United States Patent

Harrigan

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[54] BASE REACH-THROUGH ACTIVE SERIES VOLTAGE REGULATOR

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[52] **U.S. Cl.** ....**321/18,** 307/43 R, 307/75, 307/297, 321/27, 323/22 T, 323/38

[51] **Int. Cl.** **H02m 7/20**

[58] **Field of Search** ....307/44, 43 R, 64, 6 S, 75, 307/297; 321/16, 18, 27; 323/4, 9, 22 T, 22 SC, 38

[56] **References Cited**

UNITED STATES PATENTS

3,217,237 11/1965 Giger....................................323/22 T
3,375,437 3/1968 Mellott et al.......................323/22 SC
3,414,802 12/1968 Harrigan et al..........................321/16

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[57] **ABSTRACT**

The pass transistor of this series regulator supplies current at a regulated voltage only slightly below its unregulated supply voltage. The driver transistor, driven by the feedback loop, is supplied from a higher voltage source. During periods when the pass transistor cannot supply the load because its source voltage is too low, the driver transistor supplies the load through the base-emitter junction of the pass transistor without affecting the regulation.

5 Claims, 3 Drawing Figures

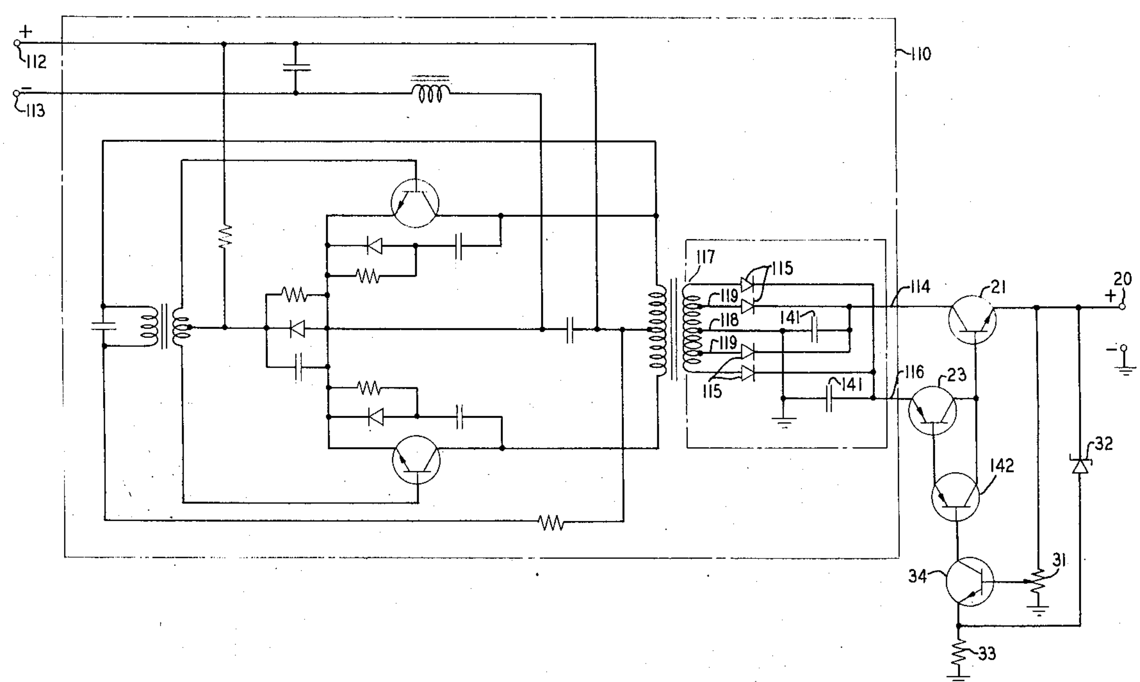


FIG. 1

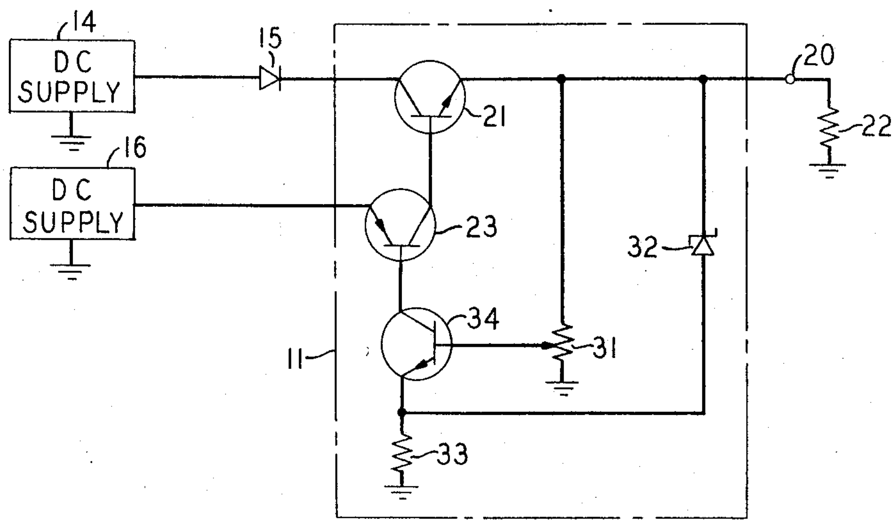
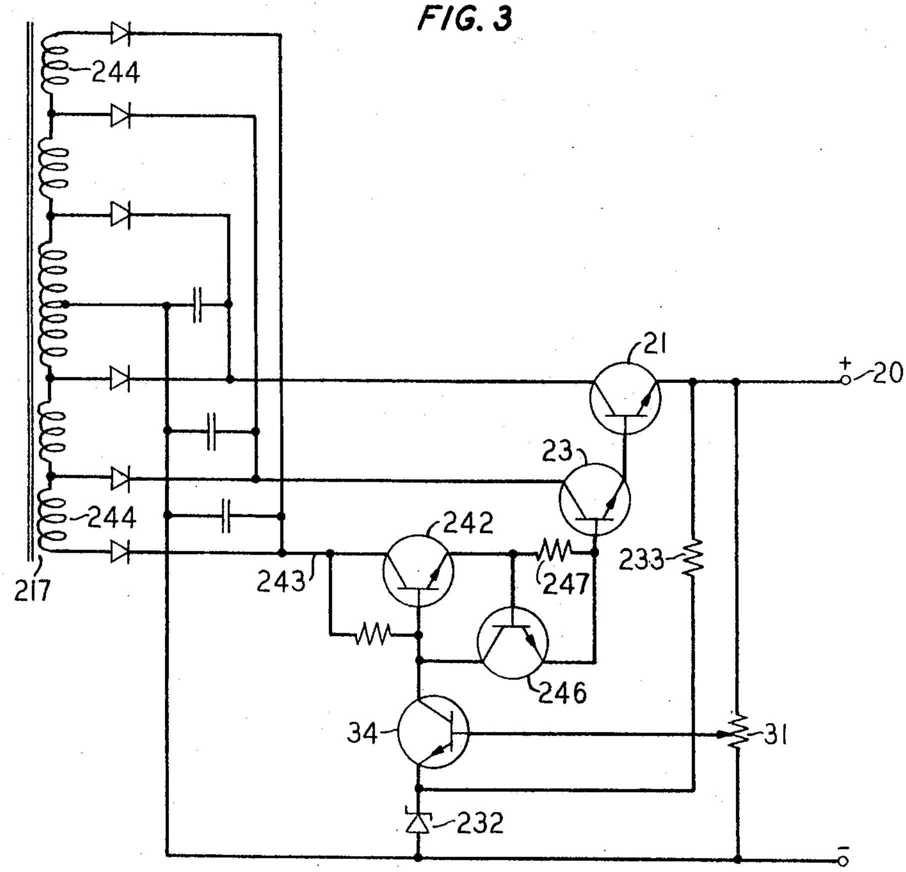


FIG. 3



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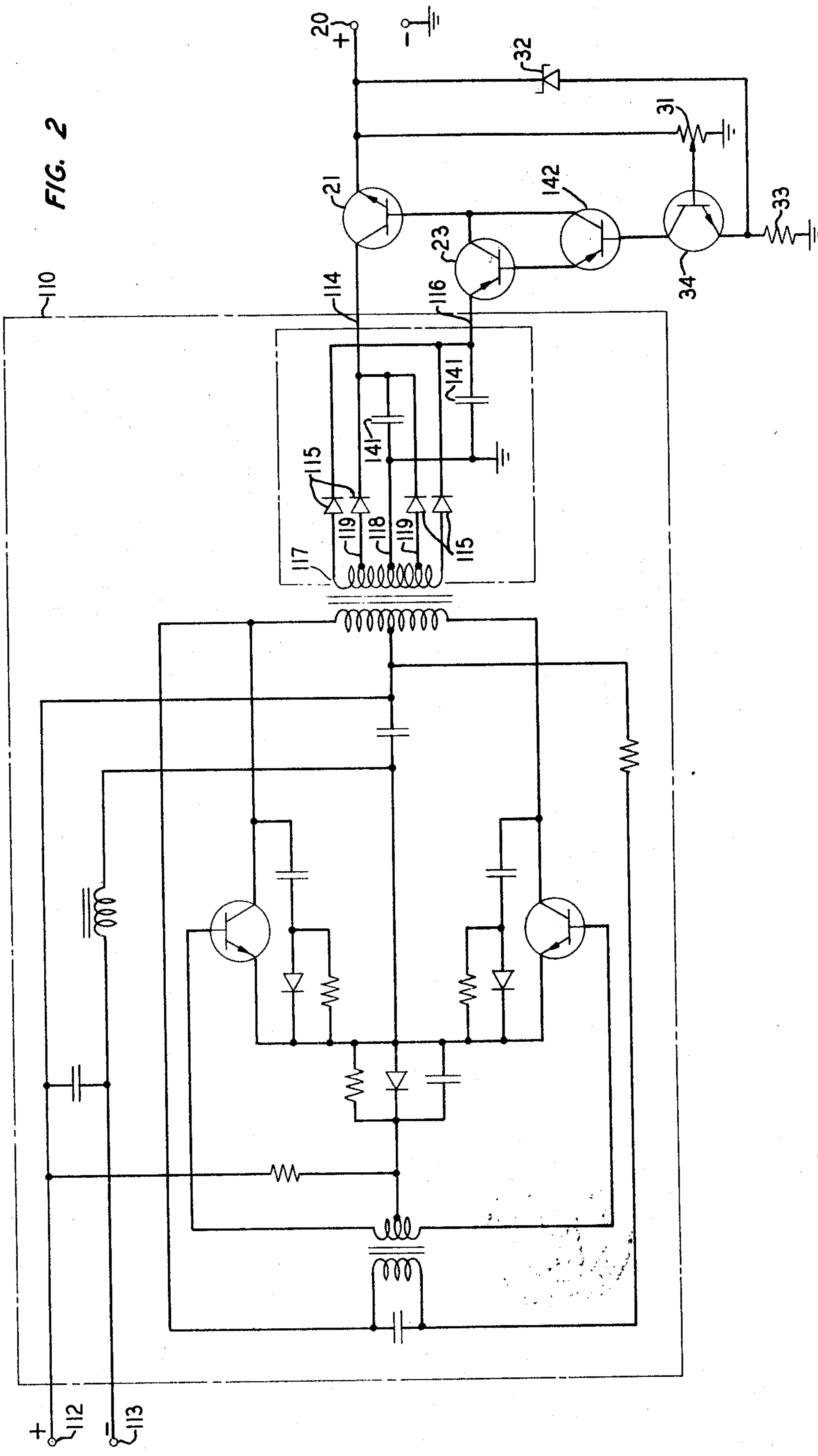

FIG. 2

BASE REACH-THROUGH ACTIVE SERIES VOLTAGE REGULATOR

BACKGROUND OF THE INVENTION

This invention relates to regulated DC power supplies. More particularly, it relates to what is known as the series type regulator in which regulation is achieved by the control of an impedance element between input and output. This is distinguished from the switching type regulator in which the duty cycle of a switch connected between input and output is controlled to effect regulation.

The choice between a series type or switching type DC voltage regulator is often a difficult one, particularly for an audio frequency communications system. The switching type regulator is very efficient, but it generates considerable noise within or slightly above the audio frequency range that can require filtering at an appreciable expense. The series type regulator, on the other hand, is in itself a dynamic filter that provides excellent regulation, but it is notoriously inefficient. The entire expected range of variation of input voltage must usually be absorbed within the series element. While in a laboratory power supply efficiency is not usually a very important consideration, in a large system, it can be very important. In a telephone system, for example, with thousands of circuits to be supplied with regulated voltage, efficiency must be considered with respect to heat and space limitations, as well as the cost of power consumption.

In U.S. Pat. No. 3,414,802, which issued to this inventor and W. E. Jewett on Dec. 3, 1968, a system is disclosed that solves the efficiency problem with a pair of stacked series regulators. The Harrigan-Jewett system uses two regulators with their outputs connected in parallel. The first regulator operates efficiently with a minimum voltage drop across it during the very high percentage of time when the input voltage is within a narrow nominal range. The second regulator, operating from a higher input voltage, is adjusted to supply a slightly lower output voltage than the first regulator supplies. The second regulator is therefore normally cut off and operates only when the output voltage falls because of a larger drop in the input voltage than the first regulator can absorb. The system is therefore particularly useful where more than one supply voltage is available and where the normal input voltage variation is not great. The system does require however, two regulators each complete with output voltage sensor, error detector feedback circuit, and pass transistor.

An object of this invention is to regulate DC voltage very efficiently over a wide input voltage range using a single series type regulator.

A second object is to provide efficient DC voltage regulation at considerable savings in cost and space.

A third object is to provide the same advantages of the Harrigan-Jewett circuit with the use of a single series type voltage regulator.

SUMMARY OF THE INVENTION

In this efficient series type voltage regulator, the collector of the pass transistor is connected to a first source of direct current, and the emitter is connected to the regulated voltage output terminal. The collector-emitter path of a driver transistor is connected between a second DC source and the base of the pass transistor. Feedback means are connected between the output terminal and the driver transistor to drive the driver transistor in response to the output voltage. The difference between the voltage of the first source and the regulated output voltage is so small that the first source voltage occasionally drops below the regulated voltage. During such periods, the driven transistor supplies the current to the output terminal through the base-emitter junction of the pass transistor from the second source, the voltage of which is high enough to remain above the regulated voltage. Efficiency is improved because the voltage drop across the pass transistor is never very large, and the current through the driver transistor is large only during periods of very low first source voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a schematic diagram of a circuit embodying the essential elements of the invention;

FIG. 2 is a schematic diagram of a particularly useful embodiment of the invention; and

FIG. 3 is a schematic diagram of an alternative embodiment of the invention.

DETAILED DESCRIPTION

In the embodiment of FIG. 1, a series voltage regulator **11** is powered by two direct current supplies **14** and **16**. Supply **14** is connected through a blocking diode **15** to the collector of the pass transistor **21** of regulator **11**. The emitter of pass transistor **21** is connected to an output terminal **20** to which a load **22** may be connected. The collector-emitter path of a driver transistor **23** is connected between supply **16** and the base of pass transistor **21**. A potentiometer **31** is connected between output terminal **20** and ground. The series combination of a zener diode **32** and a resistor **33** is also connected between output terminal **20** and ground. Finally, an error detector transistor **34** has its collector connected to the base of driver transistor **23**, its emitter connected to the junction between zener diode **32** and resistor **33** and its base connected to the tap on potentiometer **31**.

Except for the fact that driver transistor **23** and pass transistor **21** operate from different current supplies, the circuit of FIG. **1** operates in a manner similar to the well-known series type regulator. The zener diode **32**, being biased into its breakdown range by resistor **33**, maintains a relatively constant voltage across its terminals. It therefore applies directly to the emitter of error detector transistor **34** the entire variation of output voltage. The base of transistor **34** on the other hand, being connected to a potentiometer tap, sees only a portion of the variation of output voltage. The potentiometer tap acts like a source of reference potential. If the output voltage at terminal **20** tends to rise therefore, the emitter voltage of transistor **34** increases much more than its base voltage, reducing its collector current. Applied to the base of driver transistor **23**, the reduced collector current reduces the drive to base transistor **21**, in turn reducing the current to terminal **20**, hence offsetting the original tendency of the output voltage to rise. This provides the well-known series type regulation which is efficient only when the drop across the pass transistor is small.

In order to keep the voltage drop across pass transistor **21** small for high efficiency, regulator **11** is designed as if it were handling only a nominal range of supply voltage from supply **14**. That is, the regulated output voltage at terminal **20** plus the minimum drop across transistor **21** is equal to the nominal minimum output voltage of supply **14**. The nominal minimum voltage may be considered the minimum voltage that occurs relatively frequently during regular power service. With the exception of the regulator of the Harrigan-Jewett patent noted before, voltage regulators designed in this manner cannot handle the larger input voltage variations that occur relatively infrequently. Sustained operation on standby battery sources during commercial power blackout, for example, would result in a drop in output voltage that defeats the purpose of the regulator. According to the principles of this invention, however, driver transistor **23** is supplied from supply **16**, the voltage of which remains higher than that required at output terminal **20**. When the input voltage to pass transistor **21** drops far enough that its collector-emitter junction is voltage limited and therefore cannot supply all of the current called for to maintain the output voltage at terminal **20**, driver transistor **23**, operating from a higher voltage source, is not so voltage limited. It then begins to supply not merely drive current, but output current as well, right through the base-emitter junction of transistor **21** to maintain the output voltage. In order to provide this "reach-through" regulation, of course, transistor **23** and the base-emitter junction of transistor **21** must each be large enough to handle the whole load current. In addition, the nominal voltage of supply **16** must be high enough that it exceeds the output voltage at all times, even during periods when the voltage of supply **14** does not. Diode **15** prevents reverse collector current in transistor **21** driven by transistor **23**.

If the basic source voltage of supply **16** varies considerably, a relatively large voltage drop will be required across transistor **23** most of the time in order to insure adequate minimum voltage. This is the consideration in connection with the pass transistor that generally causes series regulators to be very inefficient. In this case, however, during the large percentage of time transistor **23** is supplying only base current to transistor **21** and hence is not wasting much power. It is only during periods of unusually low voltage at supply **14** that transistor **23** supplies the load. If the voltage of supply **16** is also low during these same periods, the power waste is low even then.

During normal operation, therefore, load current is supplied from supply **14** through transistor **21** efficiently because the voltage across transistor **21** is never very large. During periods of abnormally low voltage at supply **14**, the collector of transistor **21** is backbiased, and all of the load is supplied from supply **16** through transistor **23** and the base-emitter junction of transistor **21** with no drop in output voltage.

FIG. 2 shows in schematic form an embodiment of the invention that is particularly useful in supplying direct current of regulated voltage from a power system in which standby batteries are floated across the commercial power. In this figure, components and circuits have been given the same numbers as their counterparts in FIG. 1 for clarity. The two supplies in this case are both derived from one inverter **110** which has two input leads **112**, and **113** for connection to the DC power source. The particular inverter shown in an improved two-core Jensen type inverter that is the subject of U.S. Pat. No. 3,448,370, which issued to the inventor of this application, June 3, 1969. Any reliable inverter may, of course, be used in its place. The secondary winding **117** of the output transformer of inverter **110** has a center tap **118**, and two symmetrical taps **119—119** to provide the two supplies of FIG. 2. A set of diodes **115—115** connected to the ends of winding **117** and to each tap provide full-wave rectification for each supply, and filter capacitors **141—141** are connected across each supply to smooth the input voltages to the regulator. The outputs of these supplies therefore appear on conductors **114** and **116**, respectively. Pass transistor **21** is connected between conductor **114** and output terminal **20**, and driver transistor **23** is connected between conductor **116** and the base of transistor **21**, as in FIG. 1.

The standby batteries floating across input leads **112** and **113** act as large filters and hence provide some voltage regulation themselves. The voltage variation on output **114** of inverter **110**, therefore, is not very large as long as the commercial input power is uninterrupted. Transformer winding **117** is designed so that the minimum nominal voltage on output lead **114** with commercial power supplied is about 1 volt higher than the required regulator output voltage at terminal **20**. There are enough turns in remainder of the secondary winding, however, so that even after the commercial power has been off for several hours, the voltage on lead **116** is still a few volts higher than the required output voltage. To provide enough gain in the feedback loop, an additional transistor **142** has been connected to drive transistor **23** in the well-known Darlington amplifier fashion.

The required output voltage is supplied very efficiently from this low cost equipment even during commercial power failure. If standby power is needed longer than the several hours available from the batteries, auxiliary generating equipment can be started and connected to recharge the batteries with no interruption in the regulated output voltage.

An alternative regulator embodying the principles of the invention and using only NPN-transistors is shown in FIG. 3. There are three areas in which this regulator differs from that of FIG. 2, all arising from the use of transistors of a single polarity. First, the feedback amplifier transistor **242** is connected in a common emitter configuration rather than a Darlington configuration. In order to provide drive to transistor **23**, transistor **242** needs somewhat more reserve voltage because of its polarity. It is accordingly connected to a still higher voltage source **243** derived from additional turns **244—244** on transformer secondary winding **217**. With amplifier **242** operation from a higher voltage source however, when transistor **23** becomes voltage limited so that it cannot supply the output current through the base-emitter junction of transistor **21**, transistor **242** would attempt to do so by reaching through the base-emitter junction of transistor **23** in the same manner. Transistor **246** and resistor **247** are therefore connected as a current limiter between transistors **242** and **23**. As the emitter current of transistor **242** increases to increase the voltage drop across resistor **247**, transistor **246** becomes more conductive to shunt the drive to transistor **242** and therefore limit the current. Finally, zener diode **232** is connected between the negative output terminal and the emitter of error detector transistor **34**. The output voltage variations sensed by the tap on potentiometer **31** are applied to the base of transistor **34** to develop the error signal.

It will be obvious to those skilled in the art of voltage regulators that many variations can be made from the circuits specifically described including, for example, reversing the polarities of all of the transistors without departing from the spirit and scope of the invention.

What is claimed is:

1. A direct current voltage regulator for providing a regulated voltage to an output terminal comprising a first source of direct current having a voltage that may drop below said regulated voltage, a pass transistor having its collector connected to said first source and its emitter connected to said output terminal, a second source of direct current having a voltage that remains above said regulated voltage, a driver transistor having its collector-emitter path connected between said second source and the base of said pass transistor, and feedback means connected between said output terminal and said driver transistor for driving said driver transistor in response to the voltage at said output terminal whereby during periods when said first source voltage is below said regulated voltage, said driver transistor supplies current to said output terminal through the base-emitter junction of said pass transistor to maintain said regulated voltage.

2. A direct current voltage regulator as in claim 1 wherein said first and second direct current sources are derived from a common alternating current source.

3. A direct current voltage regulator as in claim 1 wherein the polarity of said driver transistor is opposite to the polarity of said pass transistor.

4. A direct current voltage regulator as in claim 3 wherein said feedback means includes a source of reference potential, means for sensing the voltage at said output terminal, comparing means for producing an error signal proportional to the difference between said regulated voltage and said reference potential and amplifying means for driving said driver transistor in proportion to said error signal.

5. A direct current voltage regulator as in claim 2 including a third DC source derived from said common AC source connected to said feedback means for providing the energy to drive said driver transistor, and current limiting means connected between said feedback means and said driver transistor whereby said feedback means are prevented from supplying current to said output terminal through the base-emitter junction of said driver transistor.

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