

[54] **SOLID STATE RELAY**

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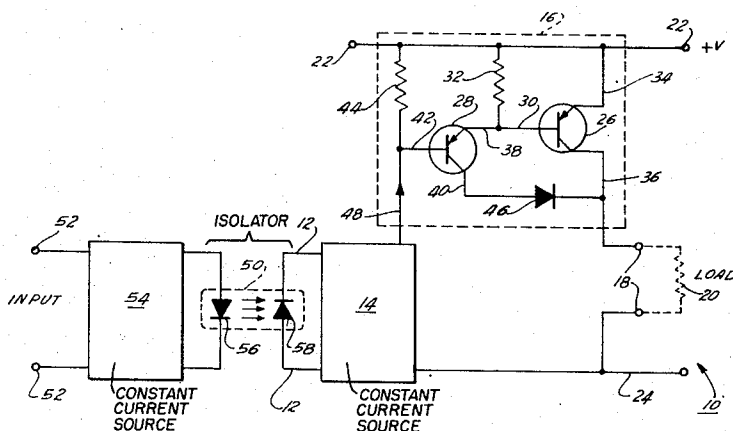
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[57] **ABSTRACT**

A solid-state switching device capable of replacing mechanical relays. When the relay is conducting rated load current, a single saturated transistor carries the current with a very low voltage drop. When the load current rises above a pre-determined level, the load-carrying circuit automatically becomes a modified Darlington circuit, which is capable of carrying substantial overloads without being damaged, and with voltage drops within a desirable range. Optionally, means are provided for disabling the load circuit and, in effect, opening the relay, when a certain level of overload current is reached, thereby turning the device into a circuit-breaker.

11 Claims, 2 Drawing Figures



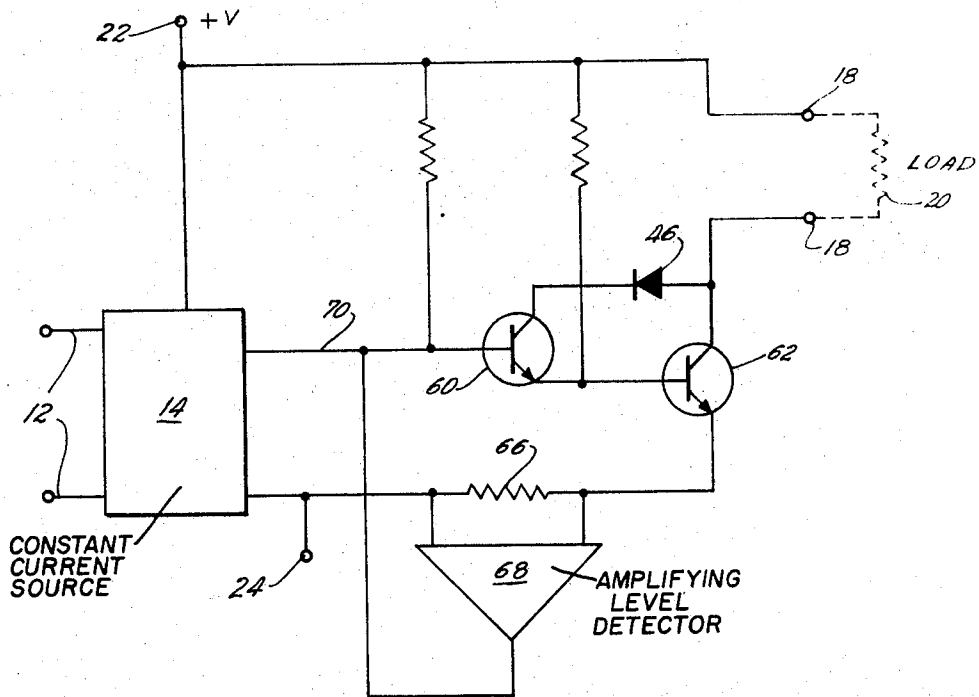
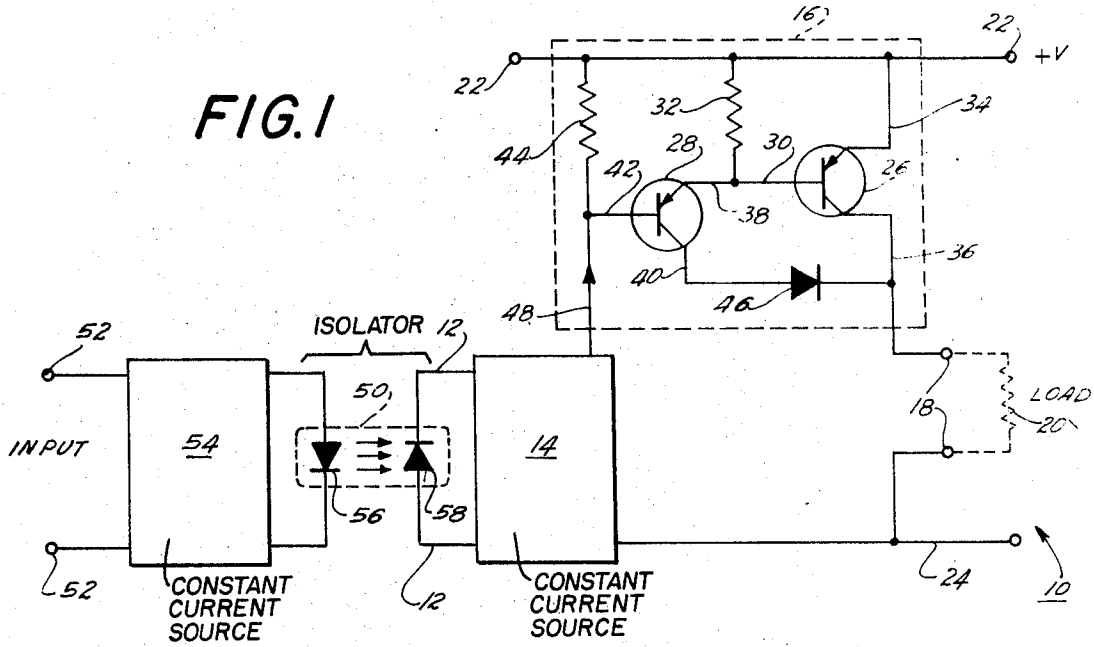


FIG. 2

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SOLID STATE RELAY

The present invention relates to electrical control devices, and particularly to electrical relays and circuit breakers. More particularly, the present invention relates to solid-state switching circuits for replacing the mechanical relays and circuit breakers.

It long has been desired to provide a solid-state circuit device which will satisfactorily replace the mechanical relay. Such a device would have the advantage of having no mechanical contacts to become fouled, and would be more reliable in operation. However, it is believed that prior attempts to provide such a device have met with only limited success. There are various reasons for the limited nature of this success. One such reason is believed to be that many prior devices burn out when excessive load currents pass through them, although the same currents do not burn out mechanical relays. Another shortcoming of such prior devices is that they are relatively large and unreliable, and they produce relatively large amounts of electrical noise. Furthermore, some prior devices are relatively inefficient and have relatively high voltage losses across the relay when in operation.

In accordance with the foregoing, it is an object of the present invention to provide a reliable, light-weight, compact, noise-free and rugged solid-state switching device which is usable in place of mechanical relays. It is another object to provide such a device which will not burn out when operated with rated overload current, which is relatively efficient at normal load currents, and has relatively low voltage losses across it at rated current levels. It is a further object to provide such a device with overload circuit-breaker capabilities.

In accordance with the present invention, the foregoing objects are satisfied by the provision of a multistage semiconductor switching device which provides a very low-impedance path between a load and an electrical source. Only one stage of the device is activated when relatively low (rated) load currents flow through the device, but, when the load current increases above a pre-determined level, the second stage of the device is activated. This enables the device to conduct substantial overload currents without damage, and with voltage drops which are within desired low limits. Preferably, the device operates as a modified Darlington circuit during the overload mode, but operates as a simple saturated transistor switch at lower, rated load levels.

The foregoing objects and advantages of the present invention will be in part described in and in part apparent from the following description and drawings.

In the Drawings:

FIG. 1 is a schematic circuit diagram of one embodiment of the present invention; and

FIG. 2 is a schematic circuit diagram of another embodiment of the present invention.

FIG. 1 shows a solid-state relay circuit 10 which has a pair of input terminals 12, and a pair of output terminals 18. The function of the additional input circuitry to the left of input terminals 12 will be explained below. The input terminals 12 are connected to a conventional constant current generator 14 which supplies constant current over an output lead 48 to a switching circuit 16 which is indicated in dashed outline. A load 20 is connected between the output terminals 18. The switching circuit 16 operates upon receiving a signal for the input terminals 12, to provide a low-impedance path between the output terminals 18 and the terminals 22 and 24 of a direct current power supply.

The switching circuit 16 includes two transistors 26 and 28, a pair of bias resistors 32 and 44, and a diode 46. The emitter lead 34 of the first transistor 26 is connected to terminal 22 of the power supply, and the collector lead of transistor 26 is connected to one of the load terminals 18. The transistors 26 and 28 are connected together to form a modified Darlington circuit. Thus, the base lead 30 of transistor 26 is connected to the emitter lead 38 of transistor 28, and the collector lead 36 of transistor 26 is connected to the collector lead 40 of transistor 28 through the diode 46. But for the presence of the

diode 46, the switching circuit 16 would be an ordinary Darlington circuit. However, the diode 46 changes the operation of the circuit quite significantly.

When an input signal is received at terminals 12, the constant current generator 14 is activated and supplies a constant output current over lead 48 to the first transistor 28. This current turns on transistor 26, and, but for the presence of the diode 46, also would turn on the transistor 28. However, when the transistor 26 is turned on, at relatively low load current levels, the voltage on the collector lead 36 and, hence, the cathode of diode 46, is relatively high; that is, it is relatively close to V , the supply voltage. The voltage on collector lead 40 of transistor 28 is substantially less than the supply voltage, with the result that the diode 46 is back-biased and does not conduct current. Thus, the transistor 28 is disabled and the transistor 26 carries the load current substantially alone. The circuit 16 now is not operating as a Darlington circuit, since the back-biased diode 46 prevents the normal negative feedback which occurs in the Darlington configuration.

During overload conditions, when the load current exceeds a pre-determined level, the voltage on the cathode of the diode 46 drops to a relatively low value and eventually drops below its anode voltage so that it now conducts negative feedback current. Under these conditions, the circuit 16 now is operating as a Darlington circuit which is capable of withstanding substantially greater overloads without burn out than would the transistor 26 alone. In this mode of operation, the transistor 26 operates in a different region of its characteristic curves than it did when the diode 46 was back-biased. The result is that the transistor 26 still operates within its saturation range so that it still presents low impedance to the flow of the current through it. Thus, the voltage drop across the solid-state relay 10 is maintained at a consistently low level, one commensurate with the voltage drops usually experienced with mechanical relays.

The portion of the circuit to the left of the input terminals 12 provides conductive isolation of two further input leads 52 from the remainder of the relay circuit. This portion of the circuit, which is optional, therefore serves to replace the solenoid or coil of an ordinary mechanical relay, without sacrificing the conductive isolation provided by such a coil.

Isolation is provided by a conventional photoncoupled isolator circuit 50, which consists of a gallium arsenide light-emitting diode 56 which delivers light to a photo-diode 58. An example of one such device is the HP 4310 isolator which is sold by the Hewlett-Packard Corp. Another constant current generator circuit 54 is provided to supply current to the diode 56. When input signals are received at the terminals 52, the circuit 54 supplies current to the diode 56, which emits and shines light on the diode 58, causing it to become conductive and send a signal through the terminals 12 to the constant current source 14. This causes the relay circuit 10 to operate in the manner described above. The circuit 50 thus provides conductive insulation of the input from the output terminals 18.

The transistor 26 should be selected so that it has current gain (β) values which are fairly constant over a reasonably broad range of currents. That is, the current gain should be relatively steady from "rated" to "overload" current values. For example, one transistor which has been tested and found to be satisfactory for a rated load of 1 amp and an overload of 10 amps is the Motorola 2N 4398 "high-power" PNP silicon transistor. Similarly, the Motorola 2N 4918 "medium-power" plastic PNP silicon transistor has been used successfully as transistor 28. The 2N 4398 transistor has a very low "on" or saturation resistance at 1 ampere. By the use of the present invention, a similarly low saturation resistance at overload current also is provided.

The diode 46 should have as small a forward voltage drop as possible. A diode which has been tested successfully is the UTX-210 diode which is sold by Unitrode Corporation.

In a circuit using the components specified above, and with a supply voltage V of 20 volts, a voltage drop of less than 100 millivolt was measured across the emitter-collector path of the

transistor 26 when rated load current of 1 ampere was flowing. At 10 amperes load current the voltage at the same location was 1.8 volts. Both of these voltage drops are substantially identical to the voltage drops across the contacts of a typical mechanical relay having the same load ratings. Moreover, the overload current of 10 amperes was sustained for substantial periods of time without burn out and without approaching the condition of thermal run-away which would cause burnout.

The alternative embodiment shown in FIG. 2 is identical to that shown in FIG. 1 except that the input isolation circuit is omitted, and NPN transistors 60 and 62 replace PNP transistors 28 and 26, respectively (with reversed emitter-collector connections, of course.) In addition, a circuit-breaking function is provided by a circuit 68 which is a conventional amplifying level detector with a latching output. Detector circuit 68 detects the voltage drop across a very small (e.g. 0.05 ohm) resistor 66 which is connected in series with the load. When the voltage across resistor 66 exceeds a pre-determined value, indicating the flow of a load current above a desired limit, the detector 68 supplies a current to the base lead 70 of transistor 60 in a sense opposing the base drive current flowing in lead 70, thus turning off transistors 60 and 62 and "opening" the relay. The output of the detector circuit 68 latches in its new condition until it receives a reset signal, or until the input signal is removed from the circuit. Thus, a convenient, safe relay with an integral circuit-breaker function has been provided.

The switching circuit portion of the circuit shown in FIG. 2 operates in the same manner as the circuit 16 shown in FIG. 1, except that the connections of the load to the transistors are reversed, in the manner shown in FIG. 2.

The solid-state relay of the present invention has numerous advantages. First, unlike some prior devices, it does not produce significantly large amounts of electrical noise. Furthermore, the relay has voltage drops across its output terminals which match those of ordinary relays having the same ratings. Also, the relay does not easily burn out due to sudden overload, thermal run-away or other effects. Additionally, the circuit is relatively simple and inexpensive to fabricate, it is compact, electrically efficient, relatively lightweight, and it is reliable. Other advantages have been explained above, and will be evident from the foregoing description.

The above description of the invention is intended to be illustrative and not limiting. Various changes or modifications in the embodiments described may occur to those skilled in the art and these can be made without departing from the spirit or scope of the invention.

I claim:

1. A relay device comprising output terminal means, semiconductor means for selectively providing a very low impedance path between said load terminal means and an electrical source, said semiconductor means comprising a current amplifier having at least two stages, means for selectively enabling said current amplifier, and means for selectively disabling at least one stage of said current amplifier in response to the flow of relatively low-level load currents to said load terminal means.

2. A relay device as in claim 1 in which said current amplifier forms a substantially saturated semiconductor switch when said one stage is disabled.

3. A relay device as in claim 1 in which said current amplifier comprises a Darlington amplifier during the flow of relatively high-level load currents to said load terminal means.

4. A relay device as in claim 1 including a constant current source for supplying bias current to said current amplifier.

5. A device as in claim 1 including circuit-breaker means for selectively disabling both of said stages in response to the flow of load currents above a pre-determined level.

6. A switching device comprising output terminal means, a Darlington amplifier circuit for providing a very low impedance path for connecting said output terminal means to an electrical source, means for enabling said amplifier circuit in response to an input signal, and means for selectively disabling one stage of said amplifier circuit when the flow of current to said output terminal means is below a pre-determined minimum value.

7. A device as in claim 6 in which said Darlington amplifier circuit includes a driver stage and a second stage, each stage including a transistor, the emitter-collector path of said second-stage transistor being connected between said output terminal means and a terminal for said source.

8. A device as in claim 7 in which said disabling means comprises unidirectional conduction means connected between the collector leads of said transistors and adapted to conduct only when the load current through said device rises to a pre-determined value.

9. A device as in claim 6 including circuit-breaker means for selectively disabling both of said stages in response to the flow of load currents above a pre-determined level.

10. A device as in claim 6 including isolator means at the input of said device for conductively isolating said input from said output terminal means.

11. A device as in claim 10 in which said isolator means comprises a light-emitting diode positioned to shine light on a photo-diode when said light-emitting diode is energized by an input signal.

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