This invention relates to electrical circuits and more particularly to circuits for supplying a controlled magnitude of electric current flow from a voltage source to a load.

It is frequently desirable to supply a constant or otherwise regulated electric current from a voltage source to a load and to have the magnitude of the current unaffected by changes in the load or the voltage source. Such a current may be supplied through a suitable regulating circuit in series with a voltage source, with this series arrangement being known as a constant current source. For example, in a coincident current core memory, it is necessary that precisely controlled half currents be applied to the reading and writing windings to assure that proper switching occurs at the addressed cores and that the half currents which are of necessity applied to non-addressed cores be of insufficent magnitude to cause undesirable switching of these non-addressed cores.

It is sometimes desirable to provide current sources in which the magnitude of the current supplied is varied in response to an external condition, such as temperature. While the output current of such circuits is not "constant" in a strict sense, the combination of the regulating circuit and the voltage source may still be considered a constant current source in that the magnitude of the current supplied is determined fully by the parameters of the regulating circuit and is independent of the load and the magnitude of the voltage of the source, at least within the operating range of the regulating circuit.

Such a temperature dependent constant source current may find utility in supplying read and write half currents to a coincident current magnetic core memory, in which the hysteretical characteristics of the magnetic cores are quite temperature dependent. It is desirable to supply a higher magnitude of read and write half currents for lower temperature operation and a lower magnitude of read and write half currents for higher temperature operation.

Accordingly, it is an object of this invention to provide an improved constant current source. It is another object of this invention to provide a constant current source which may be fabricated from inexpensive components.

It is yet another object of this invention to provide a constant current source in which the magnitude of the current supplied by the source is responsive to temperature and changes inversely with variations in the temperature in the relative amount required by magnetic cores.

Briefly stated, and in accordance with one embodiment of the invention, a constant current source is provided which includes a first transistor having a constant voltage device, such as a zener diode, connected between its base electrode and one terminal of a voltage source. The emitter electrode of the first transistor is connected through a resistor to the same terminal of the voltage source. The zener diode provides a constant voltage across the emitter resistor which is equal to the breakdown voltage of the zener diode minus the slight voltage drop across the emitter-base junction of the first transistor. This constant voltage across the emitter resistor results in a constant current flowing therethrough, with a resulting constant emitter current for the first transistor and corresponding constant base and collector currents for the transistor.

A second transistor is provided which has its base electrode connected through suitable circuit means to the collector electrode of the first transistor. A second constant voltage device, such as another zener diode, is connected between the base electrode of the second transistor and an intermediate terminal. The emitter electrode of the second transistor is connected through an emitter resistor to the intermediate terminal. The second zener diode provides a constant voltage across the emitter resistor of the second transistor and thus provides a constant current flow in the emitter circuit of the second transistor. A load device to which a constant current is to be supplied is connected between the intermediate terminal and the other terminal of the voltage source.

For a complete understanding of the invention, reference may be had to the accompanying drawings, in which:

FIGURE 1 shows a constant current source constructed in accordance with the prior art;

FIGURE 2 shows a constant current source constructed in accordance with one embodiment of the present invention; and

FIGURE 3 shows a constant current source constructed in accordance with a second embodiment of the present invention.

The prior art circuit of FIGURE 1 includes a PNP transistor 1 having the usual emitter, base and collector electrodes. A zener diode 2 or other suitable constant voltage device is connected between the base electrode of transistor 1 and an intermediate terminal 3. The emitter electrode of transistor 1 is connected to an intermediate terminal 3 through an emitter resistor 4. A resistor 5 connects the base electrode of transistor 1 to the negative terminal of a voltage source 6. The collector electrode of transistor 1 is also connected to the negative terminal of voltage source 6. The positive terminal of voltage source 6 is connected to a point of reference potential, such as ground. A load device 7 to which a constant current is to be supplied is connected between intermediate terminal 3 and the point of reference potential.

The constant current source operates as follows: The zener diode 2 provides a constant reference voltage between the base electrode of transistor 1 and terminal 3. In parallel with the zener diode 2, and thus having the same constant voltage impressed thereacross, is the series connection of the emitter-base junction of transistor 1 and emitter resistor 4. Thus, the voltage impressed upon emitter resistor 4 is equal to the breakdown voltage of zener diode 2 minus the voltage drop across the emitter-base junction of transistor 1. The voltage drop across the emitter-base junction of transistor 1 is small in comparison to the breakdown voltage of zener diode 2; for example, the breakdown voltage of zener diode 2 may be about 10 volts whereas the voltage drop across the emitter-base junction of transistor 1 may be about ½ volt. Thus, a constant voltage equal essentially to the breakdown voltage of zener diode 2 is impressed across emitter resistor 4, resulting in a constant current flow through the emitter resistor 4 equal to the constant voltage impressed thereacross divided by the magnitude of the constant current. Since emitter resistor 4 is the only circuit element connected to the emitter electrode of transistor 2, the constant current flowing therein also flows in the emitter of transistor 1, and results in constant base and collector current flow in transistor 1. The current flow in emitter resistor 4, and thus in each electrode of transistor 1, is maintained constant since any attempted change in the
current in emitter resistor 2 results in a corresponding change in the voltage thereacross, which is not allowed by zener diode 2.

It is observed that the total current flowing in load device 7 is equal to the sum of the emitter current of transistor 1 and of the current flowing through zener diode 2. As was previously described, the current flow in the emitter circuit of transistor 1 is maintained at a substantially constant value, but as will now be described, the current flow through zener diode 2 is subject to fluctuations in response to any changes in the magnitude of voltage source 6. This will be seen when it is considered that the total voltage drop across the series circuit of the load device 7, the zener diode 2 and resistor 5 is equal to the magnitude of the voltage source 6. Assuming that the current flow through load device 7, and thus the voltage drop thereacross, remains constant and considering that the voltage drop of zener diode 2 remains constant, it follows that any fluctuations in the magnitude of voltage sources 6 appear directly across resistor 5. These voltage fluctuations result in a corresponding fluctuation in the current flow in resistor 5. It is seen that the current flow in resistor 5 is equal to the sum of the base current of transistor 1 and the current flowing through zener diode 2. As was previously described, the base current of transistor 1 remains substantially constant and therefore any fluctuations in the current in resistor 5 must result in directly corresponding fluctuations in the current in zener diode 2. Since the current supplied to the load device 7 is equal to the sum of the emitter current of transistor 1 and the current flowing through zener diode 2, these fluctuations in current in zener diode 2 appear directly in the current in load device 7.

Since the current flowing in zener diode 2 will be relatively small in comparison with the emitter current of transistor 1, any fluctuations in the current flow of zener diode 2 may be of small consequence for many applications; however, in applications which require precise current control, these fluctuations in current may be of such magnitude as to render the constant current source of FIGURE 1 unsuitable. For example, these fluctuations may be of sufficient magnitude such that the constant current source of FIGURE 1 cannot be used to supply and write half currents for a coincident current magnetic core memory system.

FIGURE 2 shows a constant current source constructed in accordance with one embodiment of the present invention. The source includes a first NPN transistor 11 and a second PNP transistor 21, each having the usual emitter, base and collector electrodes. A first zener diode 12 is connected between the base electrode of transistor 11 and the negative terminal of voltage source 16. A second zener diode 22 is connected between the collector electrode of transistor 11 and the base electrode of transistor 21. A second zener diode 22 connects the base electrode of transistor 21 to an intermediate terminal 23. The series combination of a variable resistor 24 and a fixed resistor 25 connects the emitter electrode of transistor 21 to the intermediate terminal 23. Load device 26 to which the constant current is to be supplied is connected between the intermediate terminal 23 and the point of reference potential.

The constant current source of FIGURE 2 operates as follows: Zener diode 12 provides a constant voltage between the base electrode of transistor 11 and the negative terminal of voltage source 16. The voltage drop across zener diode 12 is equal to the breakdown voltage of zener diode 12 and thus the voltage drop across the emitter-base junction of transistor 11. This constant voltage across resistor 13 results in a constant current flow therethrough and a corresponding constant emitter current I₁₁ of transistor 11. This further results in a constant base current I₁ of transistor 11 being equal to the constant emitter current I₁₁ divided by the current gain of transistor 11 and a constant collector current I₁c equal to the constant emitter current I₁₁ minus the constant base current I₁b.

Zener diode 22 provides a constant voltage between the base electrode of transistor 21 and intermediate terminal 23 and a corresponding constant voltage across the series combination of variable resistor 24 and fixed resistor 25 which is equal to a breakdown voltage of zener diode 22 minus the voltage drop across the emitter-base junction of transistor 21. Resistor 24 is made variable to compensate for slight variations in the voltage drop across the emitter-base junction of transistor 21 which occur from transistor to transistor so that the circuit always supplies a fixed current regardless of the characteristics of individual components used. The constant voltage impressed across resistors 23 and 24 results in a constant current flow therethrough which is the emitter current I₁₂ of transistor 21. This constant emitter current results in a constant base current I₂b of transistor 21 and a constant collector current I₂c being equal to the constant emitter current I₁₂ minus the constant base current I₂b.

It is observed that the constant collector current I₁c of transistor 11 is equal to the sum of the base current I₁b1 of transistor 21 and the current I₂c1 flowing through zener diode 22. Since the current I₁₁ and I₂b1 are both constant, it follows that the current I₂c1 flowing through zener diode 22 must also be constant. It is further observed that the current I₂c1 in the load device 26 is equal to the sum of the emitter current I₁₁ of transistor 21 and the current I₂c2 flowing through zener diode 22, both of which currents are constant. It therefore follows that the current I₂c2 flowing through load device 26 is also constant. Thus, in accordance with the present invention, fluctuations in the zener diode current flowing in the load are prevented.

It is seen that the voltage appearing across resistor 14 is equal to the voltage of source 16 minus the constant voltage drop across zener diode 12 and thus any fluctuations in the magnitude of voltage source 16 appear directly across resistor 14, and affect a corresponding variation in the current I₁ flowing therethrough. This fluctuation of current also appears directly in the current I₂c flowing through zener diode 12, since this current is equal to current I₁c minus the constant current I₂b. However, it is observed that this current forms no part of the current I₂ flowing through load member 26 and thus any fluctuations in current in resistor 14 and zener diode 12 have no adverse effect on the operation of the circuit of FIGURE 2 as a constant current source.

It is further observed that the current flowing through transistor 11 is equal to the sum of the base current I₁b1 of transistor 21 and the current I₂c1 flowing through zener diode 22, with this sum being considerably less than the emitter current I₁₁ of transistor 21. Thus, in accordance with another feature of the invention, a relatively inexpensive low power NPN transistor 11 is utilized to control a relatively inexpensive high power PNP transistor 21 to supply a constant current of relatively large magnitude without the use of any relatively expensive high power NPN transistors.

In some applications, it is desirable to provide a constant current source from which the magnitude of "constant current" supplied remains constant, regardless of the nature of the load and the magnitude of the voltage source, but which varies in response to variations in some external temperature or parameter. Such a source still meets the definition of a constant current source in that the magnitude of the current supplied is controlled by the parameters of the circuit itself, and not of the load or voltage source. Such circuits may find
application, for example, in providing read and write half currents to a coincident current magnetic core memory, in which the hysteresis characteristics of the magnetic cores change noticeably with small changes in temperature. In such applications, it is desirable to have lower values of current for higher temperatures and higher values of current for lower temperatures.

FIGURE 3 shows a constant current source constructed in accordance with a second embodiment of the present invention in which the magnitude of current supplied with load decreases with increasing temperature and increases with decreasing temperature. The circuit is similar to that shown and described in FIGURE 2 with the addition of a thermostat 27 in series with zener diode 22. The same reference numerals and letters are used to identify the corresponding components and currents in the circuits of FIGURES 2 and 3.

The operation of the circuit of FIGURE 3 is as follows: When operating at constant temperature, the resistance of thermostat 27 remains constant and the operation of the circuit is similar to that described in FIGURE 2, with the exception that the constant voltage now being impressed upon the series resistors 24 and 25 is now equal to the sum of the breakdown voltage of zener diode 22 plus the voltage drop appearing across thermostat 27 minus the voltage drop appearing across the emitter-base junction of transistor 21. An increase in temperature decreases the resistance of thermostat 27, as is well known to those skilled in the art, and results in a corresponding decrease in the voltage drop thereacross since the current flow therethrough, I_{27}, is maintained relatively constant. This decrease in the voltage drop across thermostat 27 appears directly across the series resistors 24 and 25 and results in a corresponding decrease in the current flow I_{21} therethrough. This decrease in the current of transistor 21 results in a much smaller decrease in the base current I_{25} of transistor 21 and a corresponding slighter increase in current I_{250} since the sum of these two currents is held constant by transistor 11. Thus, the increase in temperature results in a net decrease in the sum of currents I_{25} and I_{250}, which is equal to the current I_{26} in load device 26. In a similar manner, a decrease in temperature increases the resistance of thermostat 27 and results in a corresponding increase in voltage drop thereacross which causes an increase in the voltage drop across resistors 24 and 25 and a corresponding decrease in the current I_{21} of transistor 21 and in the load current I_{26} supplied to load device 26. Thus, thermostat 27 affects a decrease in current supplied to load device 26 with increases in temperature and an increase in current supplied to load device 26 with decreases in temperature.

When the current source of FIGURE 3 is used to supply current to a coincident current magnetic core memory, the parameters of thermostat 27 are determined by the hysteresis characteristics of the magnetic cores which form the load elements of load device 26. However, thermostat 27 may also be chosen to compensate for the variations in characteristics of transistor 21, zener diode 22 and resistors 24 and 25 with temperature, as well as the variations in characteristics of load device 26. Given the temperature characteristics of these components, a single thermostat can be selected to compensate for any temperature variations so as to supply the desired level of current to load device 26.

While the principles of the invention have now been made clear in illustrative embodiments, there will be immediately obvious to those skilled in the art many modifications in structure, arrangement, proportions, the elements, materials, and components used in the practice of the invention, and otherwise, which are particularly adapted for specific environment and operating requirements, without departing from those principles. The appended claims are therefore intended to cover and embrace any such modifications within the limits only of the true spirit and scope of the invention.

What is claimed is:

1. A current source for supplying a controlled value of electrical current flow to a load comprising, a voltage source having first and second terminals, first and second semiconductors each having an input electrode and two output electrodes, a first constant voltage device connected between the input electrode of said first semiconductor and the first terminal of said voltage source, a first resistance connected between one of the output electrodes of said first semiconductor and said intermediate terminal, a second resistance connected between one of the output electrodes of said second semiconductor and said intermediate terminal, a second constant voltage device connected between the input electrode of said second semiconductor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

2. The current source of claim 1 in which said current source for supplying a controlled value of electrical current flow to a load, comprising, a voltage source having first and second terminals, first and second transistors each having an input electrode and two output electrodes, a first zener diode connected between the input electrode of said first transistor and the first terminal of said voltage source, a first resistance connected between one of the output electrodes of said first transistor and the first terminal of said voltage source, circuit means connecting the other output electrode of said first transistor to the input electrode of said second transistor, an intermediate terminal, a second zener diode connected between the input electrode of said second transistor and said intermediate terminal, a second resistance connected between one of the output electrodes of said second transistor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

3. A current source for supplying a controlled value of electrical current flow to a load comprising, a voltage source having first and second terminals, first and second transistors each having an emitter electrode, a base electrode, and a collector electrode, a first zener diode connected between the base electrode of said first transistor and the first terminal of said voltage source, a first resistance connected between the emitter electrode of said first transistor and the first terminal of said voltage source, circuit means connecting the collector electrode of said first transistor to the base electrode of said second transistor, an intermediate terminal, a second zener diode connected between the base electrode of said second transistor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

4. A current source for supplying a controlled value of electrical current flow to a load comprising, a voltage source having first and second terminals, first and second transistors each having an emitter electrode, a base electrode, and a collector electrode, a first zener diode connected between the base electrode of said first transistor and the first terminal of said voltage source, a first resistance connected between the emitter electrode of said first transistor and the first terminal of said voltage source, circuit means connecting the collector electrode of said first transistor to the base electrode of said second transistor, an intermediate terminal, a second zener diode connected between the base electrode of said second transistor and said intermediate terminal, variable resistance means connected between the emitter electrode of said second transistor and said intermediate terminal, circuit means
connecting the collector electrode of said second transistor with the first terminal of said voltage source, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

5. The current source of claim 4 in which said first and second transistors are of opposite types of conductivity.

6. The current source of claim 5 in which said first transistor is an NPN transistor and said second transistor is a PNP transistor.

7. A current source for supplying a controlled value of electrical current flow to a load, comprising, a voltage source having first and second terminals, first and second semiconductors each having an input electrode and two output electrodes, a first constant voltage device connected between the input electrode of said first semiconductor and the first terminal of said voltage source, a first resistance connected between one of the output electrodes of said first semiconductor and the first terminal of said voltage source, circuit means connecting the other output electrode of said first semiconductor to the input electrode of said second semiconductor, an intermediate terminal, a second constant voltage device and a temperature responsive element serially connected between the input electrode of said second semiconductor and said intermediate terminal, a second resistance connected between one of the output electrodes of said second semiconductor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

8. A current source for supplying a controlled value of electrical current flow to a load, comprising, a voltage source having first and second terminals, first and second transistors each having an emitter electrode, a base electrode, and a collector electrode, a first zener diode and a thermistor serially connected between the base electrode of said first transistor and said intermediate terminal, a second zener diode and a thermistor serially connected between the base electrode of said second transistor and said intermediate terminal, a second resistance connected between the emitter electrode of said first transistor and the first terminal of said voltage source, circuit means connecting the collector electrode of said first transistor to the base electrode of said second transistor, an intermediate terminal, a second zener diode and a thermistor serially connected between the base electrode of said second transistor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

9. A current source for supplying a controlled value of electrical current flow to a load, comprising, a voltage source having first and second terminals, first and second transistors each having an emitter electrode, a base electrode, and a collector electrode, a first zener diode connected between the base electrode of said first transistor and the first terminal of said voltage source, and a second resistance connected between the emitter electrode of said first transistor and the first terminal of said voltage source, circuit means connecting the collector electrode of said first transistor to the base electrode of said second transistor, an intermediate terminal, a second zener diode and a thermistor serially connected between the base electrode of said second transistor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

10. A current source for supplying a controlled value of electrical current flow to a load, comprising, a voltage source having first and second terminals, first and second transistors each having an emitter electrode, a base electrode, and a collector electrode, a first zener diode connected between the base electrode of said first transistor and the first terminal of said voltage source, a first resistance connected between the emitter electrode of said first transistor and the first terminal of said voltage source, circuit means connecting the collector electrode of said first transistor to the base electrode of said second transistor, an intermediate terminal, a second zener diode and a thermistor serially connected between the base electrode of said second transistor and said intermediate terminal, and circuit means serially connecting the second terminal of said voltage source and said intermediate terminal with a load.

11. The current source of claim 10 in which said first and second transistors are opposite types of conductivity.

12. The current source of claim 11 in which the first transistor is a NPN transistor and said second transistor is a PNP transistor.

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