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Stauffer

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[54] LOW-DROP VOLTAGE REGULATOR

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[52] **U.S. Cl.**.....**323/9,** 323/19, 323/38

[51] **Int. Cl.**.....**G05f 3/14**

[58] **Field of Search**.....323/4, 9, 16, 19, 22 T, 38

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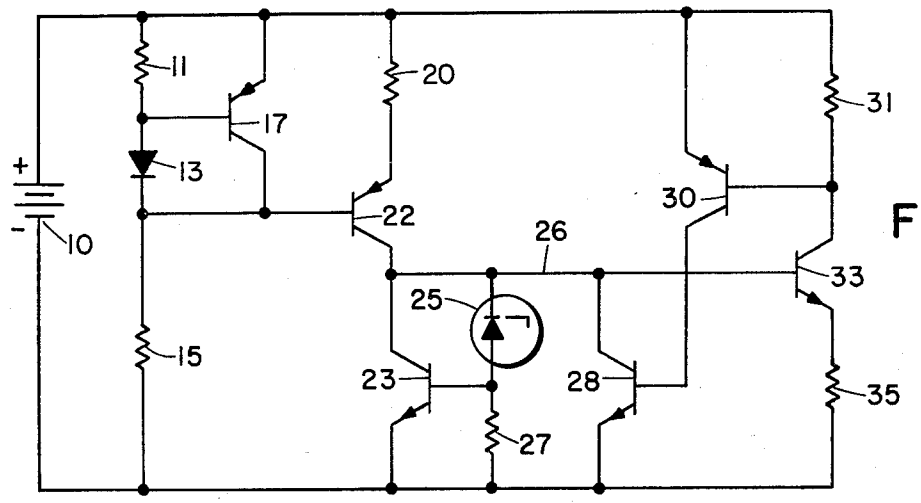
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[57] **ABSTRACT**

A follower amplifier which connects a variable and noisy power source to a load obtains its reference from a divider composed of two serially connected transistors using feedback to obtain two widely different ratios of dynamic resistance to average resistance.

9 Claims, 3 Drawing Figures



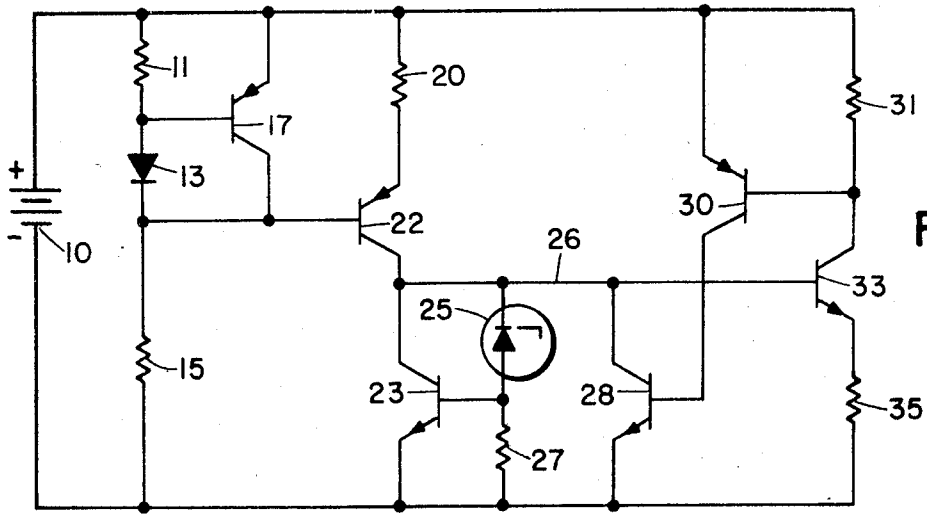


FIG. 1

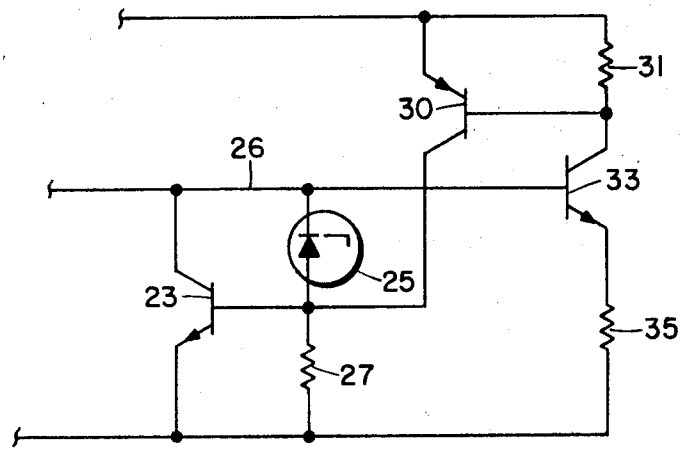


FIG. 2

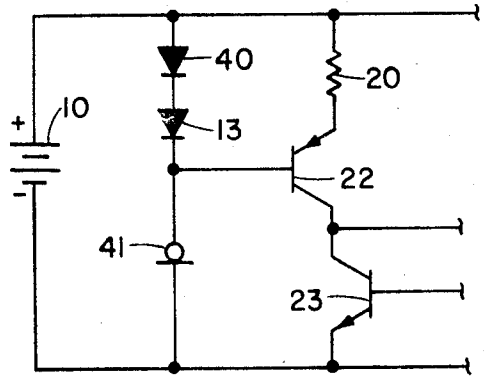


FIG. 3

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LOW-DROP VOLTAGE REGULATOR

BACKGROUND OF THE INVENTION

This invention relates to DC regulated power supplies and more particularly to such power supplies which provide a noise-free voltage level at their output which is close to their input voltage level.

A common form of an open loop voltage regulator uses a junction transistor operating as an emitter-follower amplifier to refer a load to a zener diode voltage reference. When this type of voltage regulator is used to supply power to an automobile radio receiver and where the regulator input voltage varies from 10.5 to 16 volts and includes noise as could be expected from an automobile electrical system, the regulator being required to provide 8.5 volts across the load, this regulator is deficient in its ability to regulate the output voltage and attenuate noise from the power source. Additionally, the thermal inertia of the transistor is so low that it is almost instantly destroyed by a short circuit and thus cannot be protected by a fuze, even if the voltage drop across a fuze could be tolerated.

SUMMARY OF THE INVENTION

A new voltage regulator is described herein wherein a current source having a high dynamic resistance supplies power to an improved zener diode circuit which provides the reference for the emitter-follower. The current source is based by the potential drop across a device having a low dynamic resistance connected in series with a high-resistance device as a divider across the power supply. Additionally, a low-resistance sensing means is provided for sensing load current and providing a feedback to attenuate emitter-follower drive should the load current rise above acceptable limits.

The circuits to be described may be used to provide a low noise stabilized potential directly to a useful load or may be combined with an emitter-follower to serve larger loads. Where the emitter-follower is used the voltage regulator permits the use of a simple feedback circuit to limit the current that can be drawn through the emitter-follower to a safe value.

It is thus an object of this invention to provide a low-loss voltage regulator.

It is another object of this invention to provide a voltage regulator having high noise immunity.

It is still another object of this invention to provide a DC voltage regulator which only slightly attenuates the available voltage source but which greatly attenuates power supply voltage fluctuations, especially those rapid changes observable as noise.

It is still one more object of this invention to provide a DC voltage regulator of the type described which also includes means for limiting load current to a safe value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of one embodiment of the invention.

FIG. 2 is a partial schematic showing an improved version of the invention.

FIG. 3 is another partial schematic showing additional improvements to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the following description identical numerals refer to identical elements in the various figures. Referring now to FIG. 1, there is seen generally a voltage regulator receiving an input voltage from a battery **10**, such as an automobile battery in an automobile electrical system, the regulator supplying a regulated noise-free voltage to a load schematically shown as resistor **35**. As embodied here, the invention might typically be used to supply power to an automobile radio load **35** from the automobile battery **10**. In this application it can be expected that the potential from battery **10** will vary from a minimum of 10.5 volts to a maximum of 16.0 volts while the voltage supplied across load **35** must remain constant at 8.5 volts under a load of 150 milliamperes of current. Additionally, there might be expected impressed across battery **10** and superimposed thereon a noise signal in the order of 1.5 volts peak to peak. Connected across battery **10** from its positive to its negative terminal is the serially connected circuit of resistor **11**, diode **13** and resistor **15**, respectively. A PNP-transistor **17** has its base electrode connected to the junction between resistor **11** and diode **13**, its emitter electrode connected to positive terminal of battery **10** and its collector electrode connected to the junction between diode **13** and resistor **15** and also to the base electrode of a transistor **22**.

PNP-transistor **22** has its emitter electrode connected through resistor **20** to positive terminal of battery **10** and its collector electrode connected to regulated voltage line **26**, which in turn i connected to the base electrode of NPN-transistor **33**. A zener diode **25** has its cathode connected to line **26** and its anode connected through resistor **27** to the negative terminal of battery **10**. NPN-transistors **23** and **28** have commonly connected collector electrodes connected to line **26** and commonly connected emitter electrodes connected to the negative terminal of battery **10**. The base electrode of transistor **23** is connected to the junction between zener diode **25** and resistor **27**. Previously mentioned transistor **33** has its collector electrode connected through resistor **31** to the positive side of the battery and its emitter electrode connected through load resistor **35** to the return of the battery. Another PNP-transistor **30** has its base electrode connected to the collector of transistor **33**, its emitter electrode directly connected to the positive side of the battery and its collector terminal connected to the base electrode of transistor **28**.

The high impedance at the collector of transistor **22** is further increased, in known fashion, by the connection of its emitter to the positive side of the battery through resistor **20** to provide current-dependent feedback.

The base electrode of transistor **22** is connected to the positive terminal of battery **10** through the serial arrangement of the emitter-base circuit of transistor **17** with diode **13**. This provides a bias potential fixed with respect to the positive side of the battery at the transistor **22** base electrode. The junction potential of diode **13** is further stabilized by resistor **11** connected across the base-emitter junction of transistor **17**. The current through this resistor also flows through the diode and is proportional to the nearly constant potential across the base-emitter junction of transistor **17**. In this manner the current through diode **13** is made to be relatively independent of the current gain of transistor **17** with the result that the diode dynamic resistance is greatly reduced.

By virtue of the operation of transistor **17** as a current amplifier a much larger current will flow between its collector and emitter than between its base and emitter. The bias voltage applied to the base of transistor **22** will then be determined, as aforementioned, by the sum of the nearly constant turnon potential across the base-emitter junction of transistor **17** and the junction potential of diode **13**. These aforementioned currents flow through resistor **15** together with the base current of transistor **22**. It will be noted that the potential drop between the positive terminal of battery **10** and the base electrode of transistor **22** as taken through resistor **20** and the emitter-base junction of transistor **22** must be identical to the potential drop resulting from the sum of the potential drops of the emitter-base circuit of transistor **17** and the junction potential of diode **13**. Thus, the potential drop across resistor **20** is very nearly equal to the potential drop across diode **13**. As a result of the low potential drop between the emitter and collector of transistor **22** the resultant regulated voltage on line **26** can be depressed with respect to the voltage at the positive terminal of battery **10** by an amount as small as approximately the potential drop across a single diode.

A constant voltage circuit comprised of transistor **23**, together with zener diode **25** and resistor **27** replace a single zener diode commonly found in the prior art. Zener diode **25** connected between the collector and base electrodes of transistor **23** provides a low dynamic resistance feedback cir-

cuit between these electrodes which results in a very low dynamic impedance between the collector and emitter electrodes transistor **23**. The current flow between the regulated line **26** and the negative side of battery **10**, assuming transistor **28** to be nonconductive, will divide so that the collector current of transistor **23** will equal the product of its base current and the current gain of that transistor. Resistor **27**, connected between the base and emitter of transistor **23**, is used to provide a substantially fixed additional current to zener diode **25**, generally larger than the transistor **23** base current flowing through the zener, to make the total current gain of transistor **23** so that the feedback circuit through the zener is maintained even under conditions requiring small base currents in transistor **23**. This, combined with the fact that transistor **22** operates as a resistor, provides a much higher dynamic impedance between regulated **26** and the positive terminal of battery **10**. This combination of dynamic impedances provides excellent noise isolation at regulated line **26** in addition to providing, as previously discussed, a possible very low voltage drop between the regulated line and battery **10**.

A useful load requiring only a few milliamperes of current can now be connected between regulated line **26** and the negative side of battery **10**, where it will be found that the noise derived from the power supply has been reduced by a factor of 0.0003 as measured on line **26**. Stable and noise-free potential of regulated line **26** can be more frequently used to bias the base electrode of an emitter follower, such as transistor **33**, to drive a load **35**. In this case, essentially the entire load current also flows through resistor **31**. This resistor is quite small so that the normal voltage drop thereacross is not sufficient to forward bias transistor **30**. However, if abnormally large load currents are drawn, such as by the short circuiting of the load, the voltage drop across resistor **31** will be sufficient to forward bias transistor **30**, its collector current now flowing into the base of transistor **28** to render the latter transistor conductive to reduce the potential on regulated line **26**. In this manner transistor **33** will be protected from overload and thermal runaway.

Referring now to FIG. **2**, there is seen the schematic of a simplified version of the device of FIG. **1** having certain advantages and disadvantages over that circuit. Transistor **28** of FIG. **1** has been eliminated and the collector electrode of transistor **30** has here been connected directly to the base electrode of transistor **23** at its common terminal between zener diode **25** and resistor **27**. In this case, and as a result of excess load current flowing in load **35** the voltage drop across resistor **31**, as before, forward biases transistor **30** so that now its collector current divides between resistor **27** and the base-emitter circuit of transistor **23**. Although it might appear that one of the effects of this arrangement would be to raise the voltage at the anode of diode **25** to thus raise the voltage of regulated line **26** and thereby aggravate the overload condition, in actuality, the initial reaction of this circuit is to increase current flow through transistor **23** to thereby depress the voltage on line **26** to protect the circuit from thermal runaway. The reaction of this circuit to overload is more rapid than the reaction of the circuit of FIG. **1** since transistor **23** is already somewhat conductive during normal operation of the circuit. This, in addition to the fact that a transistor may be eliminated, comprise the advantages of this circuit. Some disadvantage is present however, in the fact that transistor **30** collector leakage currents will slightly upset the operation of the zener diode, causing some undesirable fluctuation of voltage on controlled line **26**.

A field effect transistor with its gate connected to a source electrode is commercially available and has been designated as a current-regulating or current-limiting diode. With several volts applied between its terminals it exhibits a high dynamic resistance. It may be substituted advantageously for resistor **15** of FIG. **1**. Its use will also permit a modification of the left side of FIG. **1** as illustrated in FIG. **3**, where the cathode of the current-limiting diode **41** is connected to the negative side of battery **10** and its anode is connected to the base of transistor **22** in common with the cathode of diode **13**. The anode of the latter diode is connected to the positive terminal of battery **10** through another diode **40**, rather than through the base-emitter junction of transistor **17** of FIG. **1**. For this reason, transistor **17** and resistor **11** of FIG. **1** are omitted. The current-limiting diode must pass current somewhat in excess of that required for the base of transistor **22** under the most adverse combination of tolerances.

Diodes **13** and **40** are generally selected to be of the same type, and selected to provide a low dynamic resistance to the range of currents that may flow through them. The base current of transistor **22** is predictable only within a range of eight to one and there is a manufacturing tolerance on the current-limiting diode **41**, thus the range of current through diodes **13** and **40** is substantial. To keep the ratio of maximum to minimum current through these diodes within reasonable bounds, the least value of the current range for the current limiting diode is designed to significantly exceed the greatest value of the current range of current at the base of the transistor **22**.

The invention has been described as it would appear if all the semiconductor devices were made of the same base materials. Some obvious changes would be made in the circuit if more than one kind of material appeared in the circuit. For example, if transistor **22** of FIG. **3** were germanium and one of the diodes **13** and **40** were silicon, the other diode might be omitted or the value of resistor **20** increased to obtain the same results. Or if a field effect transistor were substituted for one of the junction transistors, consideration of the base current would vanish. Also, the polarity of the power source may be reversed with respect to the circuit if semiconductor devices of opposite polarity are substituted for those shown. These and other modifications of the invention might be made by one skilled in the art without departing from the true spirit and scope of the invention. Accordingly, the invention is to be limited only in accordance with the appended claims.

The invention claimed is:

1. In a voltage regulator receiving input power from a power supply having first and second terminals, an output terminal, a first current-limiting circuit having a ratio of dynamic resistance to average resistance large compared to unity connected between said first and output terminals, and a potential-limiting circuit having a ratio of dynamic resistance to average resistance small compared to unity connected between said output terminal and said second terminal, an improvement wherein said first current-limiting circuit comprises:

a resistor;

a first transistor having an emitter electrode connected through said resistor to said first terminal, a collector electrode connected to said output terminal, and a control electrode;

means providing a first constant potential drop connected between said first terminal and said first transistor control electrode; and wherein said potential-limiting circuit comprises:

a second transistor having an emitter electrode connected to said second terminal, a collector electrode connected to said output terminal, and a control electrode; and

means providing a second constant potential drop connected between said output terminal and said second transistor control electrode.

2. The improvement recited in claim **1** wherein said means providing said first and second constant potential drops are semiconductor diodes.

3. The improvement recited in claim **2** with an additional resistor connected between said second transistor emitter and control electrodes.

4. The improvement recited in claim **1** wherein said means for providing a first constant potential drop comprises:

a second current-limiting means;

a third transistor having an emitter electrode connected to said first terminal, a collector electrode connected to the

control electrode of said first transistor, and a control electrode; and,

means providing a constant potential difference connected between said third transistor control and collector electrodes.

5. The improvement recited in claim 4 with an additional resistor connected between said third transistor emitter and control electrodes.

6. The improvement as recited in claim 1 with additionally an emitter follower transistor having a control electrode connected to said output terminal, an emitter electrode connected to said output terminal, an emitter electrode adapted for having a load connected therefrom to said second terminal, and a collector electrode; and,

means for electrically connecting said emitter follower collector electrode to said first terminal.

7. The improvement recited in claim 6 wherein said means for electrically connecting comprises means for sensing current in said emitter follower collector emitter circuit and with additionally means responsive to said sensed current for reducing voltage at said output terminal.

8. The improvement recited in claim 6 wherein said means

for electrically connecting is a resistor connected between said first terminal and said emitter follower collector electrode and with additionally:

a further transistor having an emitter electrode connected to said first terminal, a control electrode connected to said emitter follower collector electrode and a collector electrode connected to said second transistor control electrode.

9. The improvement recited in claim 6 wherein said means for electrically connecting is a resistor connected between said first terminal and said emitter follower collector electrode and with additionally:

a further transistor having an emitter electrode connected to said first terminal, a control electrode connected to said emitter follower collector electrode and a collector electrode; and,

a second further transistor having an emitter electrode connected to said second terminal, a collector electrode connected to said output terminal and a control electrode connected to said further transistor collector electrode.

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