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Doubt

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[54] **TWO TERMINAL CURRENT LIMITER**

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[52] **U.S. Cl.** ..... **323/4,** 307/297, 317/33 VR, 323/9

[51] **Int. Cl.** **G05f 1/58,** G05f 1/64

[58] **Field of Search** ..... 323/4, 9, 22 T, 1; 307/296, 297; 317/33 VR, 22

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Attorney—Lindenberg, Freilich & Wasserman

[57] **ABSTRACT**

A two terminal current limiter is disclosed. The current limiter includes two (first and second) transistors and two resistors, one of which, acting as a sensing resistor, is connected in series with the collector-emitter path of the first transistor between the said two terminals. When sufficient voltage drop occurs across the sensing resistor, the second transistor is biased into conduction, which together with the second resistor, controls the biasing of the first transistor, thereby controlling the current flow therethrough.

5 Claims, 8 Drawing Figures

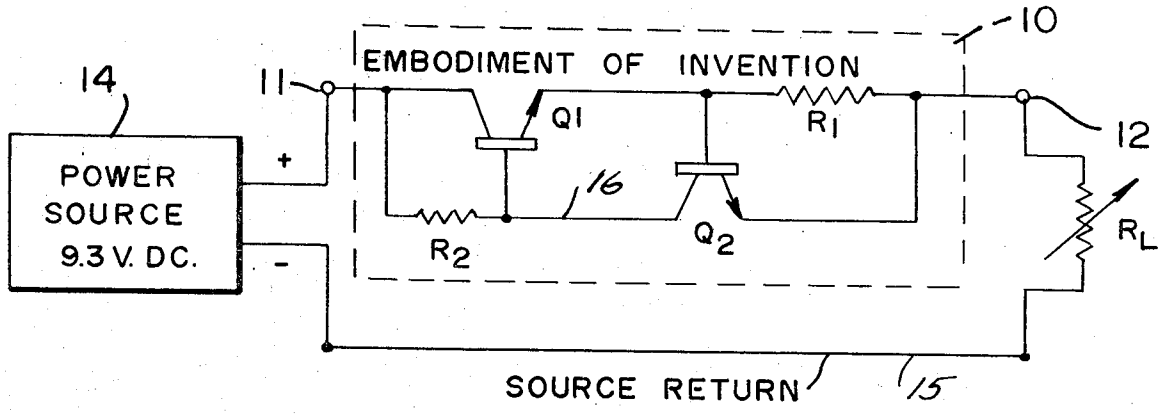


FIG. 1

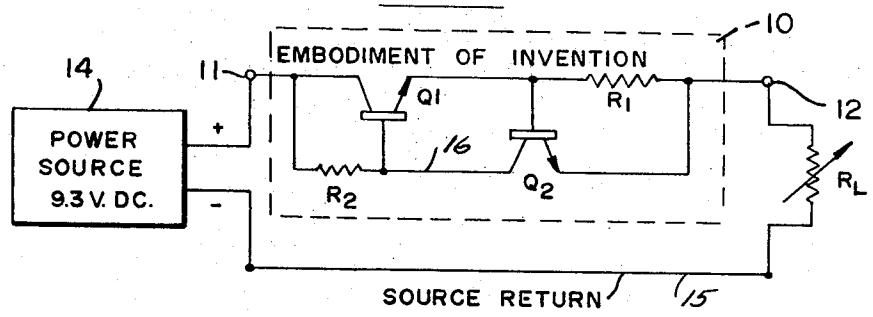


FIG. 2

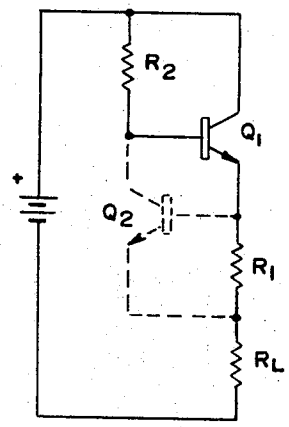


FIG. 3

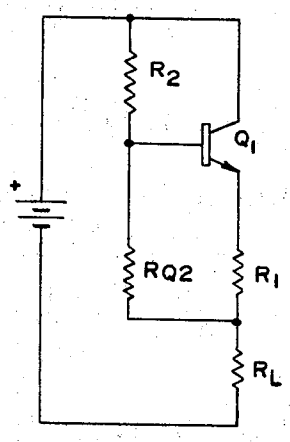


FIG. 5

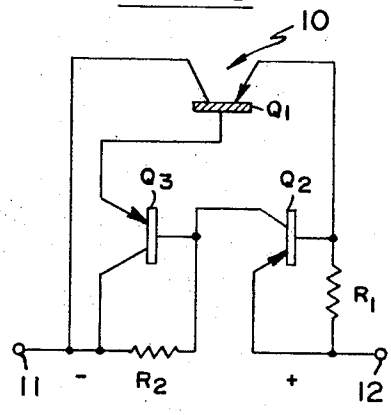
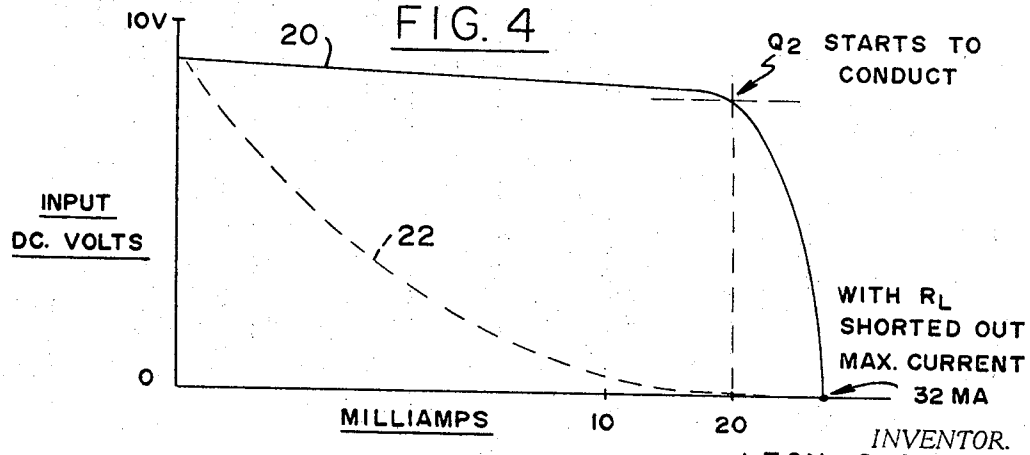


FIG. 4



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FIG. 6

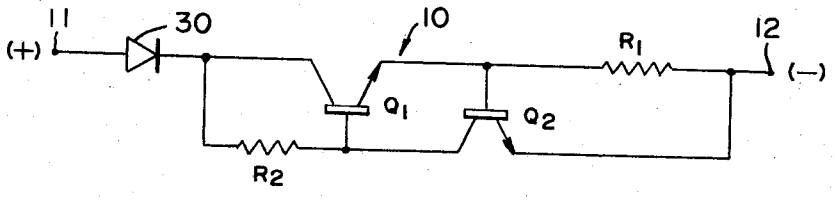


FIG. 7

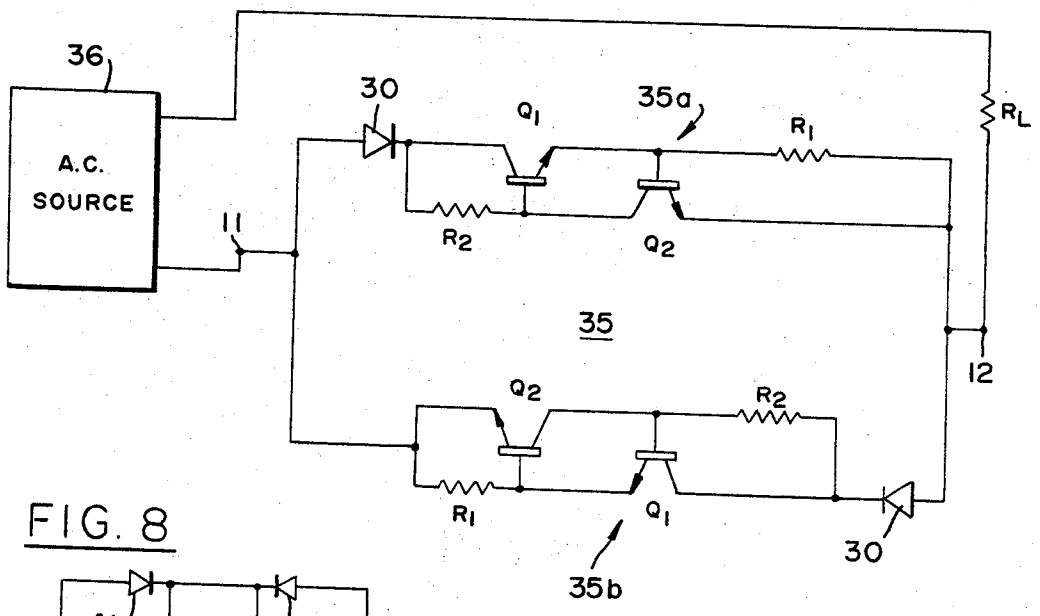
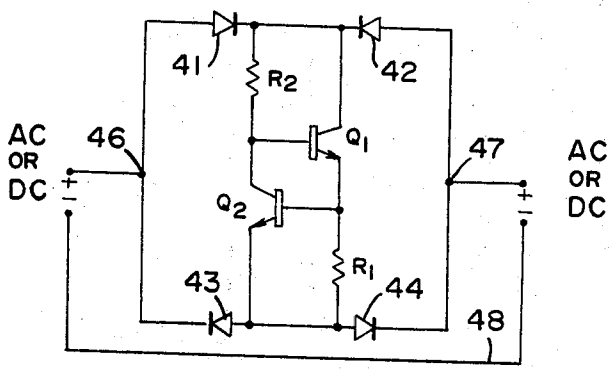


FIG. 8



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TWO TERMINAL CURRENT LIMITER

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention is directed to a current controlling device, and, more particularly, to a two terminal device for controlling the maximum current supplied by a source to a load.

2. Description of the Prior Art:

There are many devices which have been designed to control the flow of current from a source to a load. Some devices act as constant current regulators, while others act as fuses which permanently interrupt the flow of current when it exceeds a predetermined value, controlled by the fuse. In the latter a blown fuse requires manual replacement, and is much too slow to protect modern solid-state devices. Other devices act as circuit breakers which must be reset after the breaker trips which occurs whenever the current amplitude exceeds the breaker's rating; these devices likewise, are too slow to protect. None of the prior art devices which employ solid state elements, such as transistors or the like, provides the capability of controlling the flow of current to prevent it from exceeding a predetermined maximum amplitude, and which automatically resets itself whenever the current amplitude after exceeding the maximum amplitude drops below it, and in which the voltage supplied to the load is nearly constant over most of the allowable current amplitude range, nor provide the benefits of a device requiring but two terminals. Most devices require an external voltage to function, or at least a third terminal for a circuit ground, and the like. Nor will the protective devices function or operate in the nanosecond range (900 MC).

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a new improved current controller.

Another object of the present invention is to provide a new improved solid state device for controlling the amplitude of current supplied to a load from a source not to exceed a preselected maximum amplitude, the device be automatically resettable to provide a current path thereacross when the current amplitude drops below the maximum amplitude.

A further object of the present invention is to provide a solid state two-terminal fuse-like device, with automatic resetting whenever the current amplitude attempts to exceed a maximum allowable level, said level will hold at that level even if the load becomes a dead short.

Yet a further object of the present invention is to provide a two-terminal fuse-like device with automatic resetting, and wherein the voltage drop across the device is substantially constant over most of the allowable current amplitude range.

These and other objects of the present invention are achieved by providing a two-terminal device which in one embodiment consists of first and second transistors and first and second resistors. The collector and emitter of the first transistor and the first resistor are connected in series between the two end terminals of the device which in turn are connected between the source and the load. The second resistor biases the first transistor to be on or fully conductive, the base-emitter junction of the second transistor is connected across the first resistor. As long as the current through the first resistor is significantly below a maximum allowable amplitude, the voltage drop across the first resistor is insufficient to forward bias the second transistor. Therefore, the bias of the first transistor is unaltered, and uninterrupted current flows between the two terminals from the source to the load. As the current amplitude approaches the maximum limit, the voltage across the first resistor increases, forward biasing the second transistor which in turn reduces the bias of the first transistor. Consequently, the voltage drop across the first resistor determines the current limit amplitude. When the maximum current amplitude is reached, the voltage drop across the first resistor forward biases the second transistor into conduction which automatically reduces the bias of the first transistor limiting the current passing ability to a value whereby the first transistor cannot pass more than the desired maximum current, regardless of the load resistance. As will be pointed out hereafter, the teachings of the inventor may be employed to control the amplitudes of currents for either DC or AC sources.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of the device of the present invention;

FIGS. **2** and **3** are schematic diagrams useful in explaining the operation of the device;

FIG. **4** is a chart useful to summarize the operation and advantages of the device;

FIGS. **5** and **6** are schematic diagrams of other embodiments of the invention;

FIG. **7** is a schematic diagram of yet another embodiment of the invention which finds particular utility for controlling the amplitude of current from an A.C. source; and

FIG. **8** is a schematic diagram of yet another embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Attention is now directed to FIG. **1** wherein numeral **10** designates the novel device of the present invention, with its two external terminals **11** and **12** respectively connected to a DC power supply or power source **14** and to a load R_L. Line **15** provides a current return path between source **14** and R_L. In the particular embodiment shown in FIG. **1**, the device **10** comprises a pair of transistors Q_1 and Q_2 and a pair of resistors R_1 and R_2. The collector and emitter of Q_1 and R_1 are connected in series between terminals **11** and **12**. R_2 is connected across the base to collector junction of Q_1, while the base to emitter junction of Q_2 is connected across R_1 and the base and collector of Q_1 and Q_2 respectively are directly connected together by line **16**.

The value of R_1 which acts as a sensing resistor is chosen so that when the current amplitude is significantly below a maximum design level, the voltage drop thereacross is not sufficient to forward bias Q_2. Consequently, Q_2 is biased off. R_2 is chosen to forward bias Q_1 into full conduction. Under these conditions the equivalent circuit of the device is as shown in FIG. **2.** Q_2 is shown in dashed line since as long as it is fully biased off or cut off, it does not affect the circuit. As long as Q_2 is fully cut off, the bias provided by R_2 maintains Q_1 fully conductive, and therefore, current is free to flow through Q_1 and R_1 between the source **14** and the load R_L.

It is appreciated that any current flowing through sensing resistor R_1 produces a voltage drop thereacross. R_1 is chosen so that when a maximum design current amplitude flows through it, the voltage drop thereacross is sufficient to fully turn on (forward bias) Q_2. As a result, the bias of Q_1 is reduced so that it cannot pass more than desired maximum current amplitude. This is regardless of the resistance of load R_L, even in the event of a dead short across R_L. The equivalent circuit of device **10** when Q_2 is on is shown in FIG. **3.**

When the malfunction or short is removed, the current amplitude drops, hence the voltage drop across R_1 drops. Consequently, Q_2 is cut off or is less than fully on and therefore Q_1 becomes again fully forward biased to enable current to flow therethrough with a minimum of voltage drop thereacross. It is thus seen that the device of the present invention provides automatic protection against the current amplitude exceeding a maximum value. Furthermore, it provides automatic resetting when the current amplitude drops below the maximum level.

The operation of the device may be summarized in connection with FIG. **4** which is a diagram of the current flowing through the device in ma versus volts across the load R_L provided from a source of 11.7V with Q_1 and Q_2 consisting of transistors 2N4403 resistor R_1 being 24Ω and R_2 1000Ω. The voltage across R_L is represented by line **20.** R_1 was chosen to limit the current not to exceed 32 ma. At low current amplitudes a minimum voltage drop occurs across Q_1 and R_1. Thus, most of the voltage is across R_L. As the current amplitude rises, the voltage drop across R_1 increases which in turn starts to turn Q_2 on and therefore lowers the bias of Q_1. Thus, the voltage thereacross increases. However, the voltage across R_L is reasonably constant over most of the current range until the current limiting point is approached.

In the particular example the voltage drop across the load R_L is approximately 8.5V±0.5 for a current range from 0 to 20 ma. Viewed from a voltage point of view the two-terminal device **10** exhibits some of the characteristics of a voltage regulator. This is not the case when a conventional current limiting resistor is employed. In such a case the voltage to the load drops continuously as the voltage drop across the resistor increases as a function of increased current amplitude. The voltage drop across the load with a 560Ω resistor is represented by line **22.**

Since the novel device of the present invention consists of only two transistors and two resistors, it should be appreciated that it could be packaged into a very small unit. Indeed, it can be packaged into a unit the size of a type 3AG fuse and since it, like a fuse, has only two external terminals, it can be used instead of a fuse with all the attended advantages.

From the foregoing it is seen that by suitable choice of the resistance of R_1, the maximum current amplitude which the device is designed to limit may be varied upwardly or downwardly, as desired. Assuming that the selected transistors and resistors have sufficiently high wattage and dissipation ratings for the intended range of current, R_1 may be a variable resistor. In such a case, the desired maximum current amplitude could readily be adjusted. The range of currents which may be controlled extends from low milliamperes to a few amperes, provided that suitable components, including the transistors and resistors, are chosen for the appropriate wattage and dissipation ratings to meet the current and voltage requirements.

High current limiting capability can be provided by an arrangement as shown in FIG. **5.** Therein, the device **10** is shown including a third transistor Q_3. Q_3 acts as a follower (buffer) to aid Q_2 in controlling Q_1 (Q_1, now being larger or more capable of higher dissipation). In this embodiment, the collector to emitter path of Q_1 is connected in series with R_1 between terminals **11** and **12.** The base of Q_1, instead of being connected to the collector of Q_2, is connected to the emitter of Q_3. R_1, Q_2, R_3 and Q_3 control the flow of current through Q_1 as a function of the voltage drop across R_1 which is directly related to the current amplitude, in a manner similar to the control of the current flow in Q_1 of the previously described embodiment.

Herebefore the device has been described in connection with arrangements for controlling the flow of current from a DC source, such as source **14.** In such arrangements it may be desirable to add a diode to the device in order to protect it from damage, in case it is connected between the source and the load with the wrong polarity. For example in, the embodiment shown in FIG. **1,** in which terminal **11** is the plus or positive terminal, it may be desirable to insert a diode **30,** as shown in FIG. **6.** In this example the diode's anode is connected to terminal **11** and its cathode to both resistor R_2 and the collector of Q_1. Such an arrangement would prevent the destruction of the device in case terminal **11** is connected to the negative terminal of the DC source.

In the embodiment of the device in which terminal **11** is the plus terminal, and terminal **12** the minus (−) or negative terminal, as shown in FIG. **1,** the same protection can be achieved by connecting the cathode of diode **30** to terminal **12** and its anode to R_1 and the collector of Q_2. Clearly, similar protection can be provided by diode **30** in an embodiment with PNP transistors in which case terminal **11** would be the minus terminal and terminal **12** the plus terminal.

Since each of the devices, herebefore described, controls the flow of direct current (DC), it is preferable to mark one end of the device such as terminal **11** in FIGS. **1** and **6,** and terminal **12** in FIG. **5,** as the plus terminal to insure the proper insertion of the device between the source and the load. This is particularly important for those embodiments which do not incorporate a protective diode in order to prevent the destruction of the device. However, even with the protective diode the marking of one terminal is desirable to enable the proper insertion of the device in the circuit with the proper polarity for current flow.

Although herebefore the invention has been described in connection with controlling direct current (DC) from a DC source, the teachings are equally applicable for controlling and limiting alternating current (AC) from an AC source. One embodiment of such a device is shown in FIG. 7 and is designated by numeral **35**. Terminal **11** is shown connected to one terminal of an AC power source **36** and the load resistor R_L is connected between the terminal **12** and the other terminal of source **36**.

Basically, the AC control device **35** consists of two identical units **35***a* and **35***b*, as the one shown in FIG. **6**. The two units are connected in parallel and in reverse polarity or back-to-back between terminals **11** and **12**. That is, of unit **35***a* the anode of diode **30** is connected to terminal **11** and the emitter of Q_2 and resistor R_1 are connected to terminal **12**, while of unit **35***b*, it is the emitter of Q_2 and resistor R_1 which are connected to terminal **11** and the anode of diode **30** is connected to terminal **12**. In operation, during each half cycle when terminal **11** is positive with respect to terminal **12**, the current limiting is controlled by unit **35***a*, while the diode **30** of unit **35***b* is back biased, thereby preventing current from flowing through unit **35***b*. On the other hand, when terminal **11** is negative with respect to terminal **12**, current flows through unit **35***a*.

It should be stressed that the embodiment **35** shown in FIG. **7**, although primarily designed for AC operations, can also be used for DC operation. In the latter case current will flow through either unit **35***a* or unit **35***b*. Since the two provide current flow control in either direction, neither terminal of the device need be marked with a polarity marking. This is true since regardless of the connection polarity of the device in the circuit current will be able to flow in the proper direction through either unit 35a or unit 35b.

It should thus be appreciated that the device **35**, shown in FIG. **7**, provides a selectable current limiting capability for both DC and AC operations. Furthermore, the two-terminal device can be inserted in any circuit irrespective of polarity for fail-safe operation. The device includes only four transistors, four resistors and two diodes all of which can be manufactured with present day integrated circuit techniques to occupy an extremely small volume. Since the device is automatically resettable to enable unimpeded current flow when the current amplitude does not exceed the preselected limit, and the voltage drop across the device is substantially constant until the limit is approached and exceeded, the device represents a significant advance of the state of the art.

The teachings of the present invention may further be expanded to comprise an embodiment such as is shown in FIG. **8**. Therein a single device or unit such as unit **10** of FIG. **1** is associated with four diodes designated **41** through **44**. The four diodes in essence form a bridge connected across terminals **46** and **47**. As connected, when terminal **46** is positive, with respect to terminal **47**, current is conducted through diodes **41**, transistor Q_1, resistor R_1 and diode **44**. However, when terminal **46** is negative with respect to terminal **47**, current conducts through diode **42**, Q_1, resistor R_1 and diode **43**. Numeral **48** designates a common return line.

It should thus be apparent that the arrangement shown in FIG. **8** accepts current of either polarity at either end and is capable of limiting either AC or DC, thereby making the unit truly universal. Since the arrangement shown in FIG. **8** includes only one circuit unit it may be preferred over the arrangement shown in FIG. **7**, since it requires fewer components which is particularly significant from a cost point of view as current and dissipation requirements go up.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art and consequently it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. A two terminal current limiting device consisting of:

first and second terminals;

a first transistor with a base, an emitter and a collector;

a first resistor;

means connecting said first transistor collector to said first terminal, said first transistor emitter to one end of said first resistor and the other end of said first resistor to said second terminal;

a second transistor with a base, an emitter and a collector;

means directly connecting the second transistor base and emitter to opposite ends of said first resistor and the second transistor collector to said first transistor base;

a second resistor; and

means connecting said second resistor between the base-collector junction of said first transistor, whereby when the voltage drop across said first resistor reaches a predetermined value said second transistor is forward biased to vary the bias of said first transistor, provided by said second resistor to limit the current flowing through said first transistor not to exceed a preselected amplitude with the voltage drop across said first resistor not exceeding an amplitude for forward biasing said second transistor.

2. A two terminal current limiting device as in claim **1** including a diode having an anode electrode and a cathode electrode, and means for coupling one of the diode's electrodes to one of said terminals to limit the direction of the flow of current between said first and second terminals to a single direction.

3. A two terminal current limiting device, for limiting the amplitude of current from a source of alternating current to a load between which the device is connected in series comprising:

first and second units each unit including first and second terminals, a first transistor with a base, an emitter and a collector, a first resistor, means connecting said first transistor collector to said first terminal, said first transistor emitter to one end of said first resistor and the other end of said first resistor to said second terminal, a second transistor, means connecting the second transistor collector to said first transistor base, the second transistor base to the first emitter and the second transistor emitter to said first resistor, whereby only the latter is connected directly across the base-emitter junction of said second transistor, a second resistor,

means for connecting said second resistor between the base-collector junction of said first transistor, whereby when the voltage drop across said first

resistor reaches a predetermined value said second transistor is forward biased to vary the bias of said first transistor, provided by said second resistor to limit the current flowing through said first transistor not to exceed a preselected amplitude, said predetermined voltage value not exceeding the value necessary to forward bias said second transistor, and a diode for limiting the direction of current flow between said first and second terminals to a single direction; and

means for connecting the first terminal of said first unit to the second terminal of said second unit at a first junction point and the second terminal of the first unit to the first terminal of said second unit at a second junction point.

4. A current limiting device for limiting the amplitude of alternating current between a source of alternating current and a load not to exceed a preselected amplitude, the device being connectable in series between said source and said load, comprising:

first and second units, each unit including,

first and second terminals, a first transistor having emitter, collector and base electrodes, a first resistor and a diode connected in series with the emitter collector path of said first transistor between said first and second terminals, and control means including a second transistor with its base to emitter junction directly connected across said first resistor and its collector connected to the base electrode of said first transistor for controlling the current flow across the collector emitter path of said first transistor as a function of the voltage drop across said first resistor, said voltage drop not exceeding the value for forward biasing said second transistor; and

connecting means for connecting the first terminal of said first unit and the second terminal of the second unit to a first junction point adapted to be connected to said source, and for connecting the second terminal of said first unit and the first terminal of said second unit to a second junction point, adapted to be connected to said load, whereby said device is connected only between said source and load at said first and second junction points.

5. A two-terminal device to be connected between a source of direct or alternating current and a load for limiting the amplitude of the current passing to the load, the device comprising:

first and second terminals connectable between the source of current and the load, respectively;

a diode bridge consisting of four diodes, each having a collector and an emitter with two of said four diodes having their respective collectors connected to said first and second terminals and their emitters connected together at one of a pair of junctions, and the other two of said four diodes having their respective emitters connected to said first and second terminals and their collectors connected together to the other of said pair of junctions;

a first transistor having a base, an emitter and a collector, said collector being connected to one of said pair of junctions;

a first resistor being connected directly between said emitter of said first transistor and the other of said pair of junctions;

a second resistor being connected directly between said base of said first transistor and said one of said pair of junctions, said first transistor being thereby conductive of current passing between said pair of junctions;

a second transistor having a base, an emitter and a collector, said collector of said second transistor being connected to the base of said first transistor, said base of said second transistor being connected to the emitter of said first transistor and the emitter of said second transistor being connected to said other of said pair of junctions, said second transistor being normally non-conductive until a sufficient current amplitude through said first resistor produces a voltage drop thereacross which exceeds the base-emitter junction potential of said second transistor, whereupon said second transistor becomes conductive to limit the current flowing through said first transistor between said pair of junctions to an amplitude which is determined by the resistance value of said first resistor.

* * * * *