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VOLTAGE REGULATION WITH TEMPERATURE COMPENSATION

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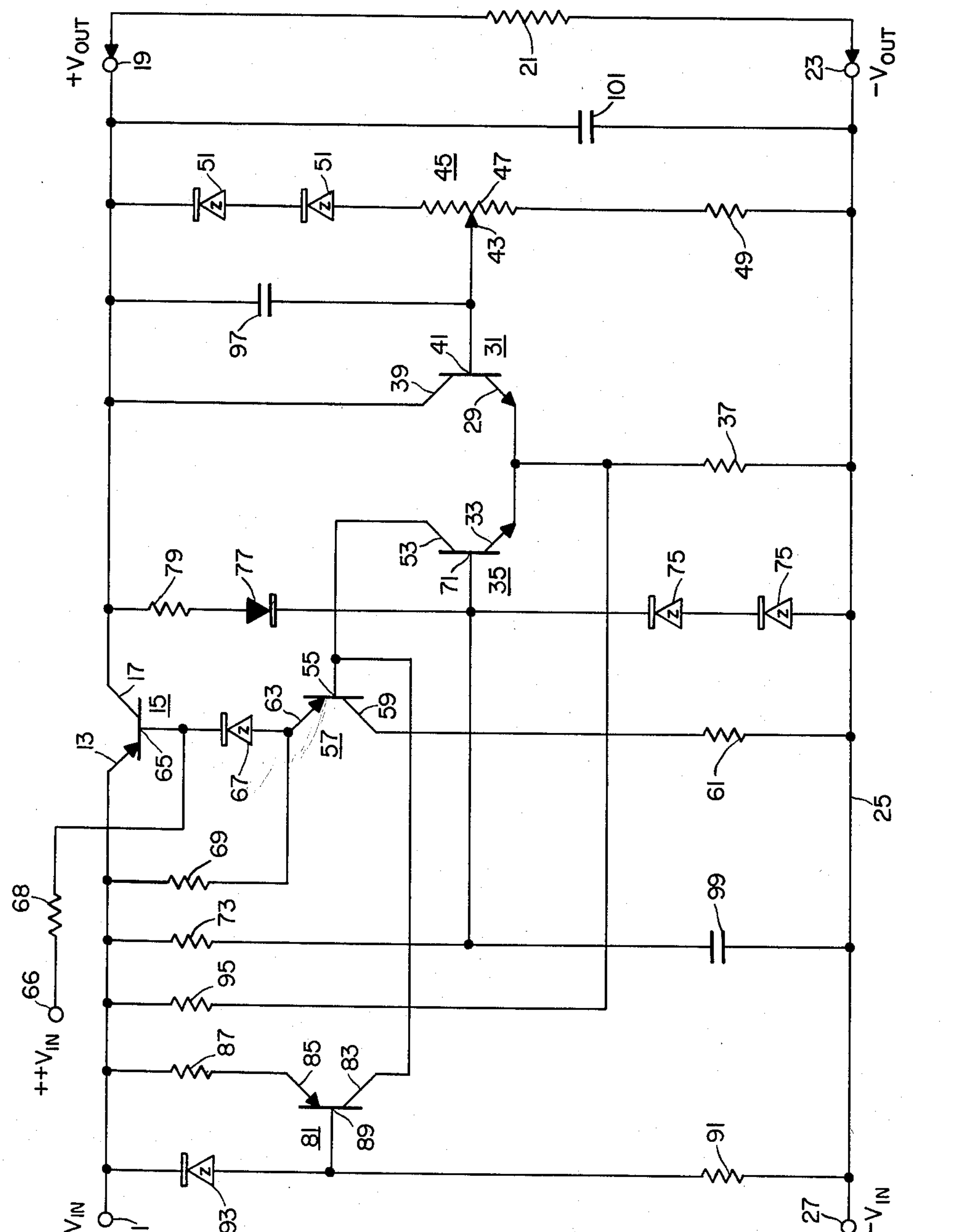

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VOLTAGE REGULATION WITH TEMPERATURE COMPENSATION

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This invention relates to direct current power supplies and more particularly to low voltage power supplies utilizing transistorized balanced amplifiers.

Transistor regulators have several advantageous characteristics such as low voltage and power requirements, fast starting time and long term reliability. However, there are two inherently poor characteristics in the transistor voltage regulator as compared with vacuum tube regulators. These poor characteristics generally are feedback response time and the variation of transistor parameters with temperature.

It is, therefore, an object of our invention to provide a low voltage direct current power supply having very nearly a purely resistive low output impedance despite the use of transistors in a variable temperature medium.

It is another object of our invention to provide a power supply of the aforementioned characteristics which is reliable in service and relatively compact and light.

It is still another object of our invention to provide a low voltage direct current power supply having a regulated output voltage with little or no change in regulation due to changes in temperature and which is capable of being subjected to relatively rough treatment.

The foregoing objects are accomplished in our invention by the use of regulating type semi-conductors along with amplifying type semi-conductors arranged in such a manner that the temperature variation in the parameters of the several semi-conductors in the regulating circuit counteract each other so as to provide a resultant of no change in output voltage with a change in temperature.

Generally, this is accomplished by providing in the line of an unregulated direct current power supply, a power transistor capable of altering the potential on the line by changing its impedance. The method of varying this impedance is by the use of three transistors in a feedback circuit. The first of these transistors is subjected to the changes in output voltage through a zener diode. The output of this first transistor determines the operation of the second which functions inversely as the first. The current of the second transistor is applied to a third transistor which acts as the driver for the power device. A fourth transistor is provided to assure operation current of the second transistor equal to that of the first. Other features of the circuit will be made clear in the detailed description which follows.

The drawing is a schematic diagram of one embodiment of the invention.

The positive terminal 11 of an unregulated power supply is connected to the emitter 13 of a PNP power transistor 15. The collector 17 of the power transistor is connected to the positive output terminal 19 of the regulator. The positive output terminal 19 is connected to a load device 21, the other side of which is connected to the negative output terminal 23 of the regulator which is directly connected through the line 25 to the negative input terminal 27.

The emitter 29 of a first NPN transistor 31 and the emitter 33 of a second NPN transistor 35 are connected to the line 25 of the device through a resistor 37. The collector 39 of the first NPN transistor is connected to

the positive output terminal 19 of the regulator. The base 41 of the first NPN transistor is connected to the wiper 43 of the potentiometer 45. The resistance portion 47 of the potentiometer 45 is connected on one side to the negative line 25 through resistor 49. The other side of the resistance portion 47 is connected to the positive regulated output terminal through one or more zener diodes 51 arranged in reverse fashion in the line; that is, with their cathodes connected toward the positive line. The collector 53 of the transistor 35 is connected to the base 55 of the PNP transistor 57. The collector 59 of the transistor 57 is connected to the negative line 25 through the resistor 61. The emitter 63 of the transistor 57 is connected to the base 65 of the transistor 15 through the zener diode 67. The zener diode 67 is connected with its cathode toward the base 65 of the transistor 15. The base 65 of the transistor 15 is connected to a source of potential 66, more positive than the voltage at the positive terminal 11, through the resistor 68. The emitter 63 of the transistor 57 is also connected to the unregulated positive terminal 11 through the resistor 69.

The base 71 of the transistor 35 is connected to the unregulated positive terminal 11 through the resistor 73. The base 71 of the transistor 35 is also connected to the negative line 25 through one or more zener diodes 75. These zener diodes like the previous zener diodes 51 are connected in reverse fashion; that is, with their anodes toward the negative line 25. The base 71 of the transistor 35 is also connected to the regulated positive terminal 19 through the diode 77, connected in normal fashion, and resistor 79.

Another PNP transistor 81 has its collector 83 connected to the collector 53 of the NPN transistor 35. The emitter 85 of the transistor 81 is connected to the unregulated positive terminal 11 through the resistor 87. The base 89 of transistor 81 is connected to the negative line 25 through the resistor 91. The base 89 of the transistor 81 is also connected to the unregulated positive terminal 11 through the zener diode 93, which like the other zener diodes, is connected in reverse fashion.

A resistor 95 is connected from the unregulated positive terminal 11 to the emitters 29 and 33 of the transistors 31 and 35. A capacitor 97 is connected across the zener diodes 51. Another capacitor 99 is connected across the zener diodes 75. Still another capacitor 101 is connected from the regulated positive terminal 19 to the negative terminal 23.

The operation of the circuit is as follows:

An unregulated source of voltage is applied across the input terminals 11 and 27. The potential is applied across the series circuit including the zener diode 93 and the resistor 91 thereby providing a voltage divider network with a constant voltage drop across the zener diode 93. The positive potential is also applied to the emitter 85 of the PNP transistor 81 through a resistor 87. The junction of the voltage divider network including the zener diode 93 is connected to the base 89 of the transistor 81. Since there is a voltage drop across the zener diode 93 and none across the resistor 87, a negative bias is applied to the base of the PNP transistor 81 and current tends to flow through the transistor 81. The positive potential is also applied to the base 71 of the NPN transistor 35 through resistor 73. The collector 53 of the NPN transistor 35 is connected to the collector 83 of the PNP transistor 81. With this arrangement current now flows from the negative terminal 27 through the line 25, the resistor 37, the emitter 33 and collector 53 of transistor 35, the collector 83 and emitter 85 of transistor 81 and the resistor 87 to the positive input terminal 11.

A portion of the current flowing through resistor 37 to the emitter 33 of transistor 35 must also flow through the base 71 of transistor 35 through resistor 73 to the positive terminal 11. This base current, in addition to allowing the collector current of transistor 81 to flow through the transistor 35 also provides for additional starting current. This additional current is supplied to the base 55 of transistor 57 to the emitter 63 of transistor 57, through the zener diode 67, the base 65 of the transistor 15, the emitter 13 of the transistor 15 to the positive terminal 11. This current causes transistor 15 to conduct.

Upon the initiation of current through the power transistor 15, the voltage output terminal 19 will become positive in potential. Consequently, the current will flow from the negative line 25 through the resistor 49, the potentiometer 45 and the zener diodes 51 to the power transistor 15. Upon the flow of current through this circuit, the wiper 43 on the potentiometer and the base 41 of transistor 31 will become positive and also since the voltage output terminal 19 is positive, the collector 39 of the transistor 31 will become positive. Consequently, the transistor 31 will commence to conduct in its normal fashion.

The collector current of the power transistor 15 is delivered to the positive output terminal 19. The load 21 is supplied from the output terminals 19 and 23. The output voltage is applied across a series circuit including the zener diodes 51, potentiometer 45 and the resistor 49. Since the voltage drop across the zener diodes is constant due to the nature of the diodes, any change in voltage drop will be applied entirely across the potentiometer 45 and the resistor 49.

Assuming a decrease in output voltage, the voltage across the potentiometer 45 and the resistor 49 would decrease. This decrease in voltage will be applied to the base 41 of the NPN transistor 31 thereby causing that transistor to conduct a lesser amount than by its nominal operation. The smaller emitter current from the transistor 31 when applied to the resistor 37 will cause a smaller voltage drop across the resistor 37 thereby making the emitter 33 of transistor 35 more negative than it had been in nominal operation. The voltage at the base 71 of the transistor 35 is held constant by the zener diodes 75. The more negative emitter causes the transistor 35 to increase its conductance. The increased current in the collector 53 of transistor 35 causes that collector voltage and the voltage at the base 55 of transistor 57 to decrease. The decreased base voltage at the PNP transistor 57 causes that transistor also to increase its conductance. The increased conductance of transistor 57 will cause an increased current in the base 65 of the power transistor 15 through the diode 67. The increased base current of power transistor 15 causes this transistor to increase its conductance and thereby decrease its impedance. The lower impedance of transistor 15 in the line between the input terminal 11 and the output terminal 19 causes a smaller voltage drop in the line than there had been under nominal operation. Consequently having a smaller voltage drop in the line, the output voltage tends to rise toward the higher input voltage.

If the output voltage had increased rather than decreased, the circuit would have operated just in the reverse of that described for a decrease in output voltage.

The transistors 31 and 35 are shown in such a manner that their temperature coefficients compensate for each other so long as they both nominally operate in the same range. This is true because the output voltage is equal to the sum of the voltages on the zener diodes 51 and 75 added to the voltage across the portion of the potentiometer 45 between the zener diodes 51 and the wiper 43 plus the difference in the base to emitter voltages of the transistors 31 and 35. As the base to emitter voltages change with temperature, their difference remains essentially constant. The transistor 31 has its collector 39 connected directly to the output terminal 19 consequently a nominal current is determined by the value of the resistor 37 and the line setting of the potentiometer 45. On the other hand, the collector 53 of transistor 35 is connected to the base 55 of the transistor 57. Since the base 55 does not draw as much current as does the collector of transistor 31, additional means are required to assume the additional current of transistor 35 so that its nominal operation may be in the same range as that of transistor 31. The additional means as shown is by the use of PNP transistor 81 whose collector 83 is connected to the collector 53 of the NPN transistor 35. The required additional current then can be determined by affixing values to the resistance 87 and the zener diode 93.

In order to start the regulator, some voltage must be applied at the base 71 of the transistor 35 and this voltage is applied through the resistor 73. To prevent a shunting of current away from the base 71 of the transistor 35, a diode 77 is placed in line with the resistor 79. This diode serves no function after transistor 15 is conducting properly.

The uses of the zener diodes 51 and 75 are twofold. First, they apply a source of reference potential and second and more important, they can be arranged in series groups so that the overall temperature coefficient is zero. This can be accomplished by selecting all zero coefficient diodes or by combinations of positive and negative coefficient diodes such that the combination has a zero temperature coefficient. Also, since diode bias current is incidental to the operation of the supply, it can be adjusted to any desired value. This becomes important in the use of silicon diodes as reference elements as their temperature coefficient can be varied by the amount of bias current flowing through them.

Again with respect to zener diodes 51 and 75, it is well known that the center voltage varies in proportion to the current through the diodes. Consequently, it is important to keep the current through the diodes at a relatively constant value. To use the diodes in a feedback path, it is necesary to vary the current through them in order to vary the conductance of the transistors 31 and 35. To minimize the effect of such feedback current, the resistors 49 and 79 are placed in series with the zener diodes 51 and 75. The current through the diodes then is determined primarily by the values of the resistances 49 and 79 and such value of current is chosen to be relatively large in comparison with the change in current due to the feedback circuit. Temperature compensation for the transistor 57 is obtained by the use of the resistor 69 in conjunction with the zener diode 67. As temperature increases, the emitter current of transistor 57 increases. The zener diode 67, having a positive temperature coefficient, increases in voltage thereby causing more current to be delivered to the emitter 63 of transistor 57 by way of resistor 69. The net result is to maintain constant base current to transistor 15 with changes in temperature. Thermal run-way of transistor 15 is prevented by the voltage 66 and resistor 68. This voltage supplies reverse base current to the transistor 15, thereby compensating for the thermal leakage current of this transistor.

The capacitors 97 and 99 are placed across the zener diodes 51 and 75 to overcome high frequency transients and the high frequency noise inherent to the diodes themselves.

The temperature coefficient crossover points of zener diodes depend primarily on the zener voltage. Low voltage silicon diodes, on the other hand have a temperature coefficient crossover point dependent upon forward current. Since these diodes also have a small differential impedance any combination of zener and low voltage silicon diodes may be used to produce the desired temperature coefficient. The currents of the zener and low voltage silicon diodes can be adjusted by varying the values of the resistors 49 and 79 and consequently provide the desired temperature coefficient.

The purpose of resistor 61 is to make the supply short circuit proof. This resistor 61 together with the input voltage 11 limits the flow of current at the output to a maximum value. This value can be set to protect the power supply from overloads.

The embodiment described herein is for a positive power supply. In the event that a negative power supply would be more desirable, the desired result can be obtained by a few simple changes in the circuit. To obtain this, all NPN and PNP transistors are reversed, to PNP and NPN transistors respectively. The input voltage polarities are reversed, and the polarity of all the diodes are reversed. The circuit configuration remains the same.

The output impedance of the power supply is made very nearly purely resistive for all frequencies of loading by the following method. The response of the slowest transistor, the series element **15**, is considered as an inductance L in series with the resistive output impedance R_1. This series combination is in parallel with the output capacitor **101** and its effective series resistance R_2. Now, if

$$R_1=R_2=\sqrt{\frac{L}{C}}$$

then the output impedance will be purely resistive for all frequencies of loading.

In general, while we have shown certain specific embodiments of our invention, it is to be understood that this is for the purpose of illustration only and that our invention is to be limited only by the scope of the appended claims.

We claim:

1. A voltage regulating circuit comprising a variable impedance means in series with the output of said regulating circuit, variation means for varying said impedance means, a first and a second constant voltage drop means, each having an additional impedance in series therewith across said output, said additional impedances being connected to different sides of said output, a first and a second current amplifying means, each having a control terminal, the control terminal of one of said amplifying means being connected to the junction of one of said constant voltage drop means and its respective additional impedance, the control terminal of the other said amplifying means being connected into the series circuit including the other of said constant voltage drop means, the output of the first said amplifying means being connected to a similar terminal of the second said amplifying means, the output of the second said amplifying means being operably connected to said variation means, and an additional current amplifying means having a control terminal, the output of said additional current amplifying means being also connected to the output of second said amplifying means, the control terminal of said additional current amplifying means being connected to the unregulated side of said voltage regulator.

2. A voltage regulation circuit as described in claim 1 wherein said constant voltage drop means are zener diodes.

3. A voltage regulation circuit as described in claim 1 wherein said constant voltage drop means are silicon diodes.

4. A voltage regulation circuit as described in claim 1 wherein said constant voltage drop means are a combination of zener diodes and silicon diodes.

5. A voltage regulating circuit as described in claim 1 wherein a second impedance means is connected between the output of said second amplifying means and the input of said regulating circuit.

6. A temperature compensated voltage regulator comprising a variable impedance in series with the output of said regulator, a first and a second transistor each having two current terminals and a control terminal, a current terminal of each being connected to the corresponding terminal of the other and one side of said output, the other of said current terminals of the first said transistor connected to the other side of said output, a first and a second series circuit each comprising a constant voltage drop means and a resistance connected across said output with said resistances being connected to alternate sides of said output, the control terminal of one of said transistors being connected to the junction of one of said constant voltage drop means and its respective resistance, the control terminal of the other of said transistors being connected into the series circuit including the other of said constant voltage drop means, a third transistor having two current terminals and a control terminal, the control terminal of said third transistor being connected to the other of said current terminals of said second transistor, a current limiting means connected to one of said current terminals of said third transistor, a constant voltage drop means having a temperature coefficient connecting the other current terminal of said third transistor to said variable impedance to adjust said variable impedance, a current limiting device connecting the other said current terminal of said third transistor to the unregulated side of said regulator.

7. A voltage regulation circuit as described in claim 6 wherein said constant voltage drop means are zener diodes.

8. A voltage regulation circuit as described in claim 6 wherein said constant voltage drop means are silicon diodes.

9. A voltage regulation circuit as described in claim 6 wherein said constant voltage drop means are a combination of zener diodes and silicon diodes.

10. A voltage regulation circuit as described in claim 6 wherein a fourth transistor having two current terminals and a control terminal has one of its current terminals also connected to the other of said current terminals of said second transistor, the control terminal of said fourth transistor being connected to the unregulated side of said voltage regulator.

11. A temperature compensated voltage regulating circuit comprising detection means for detecting variations in output voltage, a first amplifying means coupled to said detection means for amplifying the detected variations, inverting means coupled to said amplifying means for inverting the amplified variations, a first impedance means connected in series with said inverting means to provide a current path from said inverting means whereby the current in said inverting means can be equalized with the current in said first amplifying means, a second amplifying means coupled to said inverting means for amplifying said inverted variations and a second impedance means coupled to said second amplifying means, said second impedance being connected between the input and output of said regulating circuit.

12. A voltage regulator comprising, a pair of signal input terminals, a pair of signal output terminals, a transistor connected in series between one of said pair of signal input terminals and one of said pair of signal output terminals for controlling the current flow therebetween, a first network including a low impedance element connected between said signal output terminals for providing a first point of reference potential of low impedance which varies in accordance with variations in the potential difference between said signal output terminals, a second network connected between said signal output terminals for providing a second point of reference potential which is substantially constant in spite of variations in the potential difference between said signal output terminals, a differential comparator amplifier including a plurality of transistors connected to conduct through a common resistor and coupled to said first and second points of reference potential for providing an error signal representative of variations in the potential difference between said signal output terminals, and an error signal amplifier coupled between said comparator amplifier and said transistor for controlling the current flow of said transistor in response to said error signals and for limiting the current through said transistor to a selected maximum value when the potential difference between said signal output terminals becomes zero, whereby said tran-

sistor is protected from a current overload in the event of a direct short of the signal output terminals.

13. A voltage regulator as defined in claim 12 wherein said second network includes an impedance element and a zener diode connected in series, said second point of reference potential being the common junction of said element and diode.

14. A voltage regulator as defined in claim 12 wherein a current amplifier having a control terminal is coupled to said comparator amplifier, the control terminal being connected to one of said pair of signal input terminals.

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