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REGULATED POWER SUPPLY

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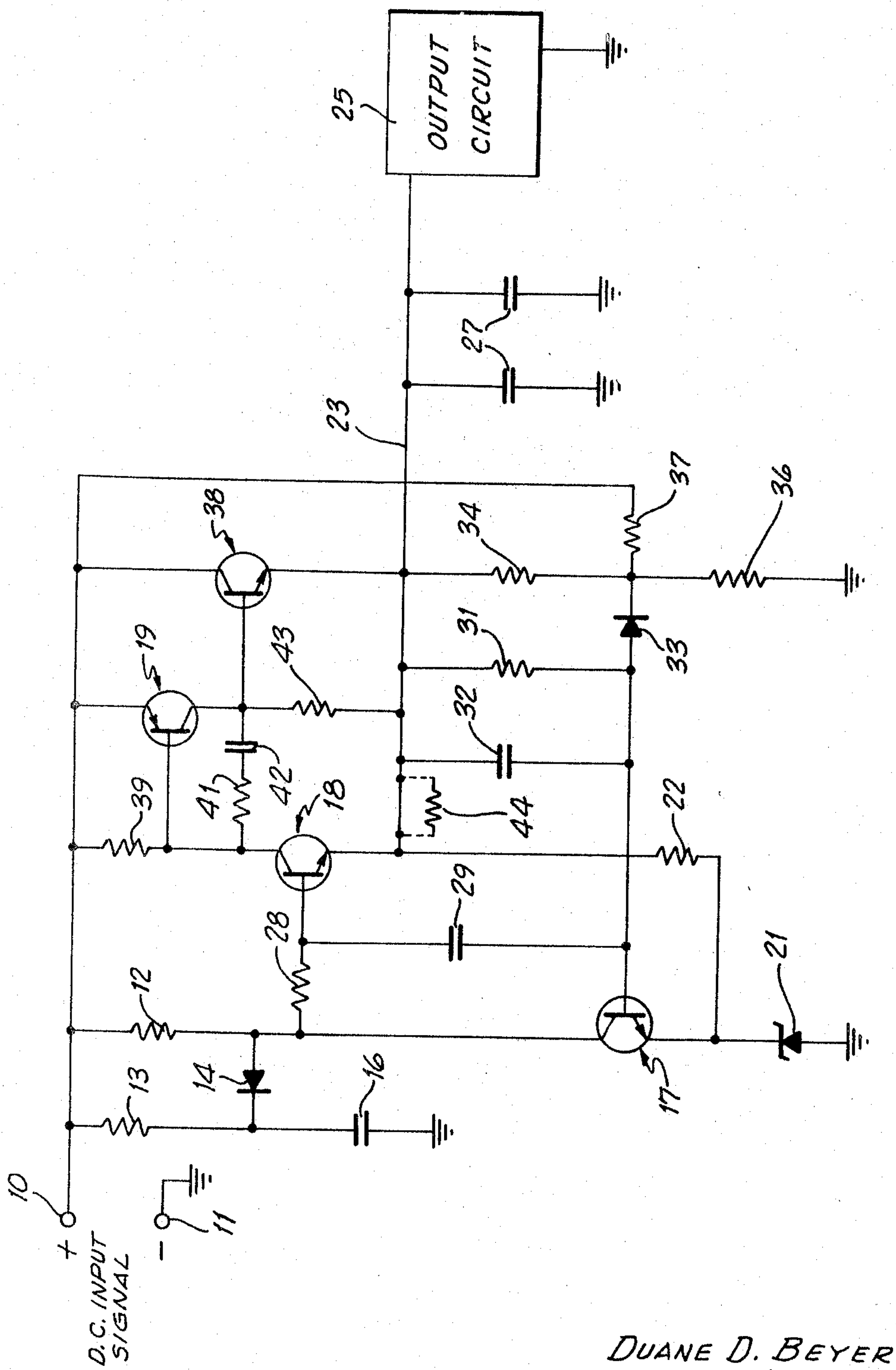

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REGULATED POWER SUPPLY

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This invention relates to regulated power supplies and particularly to an improved transistorized voltage regulator.

Various electronic devices and numerous forms of electrical and electronic equipment require a direct current power supply, the output voltage of which is maintained at a constant value notwithstanding input voltage variations and/or output load variations. Heretofore, a number of voltage regulator circuits have been developed in an attempt to provide a suitable source of input voltage for these devices and equipment. However, such previously developed voltage regulator circuits have not proven completely satisfactory.

Prior known voltage regulator circuits have been susceptible to temperature variations to the extent that adequate voltage regulation is not achieved. Moreover, voltage regulators previously employed have not had the most desirable output impedance characteristics, and have not been able to supply output currents in the desired ampere range while at the same time maintaining the necessary small potential difference between the unregulated input voltage and the regulated output voltage provided thereby.

Accordingly, it is an object of the present invention to provide a novel, improved, and simplified transistorized voltage regulated power supply.

Another object of the present invention is to provide a transistorized voltage regulator which yields a regulated output voltage irrespective of temperature variations.

A further object of the present invention is to provide a regulated power supply having the desirable characteristic of low output impedance while at the same time yielding a regulated output voltage which is maintained substantially constant notwithstanding variations in the unregulated voltage supplied thereto and/or output load variations.

Other objects and advantages will become apparent from the following description, when considered in conjunction with the accompanying drawing wherein the single figure is a schematic representation of a preferred embodiment of the transistorized voltage regulator circuit of the present invention.

In general, the regulator circuit of the present invention is designed to provide a stable regulated output voltage notwithstanding temperature variations, input supply variations and/or output load variations. In this connection, a transistor control element is serially connected to the output terminals of the regulator circuit whereacross the load is connected. The series transistor control element is normally biased in a conductive state, and a temperature compensated transistorized amplifier circuit is connected thereto so as to vary the bias in response to error signals passed by the amplifier circuit. That is, a voltage reference element is connected to the input of the transistorized amplifier circuit and to the output terminals of the regulator so that a variation in the voltage developed at the output terminals results in an amplified error signal being developed and passed by the amplifier circuit to the series transistor element.

With reference to the drawing, an embodiment of the voltage regulator includes a pair of input terminals **10** and **11**, the latter of which is grounded, whereto an unregulated direct current voltage is supplied (e.g., from a battery). A network including a biasing resistor **12**, a

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resistor **13**, a semiconductor diode **14** and a capacitor **16** is connected across the input terminals **10** and **11** and across the input to a transistor amplifier circuit including the transistors **18** and **19**. The resistor **13**, the diode **14** and the capacitor **16** are provided at the input to the amplifier circuit to minimize initial current surges in the regulator by reducing the response time of the circuit when the D.C. input voltage is first applied across the input terminals **10** and **11**.

The resistor **12** is connected in series with the collector-emitter junction of the transistor **17** and a Zener diode **21**. The Zener diode **21** serves as a voltage reference element in the regulator circuit of the present invention and sets the emitter bias for the transistor **17**. In a conventional manner, the diode **21** is reverse biased so that the voltage developed thereacross remains essentially stable.

As shown in the drawing, a resistor **22**, which serves as the Zener supply element, is connected through a resistor **44** and a conductor **23** to the load for the regulator, which is generally designated as an output circuit **25**. A pair of filter capacitors **27** are connected in parallel across the input of the output circuit **25**.

The transistor amplifier **18** has the emitter thereof connected through the resistor **44** to the conductor **23** and the base thereof connected through a resistor **28** to the junction between the collector of the transistor **17** and the biasing resistor **12**. A capacitor **29** is connected between the base of the transistor **18** and the base of the transistor **17** and forms an RC network with the resistor **28** that yields high frequency stabilization and phase compensation.

The base of the transistor **17** is also connected to the conductor **23** and thereby to the output circuit **25** through a parallel RC network including a biasing resistor **31** and a capacitor **32**. In addition, the base of the transistor **17** is connected to a temperature compensating semiconductor diode **33** that is in turn connected to the output circuit **25** through a resistor **34**; to ground through a resistor **36**; and to the input terminal **10** through a resistor **37**. The resistors **31**, **34** and **36** in conjunction with the semiconductor diode **33** control the degree of temperature compensation provided in the regulator circuit. The parallel RC network including the resistor **31** and capacitor **32** functions to supply base current to the transistor **17** and couple output voltage variations directly thereto. Finally, the resistor **37** functions to render the transistor **17** responsive to input voltage variations at the terminals **10** and **11** so that the regulated output voltage is further stabilized.

The circuit arrangement of the transistor amplifiers **18** and **19** complements that of the amplifier **17** so that a controlled bias is provided by these amplifiers for a transistor control element **38** that is serially connected to the load **25**. In this connection, a biasing resistor **39** is serially connected to the collector-emitter junction of the transistor **18** and between the input terminal **10** and the output circuit **25**. The base of the transistor **19** is connected to the resistor **39**, and a series RC network including a resistor **41** and a capacitor **42** connects the collector of the transistor **18** to the collector of the transistor **19** and to the base of a series control transistor **38**. This series network functions in a manner similar to that including the resistor **28** and capacitor **29**, and provides high frequency stabilization and phase compensation. The junction of this RC network with the collector of the transistor **19** and the base of the transistor **38** is connected to the output circuit **25** through a resistor **43** and the conductor **23**. The remaining biasing connections for the emitter of the transistor **19** and the collector of the series control transistor **38** are provided by direct connections to the positive input terminal **10**. With such circuits completed as shown, the transistors **17**, **18**, 19 and 38 are normally maintained in a conductive state with an input voltage applied across the input terminals 10 and 11.

The following description of the operation of the inventive regulator circuit is premised on the assumption that the circuit has been operating for some duration and that normal circuit operating conditions have been established. Accordingly, an unregulated input voltage E_{in} is applied across the terminals 10 and 11 and an essentially constant output voltage E_{out} is established across the load 25.

Assuming initially that load variations occur which tend to effect an increase in the output voltage developed across the output circuit 25, the potential at the base of the transistor amplifier 17 tends to become relatively more positive. That is, the increased potential at the output circuit 25 is coupled through the RC network 31, 32 so that the forward bias supplied to the transistor 17 increases. Consequently, the resistance of the transistor 17 is effectively decreased and is accompanied by an increase in collector current. Because of the variation in the conductive state of the transistor 17, the voltage developed across the resistor 12 increases and the base of the transistor amplifier 18 becomes relatively more negative.

The resulting decrease in forward bias supplied to the base-emitter connection of the transistor 18 results in the resistance thereof being effectively increased with a corresponding decrease in the collector current that flows through the resistor 39. Accordingly, the voltage developed across the biasing resistor 39 decreases and the base of the transistor amplifier 19 tends to become relatively more positive. As a result, the resistance of the transistor 19 is effectively increased and the amount of collector current flowing therethrough is accordingly diminished.

Since the voltage developed across the emitter-collector junction of the transistor amplifier 19 is thereby increased, the base of the series control transistor 38 becomes relatively more negative. As a consequence, the effective resistance of this series control element 38 is increased as is the voltage developed thereacross. The increased voltage developed across the series control transistor 38 compensates for the variation in the load voltage so that the output voltage is maintained at the desired value. Obviously, the time required to achieve this compensating variation in the voltage developed across the transistor 38 is of extremely short duration as dictated by the response characteristics of the circuit elements.

In a manner similar to that just described, when the output voltage tends to decrease, the potential applied at the base of the control transistor 38 is increased (i.e., becomes relatively more positive). As a result, the effective resistance of the transistor 38 is decreased as is the voltage developed thereacross. The compensating effect of this decreased voltage developed across the control transistor 38 serves to maintain the output voltage across the load 25 at a substantially constant value.

Not only does the circuit of the present invention effectively compensate for variations in load voltage so that a substantially constant output voltage is maintained, but the regulator also functions to produce an error voltage which is an increasing function of load current. Since the Zener diode 21 is connected to the output circuit 25 through the resistors 22 and 44, an increase in output load current causes an increase in the reference voltage established across the Zener diode 21 due to the internal impedance of this element, and the decreasing resistance of transistor 18 as outlined above.

Accordingly, notwithstanding the generation of an error voltage which is a function of the change in output voltage accompanying an increased load current, an additional error voltage is developed by the amplifier 17 due to the variation in forward bias supplied thereto that results from the increase in voltage developed across the Zener diode 21. That is, with an increase in reference voltage the forward bias is reduced so that the effective resistance of the amplifier 17 increases. As outlined above, this results in a relatively more positive potential being applied to the base of the control transistor 38 so that the effective resistance of this control element is decreased and a smaller voltage is developed thereacross. Consequently, variations in load current are accompanied by a lesser change in output voltage so that effectively the output impedance of the regulator is further reduced.

There has been described herein an improved voltage regulator circuit which, in addition to the low output impedance characteristics of the circuit, the regulator is capable of relatively stable operation over a wide range of temperatures. That is, since the diode 33 and associated biasing resistors establish various biasing conditions for the amplifier circuit, temperature variations which affect the characteristics of the transistors will similarly affect those of the diode 33 so that a relatively stable output voltage can be maintained. More particularly, assume that a temperature variation is such as to increase the resistances of the transistors and thus tend to decrease the collector currents thereof. The resistance of diode 33 is then also increased. As a result, the potential at the anode of the diode becomes more positive. This potential appears at the base of transistor 17 and tends to increase the emitter-collector current thereof. In other words, the resistance of transistor 17 is decreased to counteract the increase due to temperature variation. The temperature increased resistances of transistors 18, 19, and 38 have a net tendency to decrease the potential on output conductor 23. However, the increased potential at the anode of diode 33 effects an increase in potential on the output conductor to compensate the decrease. Conversely, when a temperature variation is such as to decrease the resistances of the transistors, the concurrent decrease in the resistance of the diode 33 operates in a manner opposite to that described above to compensate the effects of the transistor resistance decreases. In this manner, the diode effects temperature stabilization of the voltage regulator circuit. Moreover, since the emitter currents of the transistor amplifiers 18 and 19 become part of the output load current I^2R power loss within the circuit is minimized and the efficiency of the regulator is increased.

In a specific embodiment of the invention, a D.C. voltage of 24 volts was applied across the input terminals 10 and 11 an output voltage of 20,000 volts, ± 0.020 volt was maintained across the output circuit 25 while the regulator was subjected to temperature variations over a range of $-51°$ C. to $+85°$ C. The regulator circuit functioning in this fashion had a current output of either zero or 1.6 amperes and an output impedance of approximately 0.004 ohm, with resistor 44 eliminated from the circuit. If the resistor 44 is used, the output impedance drops by about 30 percent, or to 0.003 ohm approximately.

It should be understood that the foregoing is merely illustrative of the invention, various features of which are set forth in the accompanying claims.

What is claimed is:

1. A series voltage regulator comprising first and second input terminals whereto an unregulated input voltage is applied, said second input terminal connected to ground, an output circuit whereacross a load is to be connected and whereto a regulated output signal is supplied by said regulator, a first transistor having a base, an emitter and a collector, said transistor having the emitter-collector path thereof serially connected between said first input terminal and said output circuit and being normally biased in a conductive state by the input voltage applied to said input terminals, a second transistor of opposite conductivity type to said first transistor and having a base, emitter and collector, said collector of said second transistor coupled to the base of said first transistor, bias means coupling the emitter-collector path of said sec-

ond transistor between said first input terminal and said output circuit to vary the conductivity of said first transistor in direct relation to variations in the conductivity of said second transistor, a third transistor of opposite conductivity type to said second transistor and having a base, emitter and collector, said collector of said third transistor coupled to the base of said second transistor, bias means coupling the emitter-collector path of said third transistor between said first input terminal and said output circuit to vary the conductivity of said second transistor in direct relation to variations in the conductivity of said third transistor, a fourth transistor of the same conductivity type as said third transistor and having a base, emitter and collector, said collector of said fourth transistor coupled to the base of said third transistor, bias means coupling said collector of said fourth transistor to said first input terminal to vary the conductivity of said third transistor in inverse relation to variations in the conductivity of said fourth transistor, a Zener diode connected between the emitter of said fourth transistor and ground, a resistor connected between said output circuit and the common junction between the emitter of said fourth transistor and said Zener diode, and the parallel combination of a capacitor and second resistor coupled between said output circuit and the base of said fourth transistor to vary the conductivity thereof in direct relation to variations in the voltage developed across said output circuit.

2. A series voltage regulator according to claim **1**, further defined by a temperature compensating diode having first and second terminals and having a resistance varying with temperature in direct relation to resistance variations of said transistors with temperature, said first terminal connected to the base of said fourth transistor, third and fourth resistors connecting the second terminal of said temperature compensating diode to respectively said output circuit and ground, and a fifth resistor connected between said second terminal of said temperature compensating diode and said first input terminal, said compensating diode thereby varying the potential at said base of said fourth transistor in a direction to vary the resistance thereof in inverse relation to variations in the resistance of said fourth transistor with temperature and varying the potential at said output circuit in a direction opposite to that effected by variations in the resistance of said transistors with temperature.

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