

June 19, 1956

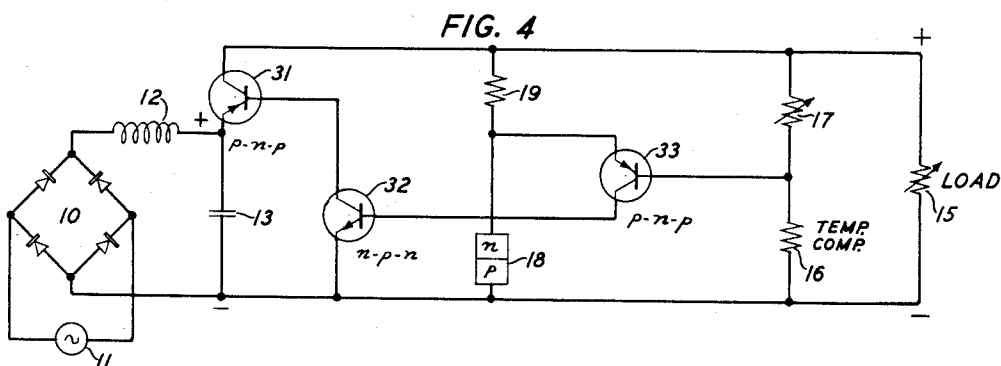
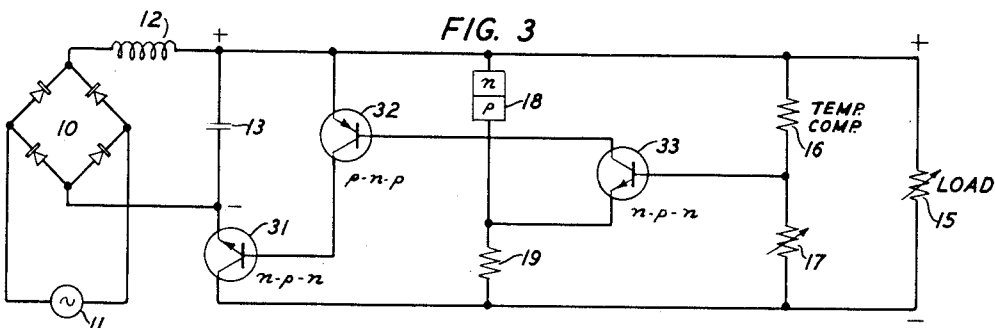
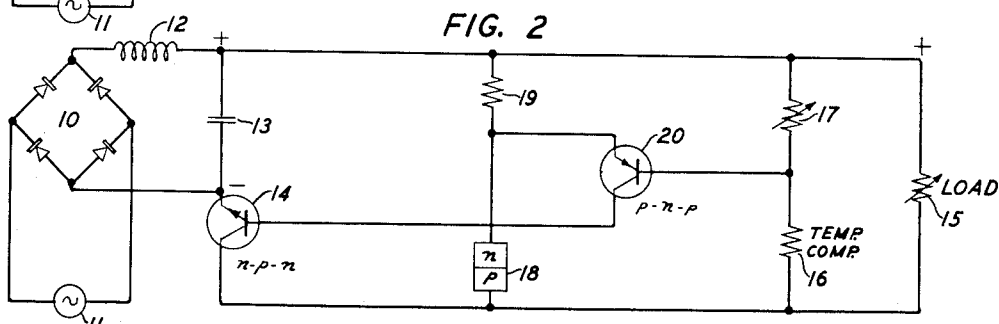
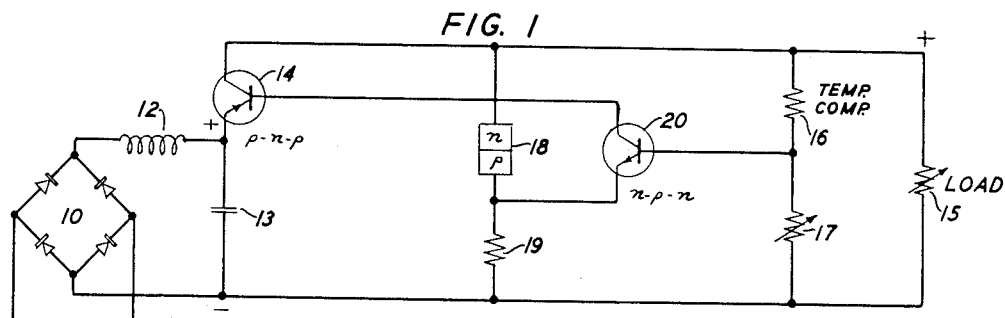
F. H. CHASE

2,751,549

CURRENT SUPPLY APPARATUS

Filed Feb. 25, 1954

2 Sheets-Sheet 1



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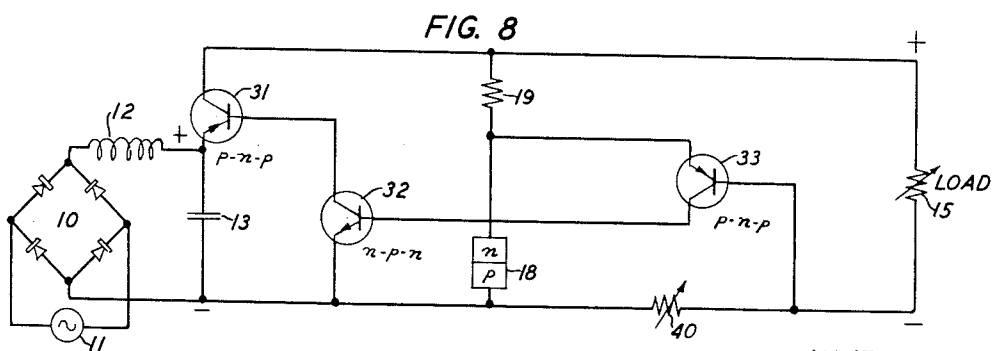
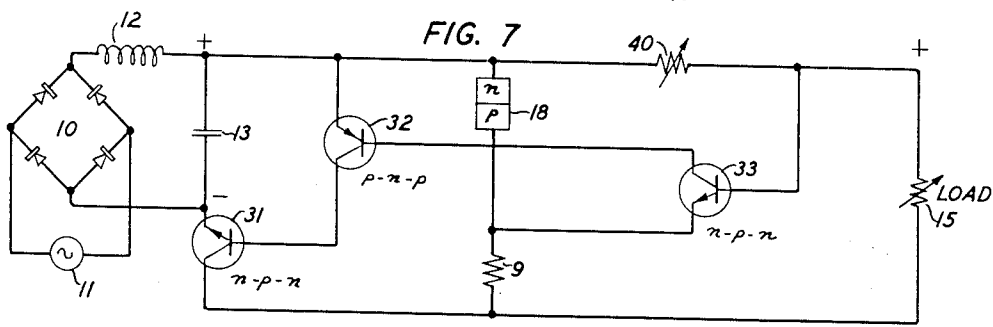
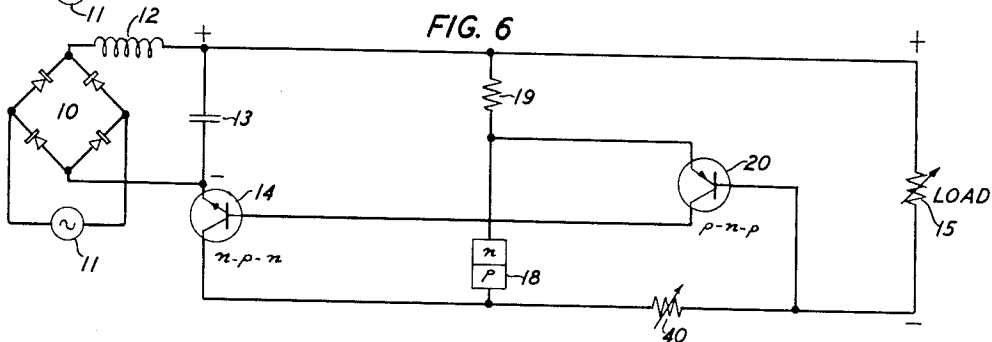
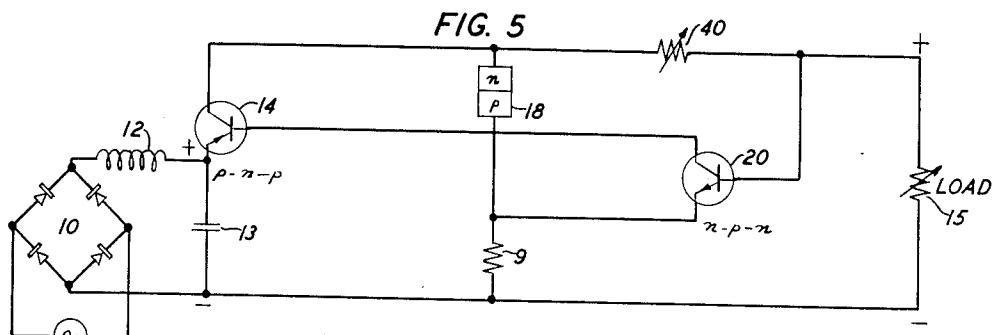
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CURRENT SUPPLY APPARATUS

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2 Sheets-Sheet 2



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2,751,549

CURRENT SUPPLY APPARATUS

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Application February 25, 1954, Serial No. 412,437

7 Claims. (Cl. 323-66)

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 or, alternatively, changes of load current.

An object of the invention is to provide an improved circuit including a plurality of transistors for regulating the supply of current from a current source to a load.

This invention is an improvement over the invention disclosed and claimed in my application Serial No. 274,951, filed March 5, 1952, now Patent No. 2,693,568, November 2, 1954.

Current supply circuits which are similar in certain respects to the current supply circuits shown and described herein are disclosed in my applications Serial No. 341,519, filed March 10, 1953, and Serial No. 385,570, filed October 12, 1953.

In a junction transistor there are two rectifiers contained in a bar cut from a single crystal of transistor material. The materials now in use are germanium and silicon, but to date almost all transistors have been made from germanium. The two rectifiers are obtained by introducing two kinds of impurities in the material from which the crystal is grown. When an impurity from the third column of the chemical periodic table is added, the material becomes a conductor of positive charges and it is therefore called p-type material. When the impurity comes from the fifth column of the table, the material is a conductor of negative charges and it is therefore called n-type material. If one-half of the material is grown from p-type material, and the other half from n-type material, there is formed a p-n junction. This junction is a rectifier because it is a good conductor of current from p toward n but only a minute current can flow from n toward p. Thus the junction, like any rectifier, has a low forward resistance and a high inverse resistance. If the crystal is grown so that there is a wafer of p-type material interposed between two sections of n-type material, there is produced an n-p-n type transistor. If there is a wafer of n-type material, between two sections of p-type material, there is formed a p-n-p type transistor. The electrical connections to the end portions of a transistor crystal are called the collector at one end and the emitter at the other end. The connection to the wafer is called the base. The n-p-n transistor operates with a collector potential which is positive with respect to the emitter potential so that current flows through the collector-base junction in the inverse or high resistance direction and through the emitter-base junction in the forward or low resistance direction. The p-n-p transistor operates with a collector potential which is negative with respect to the emitter potential so that current again flows through the collector-base junction in the inverse or high resistance direction and through the emitter-base junction in the forward or low resistance direction. Both types of transistors will amplify changes of current flow into or out of the base into much larger changes of current in a current path connected to the collector.

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In a specific embodiment of the invention shown and described herein for the purpose of illustration, there are provided two transistors, one of the p-n-p type and the other of the n-p-n type. Current from a direct-current source is supplied to a load circuit including a load through the collector-emitter path of a first of the transistors. The base of the first transistor is directly conductively connected to the collector of the second transistor so that the base current of the first transistor is the collector current of the second transistor. If the first transistor is of the p-n-p type, its emitter is preferably connected to the positive terminal of the direct-current source, and its collector is connected to the positive side of the load circuit. If the first transistor is of the n-p-n type, its emitter is preferably connected to the negative terminal of the supply source and its collector is connected to the negative side of the load circuit. When only two transistors are used in the regulating circuit, there is derived from the load circuit and impressed upon the base of the second transistor, with respect to its emitter, a control potential which varies in response to load voltage changes or, alternatively, a control potential which varies in response to changes of current supplied to the load. Changes of load voltage or load current are thus minimized.

More than two transistors may be employed to increase the sensitivity of the regulating circuit. When three transistors are used in the regulating circuit, for example, the first and third transistors are of one type, and the second transistor is of the other type. For example, there may be provided a first transistor of the p-n-p type having its collector-emitter path connected in series with the direct-current supply source and the load and a third transistor, also of the p-n-p type, having a control voltage derived from the load circuit impressed between its base and its emitter. The second transistor of the n-p-n type has its collector connected to the base of the first transistor, its base connected to the collector of the third transistor and its emitter connected to the negative terminal of the current supply source. When the first and third transistors are of the p-n-p type and the second transistor is of the n-p-n type, the second transistor is similarly connected into the circuit except that in this case its emitter is connected to the positive terminal of the supply source. More than three transistors may be employed if desired, the odd transistors being of one type, the even transistors being of the other type and conductors being provided for connecting the base of the first transistor, through the emitter-collector path of which the load current flows, to the collector of the second transistor, the base of the second transistor to the collector of the third transistor, and so forth. When the collector of a transistor of one type is connected in series with the emitter and base of a transistor of another type, the collector current of the first transistor is reduced only minutely by the added resistance of the second transistor, thus resulting in negligible loss in coupling the two transistors.

The control voltage which is derived from the load circuit and impressed between the emitter and base of one of the transistors is equal to the difference of a substantially constant reference voltage component across a p-n junction rectifier, or Zener diode, and another voltage component which may be either a portion at least of the load voltage or, alternatively, a voltage proportional to the load current. The voltage across the reference voltage diode, or Zener diode, increases about 0.08 per cent per degree rise of ambient temperature. The other voltage component, which is compared with the voltage component across the p-n junction diode is therefore preferably obtained across a resistor having a positive temperature coefficient of resistance such that the voltage changes

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across the resistor due to ambient temperature changes are substantially equal to voltage changes across the diode due to ambient temperature changes. Moreover, the portion of the circuit including the temperature compensating resistor may be designed to compensate not only for the voltage changes across the p-n junction diode due to ambient temperature changes, but to compensate also for other ambient temperature responsive changes.

The invention will be further described with reference to the accompanying drawing in which:

Fig. 1 is a schematic view of a current supply apparatus embodying the invention; and

Figs. 2 to 8 inclusive are schematic views of modifications of the current supply apparatus shown in Fig. 1.

Referring now to Fig. 1 of the drawing, there is provided a direct-current supply source comprising a bridge rectifier 10 having input terminals connected to an alternating-current supply source 11 and having a ripple filter comprising a series inductive reactor 12 and a shunt condenser 13 connected to its output terminals. Current from the direct-current supply source is supplied through the emitter-collector path of a p-n-p type transistor 14 to a load circuit comprising a load 15 which may vary, the emitter of the transistor being connected to the positive terminal of the direct-current supply source, the collector of the transistor being connected to the positive load terminal and the negative terminal of the supply source being connected to the negative load terminal. Two current paths are connected across the load. One of these current paths comprises in series a temperature compensating resistor 16 having a positive temperature coefficient of resistance and an adjustable resistor 17. The other current path comprises in series a p-n junction diode 18 and a resistor 19. The diode 18 is poled so that current flows through it in the inverse or high resistance direction. The resistor 19 has a resistance such that the current flowing through the diode 18 exceeds the so-called Zener point. Under this condition, the voltage across the diode remains substantially constant irrespective of changes of current flowing through it. There is provided a second transistor 20 of the n-p-n type having its base connected to the common terminal of resistors 16 and 17, its emitter connected to the common terminal of the constant voltage diode 18 and resistor 19, and having its collector connected to the base of transistor 14.

Current flows from the positive terminal of the current supply source into the emitter and out of the collector of transistor 14 and through the load 15 to the negative terminal of the supply source. Current also flows from the positive terminal of the load through resistors 16 and 17 in series to the negative load terminal and through the diode 18 and resistor 19, in series, to the negative load terminal. A portion of the current which flows into the emitter of transistor 14 flows out of its base, into the collector and out of the emitter of transistor 20 and through resistor 19 to the negative terminal of the supply source. The base potential of transistor 20 is preferably somewhat positive with respect to its emitter potential so that current also flows from the positive load voltage terminal through resistor 16 into the base and out of the emitter of transistor 20 and through resistor 19 to the negative load terminal.

An increase of load voltage, for example, will make the base of transistor 20 less positive with respect to the potential of the emitter because of the increased voltage drop across resistor 16 and the substantially constant voltage drop across the diode 18. Therefore, the current flowing into the base of transistor 20 will decrease to cause the current flowing out of the base of transistor 14 and into the collector of transistor 20 to decrease. As a result, the current flowing into the emitter and out of the collector of transistor 14 and through the load 15 will decrease to minimize the initially assumed rise of load voltage. An increase of ambient temperature for

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example, will make both the base and emitter of transistor 20 more negative with respect to the positive load terminal, the resistor 17 being adjustable to minimize or substantially eliminate a change of load voltage as the result of an ambient temperature change.

Figs. 2 to 8 inclusive, depict modifications of the embodiment of the invention shown in Fig. 1 and the parts of the current supply circuits of Figs. 2 to 8 which correspond to parts of Fig. 1 are designated by the same numerals. In Fig. 2, the transistor 14 having its collector-emitter path connected in series with the source and the load is of the n-p-n type and the transistor 20 is of the p-n-p type. In this embodiment of the invention, the emitter of transistor 14 is connected to the negative terminal of the current supply source and its collector is connected to the negative load terminal. The elements 18 and 19 are reversed with respect to the position of these elements in Fig. 1 and the elements 16 and 17 are reversed with respect to the position of these elements in Fig. 1. In Fig. 2, current from the positive terminal of the supply source flows through the load 15 into the collector and out of the emitter of transistor 14 to the negative terminal of the supply source. Current also flows from the positive source terminal through resistor 19 into the emitter and out of the collector of transistor 20 and into the base and out of the emitter of transistor 14 to the negative terminal of the source. An increase of load voltage, for example, makes the base of transistor 20 less negative with respect to its emitter to decrease the current flowing through the emitter-base junction of the transistor 20. Therefore, the current flowing out of the collector of transistor 20 and into the base of transistor 14 decreases to cause a decrease of current flowing through the load 15 and into the collector and out of the emitter of transistor 14. The assumed increase of load voltage is thus minimized.

Fig. 3 is a modification of Figs. 1 and 2 in which there are employed three transistors 31, 32 and 33. Transistors 31 and 33 are of the n-p-n type and transistor 32 is of the p-n-p type. The emitter and collector electrodes of transistor 31 are connected into the circuit as are the corresponding electrodes of transistor 14 in Fig. 2. The base and emitter electrodes of transistor 33 are connected into the circuit as are the corresponding electrodes of transistor 20 of Fig. 1. The base of transistor 31 is connected to the collector of transistor 32 and the base of transistor 32 is connected to the collector of transistor 33. The emitter of transistor 32 is connected to the positive terminal of the supply source and the load.

An increase of load voltage, for example, in the embodiment of Fig. 3, will make the base of transistor 33 relatively less positive with respect to its emitter. The current flowing through the emitter-base junction of transistor 32 and into the collector of transistor 33 will therefore decrease. As a result, the current flowing out of the collector of transistor 32 and through the base-emitter junction of transistor 31 will decrease, thereby causing a decrease of the current flowing from the positive terminal of the direct-current supply source through the load 15 and through the collector-emitter path of transistor 31 to the negative terminal of the supply source. The initially assumed rise of load voltage is thus minimized.

Fig. 4 differs from Fig. 3 in that the transistors 31 and 33 are of the p-n-p type and transistor 32 is of the n-p-n type. The arrangement of elements 16, 17, 18 and 19 in the circuit is as shown in Fig. 2 and the base of transistor 33 is connected to the common terminal of resistors 16 and 17 and the emitter of transistor 33 is connected to the common terminal of the constant voltage diode 18 and resistor 19. The emitter and collector electrodes of transistor 31 are connected in the circuit as are the emitter and collector electrodes of transistor 14 in Fig. 1. The base of transistor 31 is

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connected to the collector of transistor 32 and the base of transistor 32 is connected to the collector of transistor 33, as in Fig. 3. The emitter of transistor 32 is connected to the negative terminal of the direct current source and the load instead of being connected to the positive terminal as shown in Fig. 3.

In Fig. 4 an increase of load voltage, for example, makes the base of transistor 33 less negative with respect to the emitter to decrease the current flowing through the emitter-base junction of transistor 33. Therefore, the current flowing out of the collector of transistor 33 and through the base-emitter junction of transistor 32 also decreases. As a result, the current flowing through the emitter-base junction of transistor 31 and into the collector of transistor 32 decreases to cause a decrease of current flowing in the circuit from the positive terminal of the direct-current supply source through the emitter-collector path of transistor 31 and through the load 15 to the negative terminal of the supply source. The assumed voltage increase across the load is thus minimized.

The embodiments of the combination shown in Figs. 5, 6, 7 and 8 are like the embodiments of the invention shown in Figs. 1, 2, 3 and 4 respectively, except for the following differences: The resistors 16 and 17 of Figs. 1 to 4 are omitted from Figs. 5 to 8. Instead there is provided in each of Figs. 5 to 8 an adjustable resistor 40 connected in series with the load so that the load current flows through it and sets up thereacross a voltage proportional to the load current. In each of Figs. 1 to 4 the voltage impressed across the base-emitter junction of transistor 20 or transistor 33 is equal to the difference of the voltage across the diode 18, and the voltage across the resistor 16, the base preferably being positive with respect to the emitter in Figs. 1 and 3 and the base preferably being negative with respect to the emitter of Figs. 2 and 4. In each of Figs. 5 to 8 similarly, the voltage impressed across the base-emitter junction of transistor 20 or transistor 33 is equal to the difference of the voltage across the diode 18 and the voltage across the resistor 40, the base preferably being positive with respect to the emitter in Figs. 5 and 7 and the base preferably being negative with respect to the emitter in Figs. 6 and 8.

In each of Figs. 5 to 8 an increase of voltage drop across resistor 40 due to an increase of current supplied to the load will cause the current supplied to the load circuit through the emitter-collector path of transistor 14 or through the emitter-collector path of transistor 31 to decrease and hereby minimize the assumed increase of load current. This action is similar to that described above in connection with Figs. 1 to 4 in which an increase of voltage drop across resistor 16 due to an increase of load voltage will cause the current supplied to the load circuit through the emitter-collector path of transistor 14 or through the emitter-collector path of transistor 31 to decrease and thereby minimize the assumed increase of load voltage.

What is claimed is:

1. The combination with a source of direct current for supplying current to a load circuit including a load, of a first and a second transistor one of which is of the n-p-n type and the other of which is of the p-n-p type, each of said transistors having a collector, an emitter and a base, means for connecting the collector-emitter path of said first transistor in series with said source and said load circuit so that the current supplied to said load circuit flows through said collector-emitter path, and means for controlling the current in said load circuit comprising said second transistor, means for directly conductively connecting the base electrode of said first transistor to the collector electrode of said second transistor so that the current flowing out of one of said electrodes flows into the other of said electrodes, and means for controlling the current flowing through the

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base-emitter path of said second transistor to control the collector current of said second transistor.

2. In combination, a first and a second transistor each having a collector, an emitter and a base, means for supplying current from a direct-current supply source through the emitter-collector path of said first transistor to a load circuit including a load, a p-n junction diode, a resistor, means for supplying current from said supply source to a current path comprising said resistor and said diode in series, said diode being poled so that current flows through it in the inverse or high resistance direction and said resistor having a resistance value such that said current exceeds the Zener point of said diode, means for connecting the emitter of said second transistor to the common terminal of said resistor and said diode, means for connecting the collector of said second transistor to the base of said first transistor, means for deriving a unidirectional control voltage from said load circuit, and means for impressing upon a circuit connecting the emitter and base of said second transistor a voltage equal to the difference of said control voltage and the voltage across said diode.

3. In combination, a first and a second transistor each having a collector, an emitter and a base, means for supplying current from a direct-current supply source through the emitter-collector path of said first transistor to a load circuit including a load, means connected to said load circuit for deriving a substantially constant reference voltage, means connected to said load circuit for deriving a control voltage, means for impressing upon a circuit connecting the base and emitter of said second transistor a voltage equal to the difference of said reference voltage and said control voltage, and means for connecting the collector of said second transistor to the base of said first transistor.

4. In combination, a plurality of transistors of the p-n-p and n-p-n types including a first and a last transistor, each of said transistors having a collector, an emitter and a base, means for coupling said transistors comprising means for connecting the collector of each of said transistors except the last to the base of a succeeding transistor of a different type, means for supplying current from a direct-current source through the collector-emitter path of said last transistor to a load circuit including a load, and means for deriving from said load circuit and impressing upon the base with respect to the emitter of said first transistor a control voltage for regulating the current supplied through the collector-emitter path of said last transistor to said load circuit.

5. In combination, a plurality of transistors of the p-n-p and n-p-n types including a first and a third transistor of one of said types and a second transistor of the other of said types, each of said transistors having a collector, an emitter and a base, a source of direct current having a positive and a negative terminal, means for connecting the emitter of said first transistor to one of said terminals, means for connecting the emitter of said second transistor to the other of said terminals, a load circuit, means for connecting the collector of said first transistor to one side of said load circuit, means for connecting the other side of said load circuit to said other of said terminals, means for connecting the base of said first transistor to the collector of said second transistor, means for connecting the base of said second transistor to the collector of said third transistor, and means for supplying current through the base-emitter junction of said third transistor to control the current supplied to said load.

6. In combination, a first and a second transistor each having a collector, an emitter and a base, one of said transistors being of the p-n-p type and the other of said transistors being of the n-p-n type, a source of direct current having a positive and a negative terminal, means for connecting the emitter of said first transistor to one

of the terminals of said current source, a load circuit, means for connecting the collector of said first transistor to one side of said load circuit, means for connecting the other terminal of said current source to the other side of said load circuit, a first, a second and a third resistor, 5 a p-n junction diode, a first current path comprising said diode and said first resistor in series connected across said load circuit, said diode being poled so that current flows through it in the inverse or high resistance direction and said first resistor having a resistance value such that the current flowing through the diode exceeds the Zener 10 point, means for connecting the emitter of said second transistor to the common terminal of said diode and said first transistor, means for connecting the collector of said second transistor to the base of said first transistor, a second current path comprising said second and 15 third resistors in series connected across said load, means for connecting the base of said second transistor to the common terminal of said second and third resistors, said p-n junction diode having the characteristic that the voltage drop across it rises at a predetermined rate in response to increase of ambient temperature and vice versa, said diode and said second resistor having a common terminal, the voltage drop across said second resistor increasing at a rate at least as large as said predetermined rate in response to increase of said ambient temperature and vice versa. 25

7. In combination, a source of direct current having positive and negative terminals for supplying current to a load circuit including a load, a plurality of at least three 30 transistors of the p-n-p and n-p-n types each having a collector, an emitter and a base, successive transistors

being of different type respectively, means for connecting the emitter of said first transistor to one terminal of said source, means for connecting the emitter of said second transistor to the other terminal of said supply source, means for connecting the collector of said first transistor to one side of said load circuit, means for connecting the other side of said load circuit to said other terminal of said source, a p-n junction diode having a first and a second terminal, a resistor, a current path comprising said diode and said resistor in series connected across said load circuit, means for connecting the emitter of said third transistor to the common terminal of said diode and said resistor, means for conductively connecting the base of each of said transistors except said third transistor to the collector of a succeeding transistor, a control circuit including said diode connecting the emitter and base of said third transistor, and means for deriving from said load circuit and impressing upon said control circuit in opposition to the voltage across said diode a control 20 voltage for controlling the supply of current from said supply source to said load, said last-mentioned means including means for compensating in part at least for the effect of voltage changes across said diode due to changes of ambient temperature.

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