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CURRENT SUPPLY APPARATUS FOR LOAD VOLTAGE REGULATION

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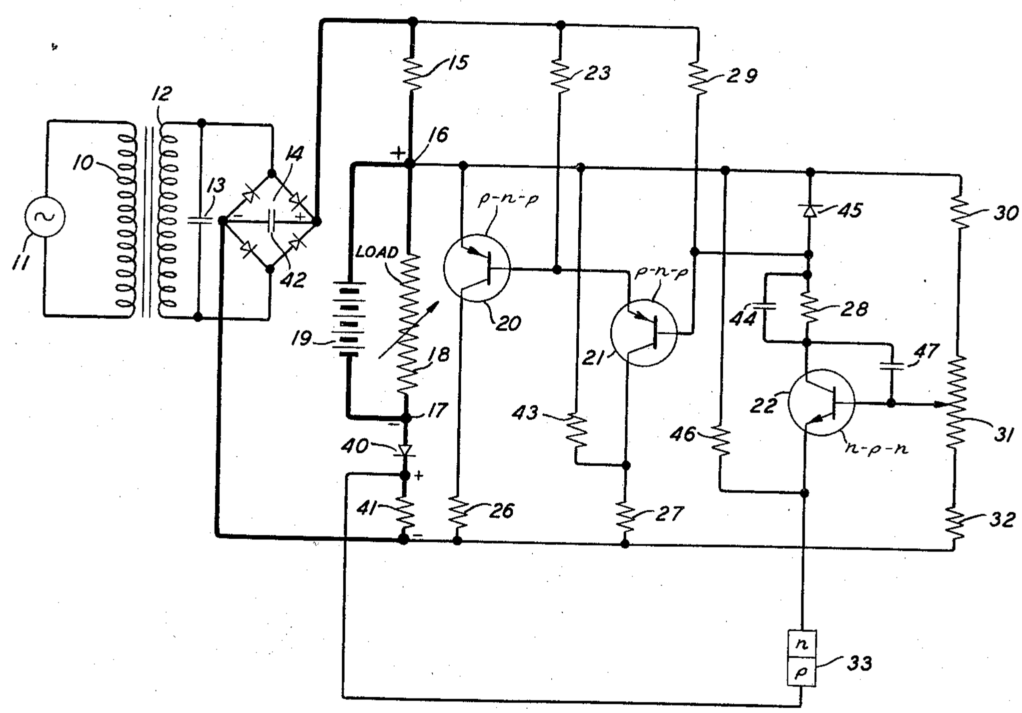

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CURRENT SUPPLY APPARATUS FOR LOAD VOLTAGE REGULATION

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This invention relates to current supply apparatus and more particularly to apparatus for controlling the supply of current from a current source to a load to minimize changes of load voltage.

An object of the invention is to provide an improved current supply circuit including a transistor or transistors to set up across a load a substantially constant voltage having a desired magnitude.

Another object of the invention is to provide a current supply circuit comprising one or more transistors for maintaining a substantially constant load voltage over a predetermined range of load current and over a wide range of ambient temperatures.

This invention is an improvement over the invention disclosed and claimed in an application of B. H. Hamilton, Serial No. 441,871, filed July 7, 1954.

In a specific embodiment of the invention herein shown and described for the purpose of illustration, direct current is supplied from a rectifier through a series resistor to a load circuit. A shunt current path connected across the load comprises the emitter and collector of a first transistor which may be of the p-n-p, for example. There is provided a transistor detector-amplifier comprising a second and a third transistor responsive to load voltage changes for controlling the base current of the first transistor and thereby the current flowing in the shunt current path across the load. The second and third transistors may be of the p-n-p and n-p-n types, respectively, for example. There are provided a current path connecting the base of the first transistor and the emitter of the second transistor and a current path connecting the base of the second transistor and the collector of the third transistor. Current is supplied from the rectifier through a first resistive path into the emitter and out of the collector of the second transistor. Current is also supplied from the rectifier through a second resistive path into the collector and out of the emitter of the third transistor. A circuit connecting the base and emitter of the third transistor comprises a source of voltage proportional to the load voltage and, in opposition thereto, a source of substantially constant reference voltage.

A decrease of load voltage due to an increase of load current, for example, will make the potential of the base of the third transistor relatively less positive or more negative with respect to its emitter potential. As a result, the currents flowing into the collector of the third transistor, into the emitter of the second transistor and into the emitter of the first transistor, respectively, will each decrease. In this way, over an operating range of load current, an increase of load current will result in a substantially equal decrease of current flowing into the emitter of the first transistor, thereby maintaining the load voltage substantially constant. When the load current has a minimum value which may be nearly zero, a maximum current flows into the emitter of the first transistor. The maximum load current for which the load voltage is maintained substantially constant is determined by the minimum current flowing into the emitter of the first transistor. A maximum operating range of load current at substantially constant load voltage is thus obtained if the current flowing into the emitter of the first transistor can be reduced substantially to zero. Any increase of load current beyond a value which causes the emitter current of the first transistor to be reduced to a minimum emitter current will result in a decrease of load voltage.

At a relatively low ambient temperature, 20 degrees centrigrade, for example, a reduction of the current flowing out of the base of the first transistor substantially to zero causes the current flowing into its emitter and out of its collector to be reduced nearly to zero. However, an increase of ambient temperature to 60 degrees centigrade, for example, with the base current at zero, will result in a substantially higher current flowing into the emitter and out of the collector. With the base current at zero, this increase of ambient temperature would thus result in a considerable decrease of the load current at substantially constant load voltage. To permit the emitter current of the first transistor to be reduced substantially to zero at a relatively high ambient temperature, there is provided a resistive current path for connecting the base of the first transistor and the emitter of the second transistor to the positive terminal of the rectifier. With this arrangement the base current of the first transistor will reverse, wthen the emitter current of the second transistor is reduced sufficiently, that is, current will flow through the resistive current path into the base of the transistor. There is also provided a resistive current path connecting the base of the second transistor and the collector of the third transistor to the positive rectifier terminal so that, when the collector current of the third transistor is reduced sufficiently, current may flow through the resistive current path into the base of the second transistor, thereby further reducing the emitter current of the second transistor. For operating conditions which may be considered to be normal, load voltage changes are minimized over a wide range of load current including a certain maximum load current and over a wide range of ambient temperature.

An asymmetrically conducting diode is provided in a path connecting the base of the second transistor to the positive load terminal to prevent the bases of the first and second transistors and the collector of the third transistor from rising to a potential considerably higher than the potential of the positive load terminal. The circuit is designed so that, without the diode in the circuit, these potentials would not become excessive as long as the regulating circuit is capable of maintaining the load voltage substantially constant. For this condition, the base of each of the first and second transistors may rise to a potential of a few tenths of a volt positive with respect to the emitter potential, for example, with the result that the current flowing into the base is substantially equal to the current flowing out of the collector. However, if the load voltage should decrease substantially below the normal constant voltage due to the battery across the load becoming discharged, the collector current of the first transistor may be reduced to zero, for example. If the diode were not provided, this would result in the voltage between the emitter and collector electrodes of the third transistor and the voltage between the base and collector electrodes of the first and second transistors rising to a magnitude such that the maximum voltage and dissipation ratings of the transistors would be exceeded. By connecting the base of the second transistor through an asymmetrically conducting diode to the positive load terminal, each of the three transistors is restricted to operating within the normal voltage and collector dissipation ratings with the result that damage to the transistors is avoided.

The invention will now be described in greater detail with reference to the accompanying drawing the single figure of which is a schematic view of a current supply apparatus embodying the invention.

Referring now to the drawing, there is provided a transformer having a primary winding 10 connected to a 115-volt, 60-cycle per second, alternating-current supply source 11 and having a secondary winding 12 shunted by a condenser 13 of 2400 micro-microfarads, for example. The transformer winding 12 is connected to the input terminals of a bridge rectifier 14. The positive output terminal of the rectifier 14 is connected through a series resistor 15 of 127 ohms, for example, to the positive terminal 16 of a load circuit comprising a dissipative load 18 which may vary and a floating battery 19 connected across the load. The negative terminal 17 of the load is connected through an asymmetrically conducting varistor or diode 40 and a resistor 41 having a resistance of 0.422 ohm, for example, in series, to the negative terminal of rectifier 14. A condenser 42 of 1000 microfarads is connected across the output terminals of rectifier 14. A transistor regulating circuit is provided for maintaining the load voltage substantially constant at 22 volts, for example, for a range of load current up to and including a predetermined maximum value, 0.1 ampere, for example.

The regulator comprises a first transistor 20 of the p–n–p type, a second transistor 21 of the p–n–p type and a third transistor 22 of the n–p–n type, each transistor having a collector, an emitter and a base. The emitter of transistor 20 is directly, conductively connected to the positive load terminal 16 and the collector of transistor 20 is connected through a resistor 26 of 81.6 ohms, for example, to the negative output terminal of rectifier 14. The base of transistor 20 is directly, conductively connected to the emitter of transistor 21. The base of transistor 20 and the emitter of transistor 21 are connected through a resistor 23 of 8250 ohms, for example, to the positive output terminal of rectifier 14. A voltage divider comprising a resistor 43 of 121 ohms and a resistor 27 of 562 ohms, in series, is connected between the positive load terminal 16 and the negative terminal of rectifier 14. The collector of transistor 21 is connected to the common terminal of resistors 43 and 27.

The collector of transistor 22 is connected through a resistor 28 of 2150 ohms, shunted by a condenser 44 of 2400 micro-microfarads, and a resistor 29 of 8250 ohms, in series, to the positive output terminal of rectifier 14. The base of transistor 21 is connected to the common terminal of resistors 28 and 29 and this common terminal is connected through an asymmetrically conducting varistor or diode 45 to the positive load terminal 16. There is provided a p–n junction diode 33 to which current is supplied through a circuit which may be traced from the positive output terminal of rectifier 14, through resistor 15 and through a resistor 46 of 3160 ohms to one terminal of diode 33, and from its other terminal, through resistor 41 to the negative output terminal of rectifier 14. The emitter of transistor 22 is connected to the common terminal of resistor 46 and the constant voltage diode 33. There is thus supplied through the diode 33 in its reverse or high resistance direction, current of sufficient amplitude to cause a substantially constant unidirectional reference voltage to be set up across the diode. A condenser 47 is provided in a path connecting the collector and base of transistor 22.

There is connected between the positive load terminal 16 and the negative terminal of rectifier 14 a section voltage dividing path comprising in series a resistor 30 of 750 ohms, a potentiometer 31 of 196 ohms and a resistor 32 of 215 ohms. The base of transistor 22 is connected to the variable tap of potentiometer 31. The constant reference voltage across the diode 33 is in opposition to the voltage across resistor 32 and a portion of potentiometer 31 in the circuit connecting the base and emitter of transistor 22. The diode 40 is provided to prevent discharge of the battery 19 through the regulator circuit if the alternating-current supply source 11 should fail. The resistor 41 is connected in the base-emitter circuit of transistor 22 so as to compensate for the voltage drop produced by the load current flowing through the diode 40.

When the load current does not exceed the upper limit of a normal operating range, 0.1 ampere, for example, the regulating circuit will main the load voltage substantially constant at 22 volts, for example, over a wide range of ambient temperature, say from minus 40 degrees Fahrenheit to plus 140 degrees Fahrenheit. If the load current should increase, for example, the voltage drop across resistor 15 would increase to cause a reduction of the load voltage. The reduction of load voltage makes the base of transistor 22 relatively less positive with respect to the emitter of transistor 22. The current flowing through resistors 29 and 28 into the collector of transistor 22 is thus reduced and the base of transistor 21 becomes relatively less negative or even slightly positive with respect to the emitter of transistor 21. As a result, the current flowing through resistor 23 into the emitter and the current flowing out of the collector of transistor 21 are reduced and the potential of the base of transistor 20 becomes less negative or even slightly positive with respect to the emitter of transistor 20. Therefore, the current flowing into the emitter and the current flowing out of the collector of transistor 20 are reduced. In this way, as the load current increases, the current flowing in the shunt path comprising transistor 20 and resistor 26, in series, decreases, thereby minimizing changes of current flowing through resistor 15 and changes of load voltage.

The regulator also corrects for changes of output voltage of rectifier 14 due to voltage changes of the supply source 11 in a somewhat similar manner. A decrease of output voltage of rectifier 14, for example, causes both the load voltage and the voltage across resistor 15 to be reduced. The regulator then functions to reduce the current flowing in the shunt current path comprising transistor 20 to cause a further reduction of the voltage drop across resistor 15. This reduction of voltage across resistor 15 minimizes the voltage change across the load.

The voltage drop across resistor 41 increases in response to an increase of load current and the voltage across the diode 40 also increases somewhat in response to an increase of load current. The voltage across resistor 41 is included in the base-emitter circuit of transistor 22 to compensate for the change in voltage drop across the diode 40 when the load current changes. An increase of voltage drop across the diode 40 due to an increase of load current, for example, would reduce the load voltage if no compensation for this effect were provided. However, the accompanying increase of voltage drop across resistor 41 due to the increased load current makes the base of transistor 22 relatively less positive with respect to the emitter potential. As a result the emitter current of transistor 20 is decreased to cause the voltage drop across resistor 15 to decrease, thereby compensating for the increased voltage drop across the diode 40.

It is desirable to maintain the load voltage constant over a wide range of load current. A maximum operating range of load current is realized when the current flowing into the emitter of transistor 20 can be reduced to zero. At a relatively low ambient temperature, a reduction of the current flowing out of the base of transistor 20 to zero will cause the current flowing into the emitter and out of the collector to be reduced nearly to zero. However, the minimum or leakage collector current of the transistor increases with increasing ambient temperature. At a relatively high ambient temperature, therefore, in order to reduce the emitter curent substantially to zero, it is necessary for the base current to reverse so that the current flowing into the base is substantially equal to the current flowing out of the collector.

Let us first consider the operation of the circuit with the diode or varistor 45 omitted and with the ambient temperature relatively high. Assume further that the load current increases to a maximum amplitude within the normal operating range for constant load voltage, or nearly so. The resulting decrease of load voltage will cause the curent flowing through resistor 29 into the collector of transistor 22 to be reduced to increase the potential of the base of transistor 21. The current flowing out of the base is reduced or, possibly, the potential of the base may become slightly positive with respect to the emitter so that curent flows into the base and out of the collector of transistor 21. The resulting reduction of current flowing through resistor 23 into the emitter of transistor 21 causes the potential of the emitter of transistor 21 and the potential of the base of transistor 20 to increase. The base potential of transistor 20 becomes positive with respect to its emitter potential by a few tenths of a volt and the current flowing into the base is substantially equal to the current flowing out of the collector. The emitter curent of transistor 20 is thus reduced substantially to zero.

If the load current should further increase by a substantial amount, due to battery 19 becoming discharged, the increased voltage drop across resistor 15 will be sufficiently large to reduce the load voltage considerably below its normal, substantially constant amplitude. As a result of the reduction of load voltage, the current flowing through resistor 29 into the collector of transistor 22 may be reduced to zero, for example. The potential of the base of transistor 21 may therefore rise to an abnormally high value, say, to the potential of the positive terminal of rectifier 14. If, under the normal condition of substantially constant load voltage, current flows through resistor 23 into the emitter and out of the base of transistor 21, through resistor 28 and into the collector of transistor 22, this current is interrupted for the abnormally low load voltage condition, so that the potential of the base of transistor 20 also rises to an abnormally high value, that is, to the potential of the positive terminal of rectifier 14. Without the use of the diode 45, therefore, the base to collector voltages of transistors 20 and 21 and the collector to emitter voltage of transistor 22 may increase to such amplitudes, under an abnormal operating condition, as to cause the transistors to become damaged by exceeding the safe operating limits.

The use of the diode 45 prevents damage to the transistors by limiting the potential increase of the bases of transistors 20 and 21 and of the collector of transistor 22. Whenever the potential of the base of transistor 21 and of the collector of transistor 22 becomes positive with respect to the potential of the positive load terminal 16, current flows from the positive output terminal of rectifier 14 through resistor 29 and through the diode 45 to the positive load terminal. The resulting increased voltage drop across resistor 29 prevents the base of transistor 21 and the collector of transistor 22 from increasing more than a few tenths of a volt above the potential of the positive load terminal. When the potential of the base of transistor 21 rises to an excessively high value, the emitter of transistor 21 and, therefore, the base of transistor 20, also rises to an excessively high potential, the base and emitter of transistor 21 being nearly at the same potential. Thus, preventing an increase of potential of the base of transistor 21 to an excessively high value also prevents the base of transistor 20 from rising to an excessively high potential.

The use of the voltage divider comprising resistors 43 and 27 increases the potential of the collector of transistor 21 with respect to the potential of the negative output terminal of rectifier 14. This arrangement reduces the emitter-collector voltage of transistor 21 and permits a higher output current of transistor 21 while preventing excess dissipation therein.

What is claimed is:

1. In combination, a transistor having a plurality of electrodes comprising an emitter, a collector and a base, means for supplying unidirectional current from a direct-current supply source into one of said emitter and collector electrodes and out of the other of said emitter and collector electrodes, a resistive current path connecting said base to said current supply source, means for supplying varying unidirectional current from said source to said resistive path to control the potential of said base with respect to the potential of said emitter and means for limiting the voltage of a predetermined polarity between said emitter and said base comprising means for further controlling the current through said resistive path.

2. In combination, a transistor having a plurality of electrodes comprising an emitter, a collector and a base, a source of direct voltage, a resistor, a first direct-current circuit comprising in series said resistor, said emitter and collector electrodes and said voltage source, means for varying the current in said first circuit, an asymmetrically conducting varistor and a second direct-current circuit comprising in series said voltage source, said resistor and said varistor in which circuit current is caused to flow in response to a reduction to a predetermined amplitude of the current flowing in the said first circuit.

3. An electric circuit comprising an n-p-n transistor having a collector, an emitter and a base, a source of direct voltage having positive and negative terminals, a resistor having a first and a second terminal, means for connecting the first terminal of said resistor to said positive terminal, means for connecting the second terminal of said resistor to said collector, a current path connecting said emitter to said negative terminal, means for controlling the potential of said base to vary the current flowing through said resistor into said collector, an asymmetrically conducting varistor and a current path comprising said varistor for connecting the second terminal of said resistor to a point in said circuit having a lower potential than the potential of said positive terminal.

4. An electric circuit comprising a transistor having a collector, an emitter and a base, a source of direct voltage having a positive and a negative terminal, means for connecting said emitter to one of said terminals, means for connecting said collector to the other of said terminals, an asymmetrically conducting varistor and means for controlling the potential of said base comprising a resistive path connecting said base to said positive terminal, means for varying the current supplied from said source to said resistive path and a path including said varistor connecting said base to a point in said circuit having a lower potential than the potential of said positive terminal.

5. An electric circuit comprising a transistor having a collector, an emitter and a base, a source of direct voltage having a positive and a negative terminal, means for connecting said collector to one of said terminals, a first and a second resistor, means for connecting said emitter through said first resistor to the other of said terminals, means for connecting said base through said second resistor to said other terminal, a circuit for supplying to said second resistor from said supply source a current which may vary, an asymmetrically conducting varistor and means for connecting said base through said varistor to a point in said circuit having a potential intermediate the potentials of said positive and negative terminals.

6. An electric circuit comprising a first and a second transistor each having a plurality of electrodes comprising a collector, an emitter and a base, a direct voltage

source having a positive and a negative terminal, current paths for connecting one of said collector and emitter electrodes of said transistors, respectively, to said negative terminal, means for connecting the other of said collector and emitter electrodes of said first transistor to said positive terminal, means for conductively connecting the base of said first transistor to the emitter of said second transistor, a first and a second resistor, means for connecting the base of said first transistor and the emitter of said second transistor through said first resistor to said positive terminal, means for connecting the base of said second transistor through said second resistor to said positive terminal, a circuit for supplying to said second resistor from said voltage source a current which may vary, an asymmetrically conducting varistor and means for connecting said base of said second transistor through said varistor to a point in said circuit of lower potential than the potential of said positive terminal.

7. Appraratus for supplying current from a direct-current supply source having a posititive and a negative terminal to a load circuit including a load having a positive and a negative terminal comprising a first resistor for connecting the positive terminal of said source to the positive terminal of said load, means for connecting the negative terminal of said source to the negative terminal of said load, a first transistor of the p-n-p type having a first collector, a first emitter and a first base, means for connecting said first emitter to said positive load terminal, means for connecting said first collector to said negative terminal of said source, a second transistor of the p-n-p type having a second collector, a second emitter and a second base, means for conductively connecting said first base to said second emitter, a second resistor for connecting said first base and said second emitter to said positive terminal of said source, a third resistor for connecting said second base to said positive terminal of said source, a voltage divider comprising a fourth and a fifth resistor in series connecting said positive load terminal to the negative terminal of said source, means for connecting said second collector to the common terminal of said fourth and fifth resistors, an asymmetrically conducting varistor connecting said second base to said positive load terminal, said varistor being poled to conduct current through it in the low resistance direction from said second base to said positive load terminal, a third transistor of the n-p-n type having a third collector, a third emitter and a third base, a current path comprising said third resistor for connecting said third collector to said positive terminal of said source and means for impressing upon said third base with respect to said third emitter a potential having variations corresponding to load voltage changes.

8. In a circuit for supplying current from a direct-current supply to a load circuit comprising a dissipative load and a floating battery across across said dissipative load, regulating means, means for controlling said regulating means in response to load voltage changes for minimizing voltage changes across said load, means for normally supplying energizing current from said supply source to said regulating means, an asymmetrically conducting varistor, means for connecting said varistor in series with said load circuit and said regulating means to minimize the discharge of said battery through said regulating means in the event of failure of said supply source under an abnormal condition, the battery discharge current through said regulating means flowing through said varistor in its reverse or high resistance direction, said varistor also being connected in series with said supply source and said load circuit so that the load current normally flows through said varistor in its forward or low resistance direction to produce a voltage drop across said varistor which increases in response to an increase of load current, and means for further controlling said regulating means to reduce or substantially prevent a change of load voltage due to a change of voltage drop across said varistor.

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