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R. L. VON ESCHEN ET AL

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VOLTAGE REGULATOR

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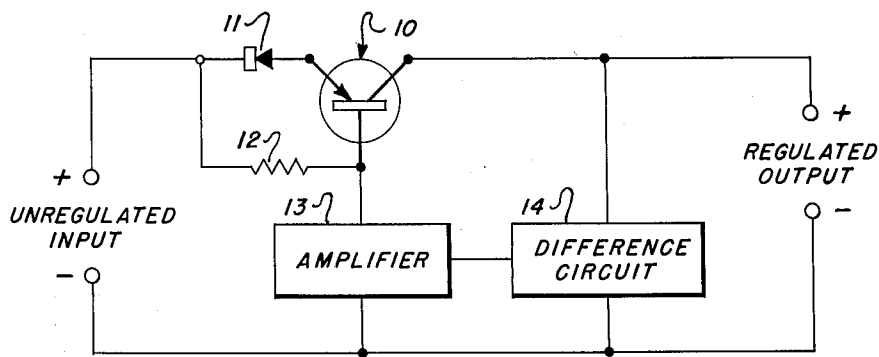


Fig. 1

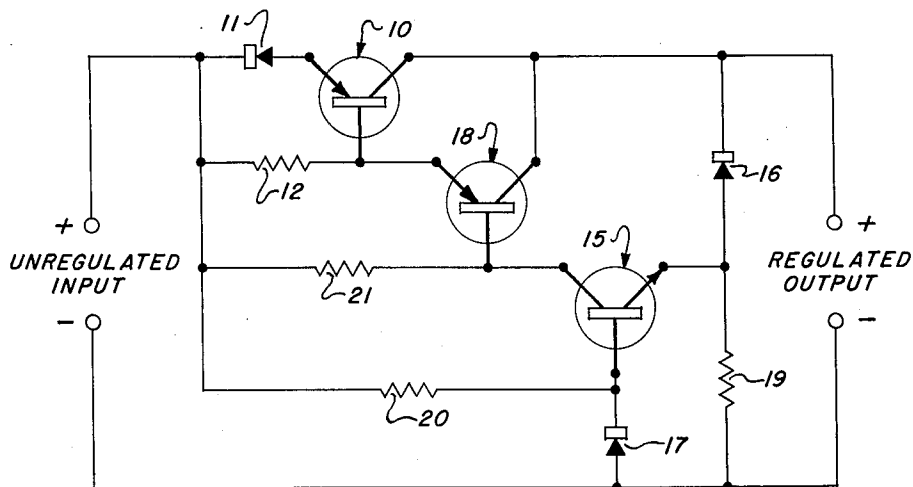


Fig. 2

INVENTORS:

Robert L. Von Eschen

Paul F. Scheele

BY

Robert A. Anderson

Attorney

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VOLTAGE REGULATOR

Robert L. Von Eschen and Paul F. Scheele, Albuquerque, N. Mex., assignors, by mesne assignments, to the United States of America as represented by the United States Atomic Energy Commission

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1 Claim. (Cl. 323-22)

The present invention relates generally to voltage regulators, and more particularly to voltage regulator circuits having a regulating transistor connected in series with the positive line of a power system.

Series voltage regulators of this type are popular because they draw a very small amount of current from the power supply under no-load conditions. The other basic type of regulator uses the shunt method and has the characteristic of drawing full-load current from the power supply at all times.

In general, the series type voltage regulator operates by comparing the regulated voltage with a reference voltage standard, deriving a voltage which is representative of the difference between the two and using this difference voltage to control the impedance of the transistor connected in series with the supply line. A negative feedback connection is used so that an increase in the difference voltage causes an increase in the impedance of the series transistor, increasing the voltage drop across the transistor and thereby causing the output voltage to drop to normal. The rise in difference voltage may be due to variations in load current, input voltage, or temperature of the series transistor.

A serious limitation in the operating temperature range of series voltage regulators has been the effect of rising temperatures on the impedance of the series transistor, which is to decrease the internal impedance of the series transistor, thereby allowing the output voltage to rise. The difference voltage generated therefrom then is applied to the base of the series transistor in an attempt to increase the transistor impedance and regain control of the voltage. The usual method of controlling a transistor includes holding the base electrode negative with respect to the emitter, so that there is a base current flowing out of the transistor at all times. When rising temperatures prevail, therefore, the base electrode is driven less and less negative, increasing the internal impedance, until the base reaches the same potential as the emitter. Further control of the transistor necessitates driving the base electrode more positive than the emitter, reversing the direction of flow of base current. Circuits have been devised for performing this action in connection with NPN transistors, which are the type of transistors usually used in the positive line of a power system.

At the present time, germanium transistors of NPN type are available only for low-powered applications. Silicon transistors are available to handle large amounts of power, but their cost is several times that of germanium PNP-type transistors. Therefore, in circuit applications where it is necessary that a common negative lead be carried through the voltage regulator, it is quite desirable from an economic standpoint that PNP-type transistors can be used in the more economical series voltage regulator.

It is also important that circuitry be designed which will operate in the vicinity of 180° F. for use in modern guided missile applications. It has been found through experience that prior art series regulators lose control of the voltage at approximately 140° F.

Therefore it is a general object of this invention to provide a transistor series voltage regulator having a common negative lead and having an operating temperature range in excess of that of prior-art regulators. The

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present invention will provide very close voltage regulation up to the vicinity of 180° F., the upper temperature limit being set only by the allowable maximum junction temperature of the series transistor, rather than by the decrease of base current to zero.

Briefly, the present invention includes a novel arrangement of a Zener diode and a resistor in the base-emitter circuit of the series transistor. The Zener voltage of the diode is related to the size of the resistor such that a decrease in normal current flow through the resistor will create a reversal of the polarity of the base-emitter voltage thereby reversing the direction of flow of base current and extending the useful temperature range of the series transistor. The existence of the Zener diode allows a similar reversal of base current in a transistor amplifier in the negative feedback circuit as well, where a transistor amplifier is applicable.

Other objects and advantages of the present invention will become apparent from reading the more detailed description to follow, in conjunction with the attached drawing, in which:

FIG. 1 shows a preferred embodiment of the invention in its most general form; and

FIG. 2 shows a more specific form of the preferred embodiment, using semiconductor elements in the feedback circuit.

As shown in FIG. 1, PNP transistor 10 is connected with its emitter-collector path in series with the positive line of a power system which has a common negative line. Zener diode 11 is connected between the positive input terminal of the voltage regulator circuit and the emitter of transistor 10. The Zener diode has the characteristic of a constant voltage drop across its terminals over a wide range of currents flowing through the diode in a reverse direction. Therefore, the voltage drop from the positive input terminal to the emitter of transistor 10 will remain constant over the useful range of the diode. Resistor 12 is connected from the positive input terminal to the base of transistor 10, and to the output of amplifier 13. The amplifier is constructed so that it draws a relatively constant amount of current through resistor 12, sufficient to create a voltage drop across the resistor in excess of the Zener voltage of diode 11. The base is then negative with respect to the emitter. This situation prevails at the lower part of the temperature range of transistor 10.

Difference circuit 14 detects a rise in the regulated output voltage caused by any one of the several factors previously mentioned, and applies a difference voltage to amplifier 13. The amplified difference voltage, when applied to the base of transistor 10, raises the voltage thereof, lowers the base current, and increases the impedance of the transistor. The voltage drop across the transistor increases, with the result that the regulated output voltage decreases to the desired value. An original decrease in regulated output voltage will have the opposite effect on the circuit.

If the change in output voltage is sufficient, amplifier 13 raises the base voltage until it equals the emitter voltage. In prior-art circuitry, this would indicate the limit of regulation of the circuit, but in the present invention, further increase in difference voltage decreases the voltage drop across resistor 12, so that it is less than the Zener voltage of diode 11, thereby reversing the polarity of the emitter-base bias voltage and making the base positive with respect to the emitter. Control of the impedance of the transistor 10 is thereby maintained beyond the limit of control found in earlier circuits.

The circuit of FIG. 2 makes exclusive use of transistors and Zener diodes in the amplifier and in the difference circuit. The emitter-base path of transistor 15 is connected in series with Zener diodes 16 and 17 across

the output terminals of the regulator. Since the voltage drop across each of the diodes is constant, regardless of changes in the regulated output voltage, the entire change in output voltage (or difference between the output voltage and the sum of the Zener voltages) appears between the base and the emitter of transistor 15. This difference voltage is amplified and applied to the base of amplifying transistor 18. The further amplified signal is conducted to the base of transistor 10 where it performs the corrective action on the transistor impedance. Resistor 19 limits the current through diode 16 to within its operating range and provides a current path for transistor 15. Resistor 20 performs the same limiting function for diode 17, and is connected to the positive input terminal so that an initial reference voltage will be developed across diode 17 for proper initial operation of the circuit. Resistor 21 furnishes collector and base currents for transistors 15 and 18 respectively, from the positive input terminal.

Reversal of the base currents of transistors 15 and 18 may occur as follows: Circuit values are chosen so that at the lower part of the temperature range of transistor 15 its base is held positive with respect to its emitter. Diode 17 holds the base voltage constant with respect to ground. (Since transistor 15 is a NPN-type transistor, this is the usual polarity of the bias.) A large rise in difference voltage, however, will raise the emitter voltage above that of the base, thus reversing the bias. The emitter of transistor 18 remains at a fairly constant voltage, there being only changes of a few tenths of a volt necessary to control the impedance of transistor 10. However, changes in the collector current of transistor 15 are fairly large due to the changes in difference voltage and are reflected in large changes in the voltage drop across resistor 21. The large size of resistor 21 relative to resistor 12 emphasizes this effect. The result is that at large increase in difference voltage raises the base voltage of transistor 18, reversing the normal negative emitter-base-bias on that PNP-transistor and thereby extending its effective range.

Even if changes in input voltage and load current are not sufficient to change the difference voltage, the changes in internal impedances of the three transistors due to changes in temperature frequency are enough to require the reversal of base currents therein.

The following table lists suggested circuit values and component types for a preferred embodiment of the invention designed to produce a 12-volt regulated output from an unregulated input voltage which may vary between the limits of 24 volts and 33 volts. Regulation has been found to be within $\pm 1\%$ over a temperature range from 20° F. to 180° F.

Circuit element:	Value or type
Transistor 10	2N158
Diode 11	SV906
Resistor 12	ohms-- 750
Transistor 15	2N228
Diodes 16, 17	1N429
Transistor 18	2N45
Resistor 19	ohms-- 1000
Resistor 20	do-- 3000
Resistor 21	do-- 3600

A preferred embodiment of a novel series transistor voltage regulator circuit has been described as an example only. It is recognized that the use of amplifier 13 is optional, depending on the magnitude of the difference voltage supplied by difference circuit 14. The difference circuit shown in FIG. 2 may be modified to eliminate diode 16 and resistor 19, connecting emitter of transistor 15 directly to the positive output terminal. This results in slightly poorer regulation and necessitates the Zener voltage of diode 17 being equal to the desired output voltage. Other modifications to the circuitry shown will occur to a person skilled in the art and may be followed without departing from the sphere and scope of the invention as described in the claim below.

What is claimed is:

A transistor series voltage regulator for providing a regulated output voltage from an unregulated input voltage, comprising: a first transistor of the PNP type having its collector connected to a positive output terminal; a negative terminal common to both input and output; a first Zener diode connected in the reverse direction between a positive input terminal and the emitter of the first transistor; a first resistor connected between the positive input terminal and the base of the first transistor; a second transistor of the NPN type; a second Zener diode connected in the reverse direction between the positive output terminal and the emitter of the second transistor; a second resistor connected from the emitter of the second transistor to the negative terminal; a third Zener diode connected in the reverse direction from the base of the second transistor to the negative terminal, whereby the difference between the output voltage and the sum of the Zener voltages of the second and third Zener diodes is applied between the emitter and the base of the second transistor; a third resistor connected from the positive input terminal to the base of the second transistor, for limiting the current in the third Zener diode; a third transistor of the PNP type, having its collector connected to the positive output terminal, its emitter connected to the base of the first transistor, and its base connected to the collector of the second transistor; and a fourth resistor connected from the base of the third transistor to the positive input terminal, whereby the base current of the third transistor may reverse in response to large difference voltages.

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