing the power dissipated by the circuit elements of the regulator but also provides protection to the load element receiving the current. Since in such a regulator the size of the series pass transistor and its heat sink are determined by the maximum power they are required to dissipate, foldback current limiting can effectively reduce the size and cost of these elements as well as those in the load. In many instances loads are saved from catastrophic failure by foldback current limiting.

SUMMARY OF THE INVENTION

It is therefore a general object of the present invention to provide an improved power supply. It is a further object to provide an improved voltage regulator with foldback current limiting characteristics. It is an additional object of the present invention to provide a power supply in which the output current is exponentially related to the voltage drop across a component within the device. It is a further object to use the voltage drop across the component for supplying positive feedback to further reduce the output of the power supply.

This is accomplished according to the present invention by providing a foldback current limiting voltage regulator having a nonlinear component in which the current through the device is an exponential function of the voltage across the device. In this way a slight change in voltage results in a large decrease in current. Furthermore by maintaining a sizable voltage drop in respect to the current across the nonlinear element, a junction in a transistor is suitably biased to further reduce the output signal of the regulator.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block schematic diagram of an embodiment of the invention;

FIG. 2 is a diagram of a typical voltage - current response of a regulated power supply both with and without the diode of FIG. 1; and

FIG. 3 is an alternate embodiment of a portion of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 there is shown a voltage regulator such as a μA 723 type manufactured by Fairchild Semiconductor. The regulator 10 has a typical differential amplifier 11 having both a noninverting and an inverting input terminals marked + and −, respectively. The output terminal of differential amplifier 11 is connected to the base of a transistor 12, and the collector of a transistor 13. In addition a compensation capacitor 14 is connected between the output and inverting input terminals of amplifier 11. Capacitor 14 as shown represents the internal capacitance in the circuit. However, an external capacitor (not shown) may be connected across capacitor 14 for additional compensation. Transistors 15 and 16 are connected to transistor 12 and to each other in a well-known Darlington configuration. A supply voltage +V is connected to differential amplifier 11 and the collectors of transistors 12, 15 and 16. A series circuit 20 comprised of a diode 21 and a resistor 22 is connected between the emitter of transistor 16 and an output terminal 23. A voltage divider circuit comprised of serially connected resistors 24 and 25 are connected between output terminal 23 and the ground. Both resistors 24 and 25 are of high ohmic resistance so that they conduct only a small amount of current. A contact 26 connected intermediate resistors 24 and 25 provides an input to the inverting terminal of amplifier 11 by means of a line 27. The signal from terminal 26 is an error voltage applied to the inverting input terminal of differential amplifier 11. This signal is compared with a reference voltage $+V_1$ applied to the noninverting terminal. If the voltage level at terminal 26 should increase the output signal amplitude decreases and vice versa. In this manner a constant output voltage is retained at terminal 23. A voltage divider circuit comprised of resistors 31 and 32 are connected between the emitter of transistor 16 and ground with a contact 33 located intermediate resistors 31 and 32 connected to the base electrode of transistor 13. The emitter of transistor 13 is then connected to output terminal 23 through line 34.

In normal operation the signal from differential amplifier 11 is amplified by transistors 12, 15 and 16 so that a load current is supplied from transistor 16 through series circuit 20 to output terminal 23. In addition a small amount of current is supplied through series resistor 31 and 32 to provide a voltage at the base of transistor 13. However, at this time the voltage applied to the base of transistor 13 is not sufficient to bias the transistor into a conducting state. Should an overload occur at output terminal 23 the voltage across circuit 20 is raised and in turn raises the voltage betwen terminals 23 and 33 biasing transistor 13 into conduction. This causes a reduction in voltage at the base of transistor 12 thereby reducing the current through Darlington circuit transistor 16.

At this time a voltage drop across circuit **20** remains close to constant since most of the voltage drop in circuit **20** is across diode **21** whose voltage drop is almost constant even though the current through it changes greatly as can be seen on normal characteristic curves (not shown). Furthermore, the voltage at the emitter of transistor **13** is lowering at a faster rate than the voltage drop across resistor **31** due to the voltage - current characteristics of diode **21** and the regulating action of the emitter-base diode of transistor **13**. Therefore the base-emitter voltage in transistor **13** increases causing increased conduction in transistor **13** which further reduces the signal from transistor **16** as explained above.

The voltage on terminal **23** at this time will continue to drop until it reaches a very low value. The current through series circuit **20** is called the short circuit current and is greatly reduced by the diode **21** which conducts an output current that is an exponential function of the voltage across the diode. In the present circuit when overload conditions occur the output voltage at the emitter of transistor **16** is so reduced that the diode is capable of both maintaining a sufficient voltage drop across the emitter-base electrodes of transistor **13** and inhibiting most of the current flow through circuit **20**.

When the overload at terminal **23** is removed the voltage V_o is raised thereby increasing the voltage at terminal **28**. The voltage across circuit **20** remains fairly constant as does the current through resistor **31**. The voltage at terminal **33** is raised and therefore supplies a larger proportion of current from resistor **31** through resistor **32**. This reduces the current available to transistor **13** tending to shut it off. This enables the Darlington circuit to again supply rated voltage.

In addition to the components shown in FIG. **1**, a resistor (not shown) may be inserted between the base-electrode of transistor **13** and terminal **33** in order to improve the recovery characteristics of the device after the overload condition has been removed by reducing the base-emitter voltage in transistor **13**.

Looking at the operation of the device in a practical situation where the voltage drop across resistor **22** is small compared to the drop across diode **21**, it can readily be seen that

$$F = e^{d1\ dsc} \qquad (1)$$

where foldback current ratio F is equal to the limiting current divided by the current at short circuit load. V_{d1} and V_{dsc} are the respective voltages across diode **21** at limiting current and short circuit current, and c is a constant at room temperature.

In a typical application using an output voltage of 30 volts and a limiting current of one ampere, it was found with a 1N4005 diode for component **21** and a resistor **22** of 0.1 ohms, an *F of* 200 was attainable. There is shown in FIG. **2** the voltage - current characteristics of the output of the circuit of FIG. **1** both for using a 1N4005 diode and a 0.1 ohm resistor in the control circuit **20** as shown in the solid line curve and for replacing the diode and 0.1 ohm resistor with a resistor of 0.55 ohms as shown in the dashed line curve.

FIG. **3** shows an alternate embodiment of a portion of FIG. **1** wherein the letter "*a*" is used to denote corresponding items in FIG. **1**. All electrical connections of these items are the same as in FIG. **1**. In FIG. **3** there is shown a schematic diagram of a diode **21*a*** and transistor **13*a*** forming an integrated circuit on the same substrate **40**. This arrangement tends to compensate for the temperature sensitivity of the diode **21*a*** since the temperature sensitivity of the base-emitter junction of transistor **13*a*** follows the same thermal relationship. The substrate **40** in addition acts as a heat sink and should be large enough to prevent significant self-heating of the components which would change the maximum current and operating parameters of the circuit.

There has therefore been shown a foldback current limiting voltage regulator wherein the current limiting has been improved by magnitudes by making use of the nonlinear voltage-current characteristics of a diode that is inserted in the output control circuit of the foldback current limiting device. In addition, the emitter-base PN junction of a transistor that operates to effect a shutdown of the device can be mounted on the same substrate as a diode to temperature track the diode.

It will be understood that various changes in the details, materials, steps and arrangements of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. A voltage regulator having foldback current limiting characteristics comprising:

power supply means for providing an output of constant voltage when the current is below a predetermined level;

first reduction means including a serially connected diode and resistor connected at one end to receive the output of said power supply means and having a nonlinear voltage-current characteristic for providing a current output at an output terminal connected to the other end of said serially connected diode and resistor which decreases at a more rapid rate than its voltage, said output further providing a feedback signal to said power supply means; and

second reduction means connected to receive the outputs of said power supply means and said first reduction means including a voltage divider circuit connected to said one end of said serially connected diode and resistor, and control means connected to said voltage divider circuit, for providing a feedback to said power suply means for substantially reducing the voltage and current from said power supply means when said power supply means current exceeds said predetermined level.

2. A voltage regulator having foldback curent limiting characteristics according to claim **1** wherein said control means comprises an NPN transistor.

3. A voltage regulator having foldback current limiting characteristics according to claim **2** wherein said power supply means further comprises:

signal means for providing an output signal; and

a Darlington circuit connected to said signal means for amplifying said output signal for providing said constant voltage when supplying said current beneath said predetermined level and further connected to said first reduction means for having the amplification controlled by said second reduction means when said current exceeds said predetermined level.

4. A voltage regulator having foldback current limiting characteristics according to claim 3 wherein said signal means further comprises:

a differential amplifier having an inverting and a noninverting input terminals adapted to receive a bias signal on said noninverting terminal for supplying an output signal indicative of the signals applied to said input terminals; and

a voltage divider circuit connected to said output terminal for feeding back a portion of the voltage on said output terminal to said inverting input terminal.

5. A voltage regulator having foldback current limiting characteristics according to claim 4 wherein said Darlington circuit further comprises:

first, second and third transistors having collector electrodes connected in common with the base of said first transistor connected to receive said signal means output signal and further connected to the collector of said NPN transistor, the emitter of said first transistor connected to the base of said second transistor, the emitter of said second transistor connected to the base of said third transistor and the emitter of said third transistor connected to said first reduction means.

6. A voltage regulator having foldback current limiting characteristics according to claim 5 wherein said first, second and third transistors are NPN transistors.

7. A voltage regulator having foldback current limiting characteristics according to claim 6 further comprising temperature compensation means connected to said control means and to said diode for dissipating the heat generated with said control means and said diode and for keeping said diode and said control means at the same temperature.

8. A voltage regulator having foldback current limiting characteristics according to claim 7 wherein said temperature compensation means comprises a substrate of an integrated circuit comprising said diode and said control means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,753,079 Dated August 14, 1973

Inventor(s) Ted R. Trilling

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

Column 3, line 45, "$F = e^{dl\ dsc}$" should read

-- $F = e^{c(V_{dl} - V_{dsc})}$ --.

Signed and Sealed this

sixteenth **Day of** *March 1976*

[SEAL]

Attest:

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Commissioner of Patents and Trademarks

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