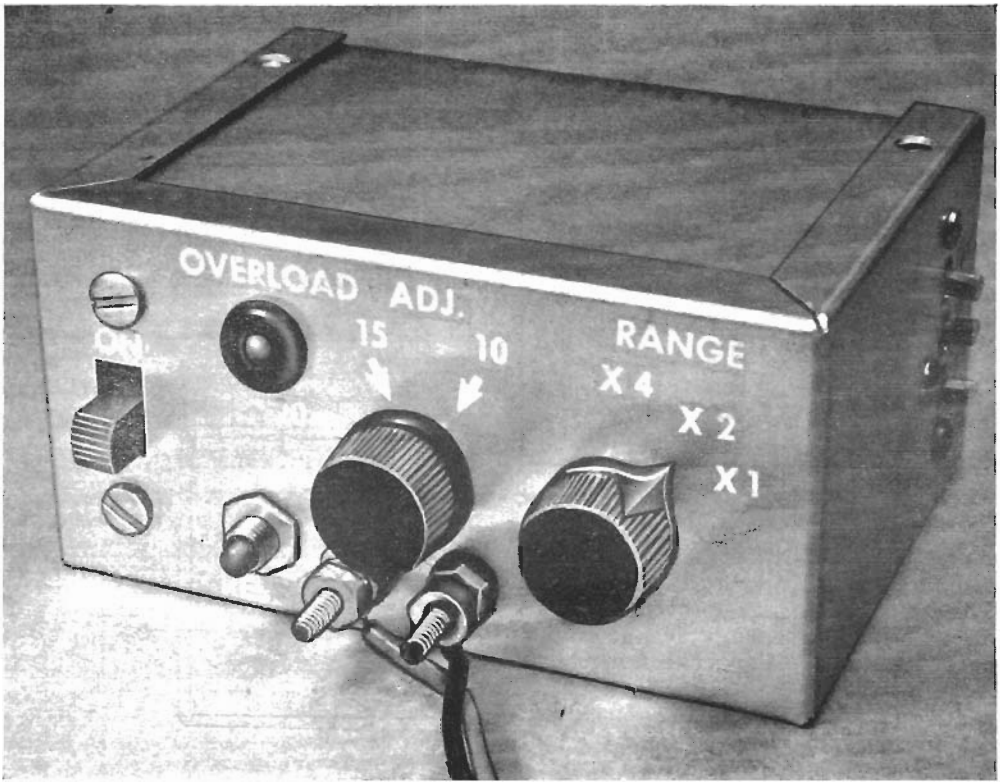


ELECTRONIC

Overload Protection

CURRENT LIMITER FOR YOUR SEMICONDUCTORS

BY JOHN L. KEITH

ELECTRONICS experimenters are finding more and more uses for the latest microminiature solid-state devices—and with good reason. These components simplify circuit design and construction, making it possible for the experimenter to build projects that were formerly too complex and expensive to duplicate. There is one great care the experimenter must exercise, however: most semiconductor devices are extremely current sensitive. Exceed the rating just a little bit, and the device may be permanently damaged. To prevent such occurrences, try the electronic overload protector described here.

When connected between the power supply and the experimental circuit, the overload protector automatically limits the current drawn by the circuit to a value consistent with the known ratings of the semiconductor devices you are using.

The protector, whose circuit is shown in Fig. 1, operates on the principle of a shunt current meter. The load current must flow through one of the range resistors, *R8-R10*. The voltage drop across the resistor is then applied through potentiometer *R11* to the base of *Q1*. The use of *R11* makes each range continuously variable.

With no overload condition, *Q1* conducts slightly, allowing *Q2* to conduct

PARTS LIST

D1,D2—1N34A diode
D3—1N2096 diode
I1—#327R incandescent pilot lamp (28 volts at 40 mA)
K1—S.p.d.t. relay, 5500-ohm at 2.9-mA winding
Q1,Q2—2N508 transistor (see text)
R1—680-ohm
R2—220-ohm
R3,R5—220,000-ohm
R4—82,000-ohm
R6—9100-ohm
R7—10,000-ohm (see text)
R8—20-ohm
R9—10-ohm
R10—5-ohm
All resistors ½-watt
R11—5000-ohm linear taper potentiometer
S1—S.p.s.t. slide or toggle switch
S2—Momentary-action, push-to-close switch
S3—Three-position, non-shorting rotary switch
7—Five-way binding posts or banana jacks for contacts 1 through 7
1—metal utility box
Misc.—Rubber grommet for I1; hardware; hook-up wire; solder; etc.

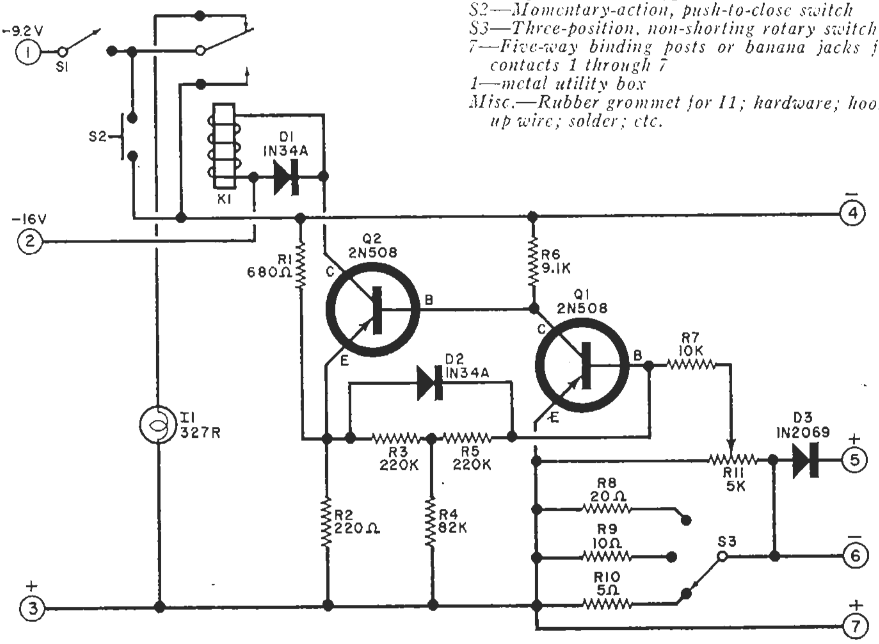
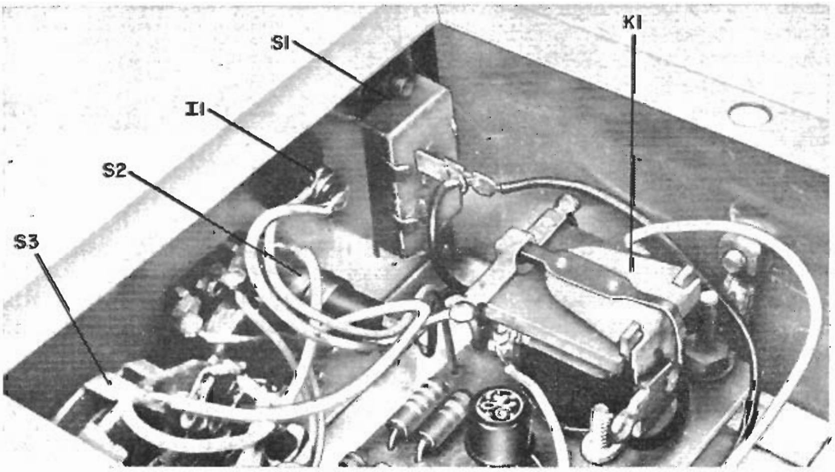


Fig. 1. Input power is applied via contacts 1 and 2; separate 16-volt supply for K1 via 2 and 3; load via 4 and 5. Load current is measured as voltage drop between 6 and 7 and converted to current with Ohm's Law.

Switches S1-S3, potentiometer R11, and indicator lamp I1 mount directly to front panel of utility box. Load connectors, also on front panel, can be five-way binding posts.



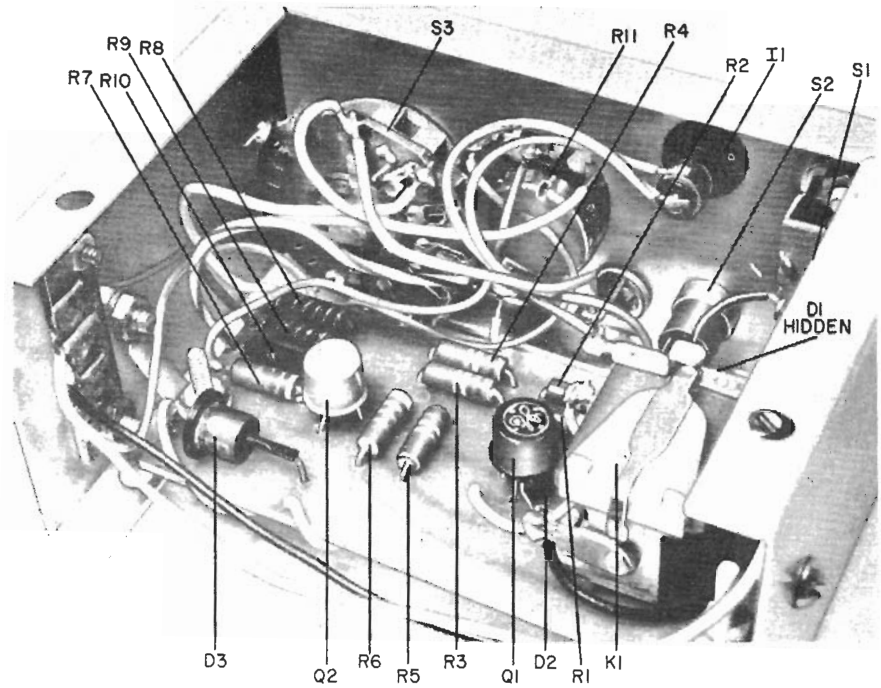


Fig. 2. Although printed circuit board construction is shown, circuit is simple enough to be assembled with point-to-point wiring. Terminal strip at left is for power inputs.

heavily and energize relay *K1*. Emitter-to-base negative feedback is used as temperature compensation.

When an overload occurs, *Q1* becomes forward biased, lowering the *Q2* bias and deenergizing *K1*. This action disables the output circuit. Then when reset switch *S2* is momentarily depressed, bias is restored to *Q1*, *Q2*, and the output. If the overload still exists, *Q2* will remain cut off, and *K1* will not energize. But if the overload is removed, *Q1* conducts and energizes *K1* when *S2* is depressed.

The three ranges chosen provide accurate current control in steps of 10-25 mA, 20-50 mA, and 40-100 mA at 9 volts d.c. Also provided are connections for measuring the voltage drop across the range resistors (contacts 6 and 7). This voltage can be converted, by Ohm's Law, to current and indicated on a graph.

Although designed for 9-volt operation, the overload protection circuit can be used with other input voltages to provide corresponding output voltages. Just be sure to take into account the change of current flowing through the range resistors with the new voltage.

The construction and layout of the electronic overload protection circuit are not critical. While the original prototype shown in Fig. 2 was assembled with the aid of a printed circuit board, the circuit is simple enough to permit point-to-point wiring. Almost any general-purpose transistor should work satisfactorily, provided that the one employed as the shunt amplifier has high enough gain, and the transistor for relay control has a VCBO of 16 volts or more. If the transistor (*Q2*) gain is too low, the value of *R7* might have to be reduced to 4700 ohms.

VOLTAGE TO CURRENT RELATIONSHIPS

	RANGE SWITCH POSITION		
VOLTS	A	B	C
0.2	10 mA	20 mA	40 mA
0.3	15 mA	30 mA	60 mA
0.4	20 mA	40 mA	80 mA
0.5	25 mA	50 mA	100 mA

For your convenience, the table gives the voltage-to-current specifications for the three settings of range switch *S3*. This table can be cut out or copied and pasted to the enclosure. -30-

Low-loss shunt protects high-current supplies

by Roy Hartkopf and Ron Kilgour
Alphington, Victoria, Australia

The usual method for providing short-circuit protection in low-voltage, high-current power supplies is to employ a current-sensing resistor in series with the load. Unfortunately, this scheme develops an appreciable voltage drop across the resistor when large currents flow and may consequently reduce the available output voltage to a great degree. The voltage drop can be virtually eliminated with an alternative method, shown here, which uses an audio transformer and a single-turn winding to sense the overcurrent condition at the secondary of the supply's power input transformer. Besides being inexpensive, the current sensor will react faster to overloads than some of the more conventional circuits.

As shown in the figure, current protection may be secured for a typical 27-volt, 20-ampere supply by winding a single turn of 10-gauge wire, which is placed in series with the power transformer's secondary and the supply's rectifier bridge, onto a small audio transformer connected in the control section of the supply. During normal operation, transistor Q_1 will be saturated because current is delivered to its base from the 27-v supply line. Note that the secondary of the audio transformer, in conjunction with diode D_1, will contribute a relatively small negative voltage at the summing junction of P_1.

Should the current demands increase, however, the magnitude of the negative voltage developed at the audio transformer's secondary will increase and, consistent with the setting of potentiometer P_1, pull the base-to-emitter voltage down to cut off Q_1. The 2N2646 unijunction transistor will then turn on and trigger the silicon controlled rectifier, and the control signal will be brought low. Thus this signal can be used to cut off the supply. This action will be instantaneous, occurring on the first overload cycle. ☐

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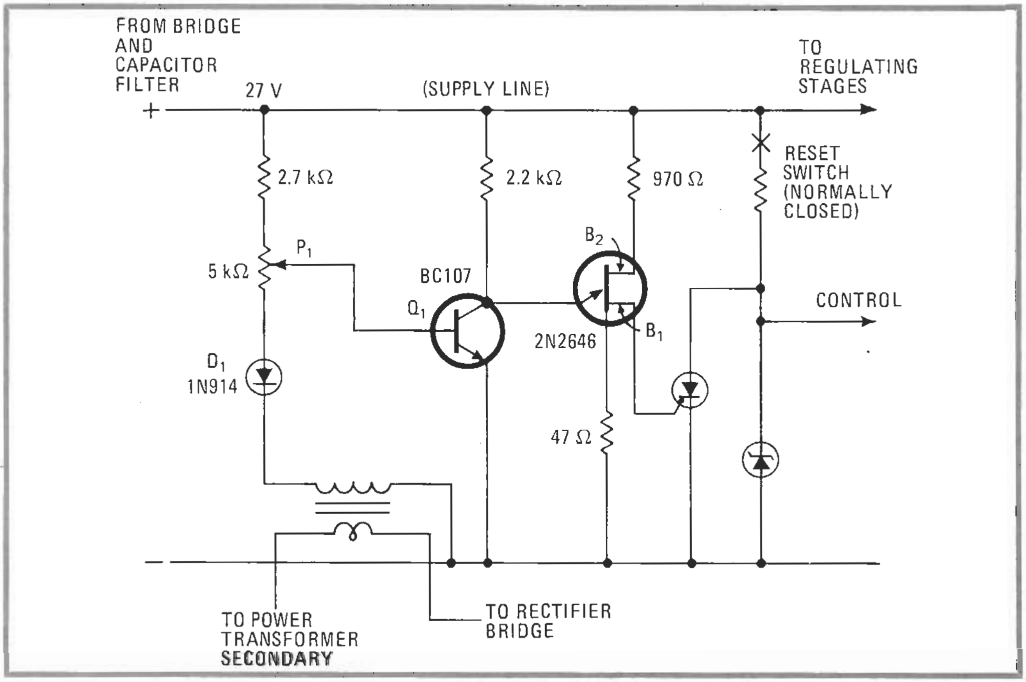


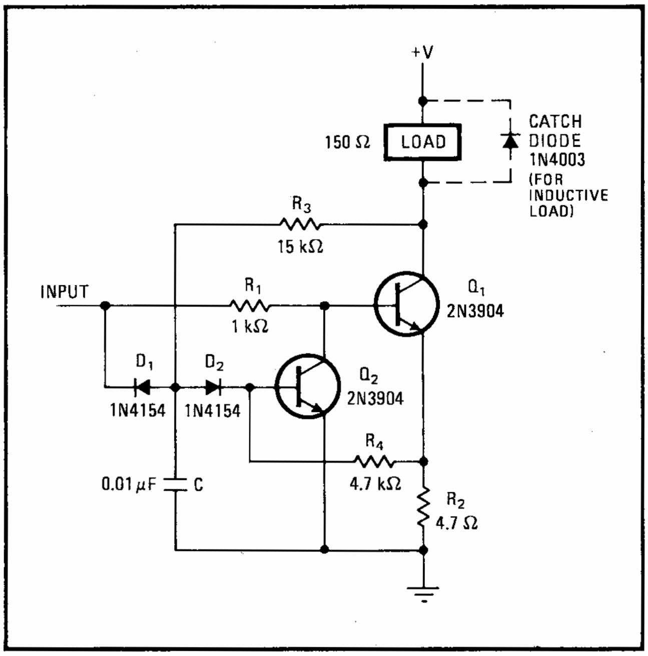
Current gauge. An audio transformer and a single turn of heavy-gauge wire, placed between input transformer's secondary and rectifier, give high-current supplies overload protection without introducing input-to-output voltage drop that occurs with units employing current-sensing resistors. Potentiometer P_1 sets the overload point. Overload detection is instantaneous, occurring on the first positive cycle of input voltage.

Current and power limiter protects switching transistor

by R.M. Stitt
Burr-Brown Research Corp., Tucson, Ariz.

Although a switching transistor dissipates little power in normal operation, it must be protected from destructive current and power overloads. Current-limiting alone is not sufficient protection; power-limiting is also necessary. But fortunately, a few components can be added to conventional current-limiting circuitry to provide power-limiting. A voltage rise across a transistor is sensed and used to cut down the drive current.

To understand why current-limiting alone fails to provide adequate protection, consider a switching transistor controlling a 100-ohm load connected to a 100-volt supply. The power dissipated in the load might be about 100 watts, but the maximum power dissipated in the transistor is merely the load current times the transistor's saturation voltage (if switching losses are neglected). The load current is about 1 ampere, so the transistor dissipates less than 1 W. A designer might use a 3-W device and provide a current-limiting level of 1.5 amperes.



Two-way protection. Switching transistor Q_1 is protected against excess current and/or excess power dissipation. If load current approaches limit, IR_2 drop turns on transistor Q_2 to shunt base drive from Q_1. A voltage rise across Q_1 acts through R_3 to turn on Q_2 and turn off Q_1. Capacitor C provides delay that allows Q_2 to saturate with each new cycle, and lets power-limiter ignore transient high currents. Diodes D_1 and D_2 reset power-limiter when input is low.

Suppose, however, that the load is short-circuited so that the collector of the switching transistor is connected directly to the 100-V supply. Then the transistor dissipates 150 W, which destroys it.

To prevent this destruction, a power-limiter is required. Power-limiting can be added to a standard current-limiter by use of only four simple components. In Fig. 1, Q is the switching transistor, and the conventional current-limiter is formed by Q_2, R_2, and R_4. The power-limiter consists of capacitor C, diodes D_1 and D_2, and resistor R_3. To illustrate the operation of the circuit, assume that Q_1 is saturated and in normal operation. As the load current increases, the voltage drop across R_2 increases, turning on transistor Q_2 and thus shunting drive current away from the base of Q_1. Therefore, Q_1 begins to come out of saturation, so its collector voltage rises. This voltage across Q_1 further turns on Q_2 through R_3 and regeneratively turns off Q_1.

Diodes D_1 and D_2 form a switch so that the collector voltage of Q_1 is sampled only when its input is high. This switch also resets the power-limiting circuitry with each cycle of the input. The value of capacitor C is chosen to give the power-limiting portion of the circuit a turn-on delay, allowing time for Q_2 to become saturated. This delay also permits higher current transients to flow during switching, such as those that might occur in a switching regulator in which the catch diode must be discharged during each cycle.

The current-limiting portion of the circuitry is active at all times, protecting the switching transistor from current overloads. The circuit was set up to be driven by a TTL-level signal and to switch a 100-mA load at 400 Hz to +15 V. The protection circuit can easily be modified for nearly any input and output configuration. If a pnp-transistor switch is to be protected, transistor Q_2 should also be a pnp, and the polarities of D_1 and D_2 should be reversed. □

Two diodes protect logic-level translator

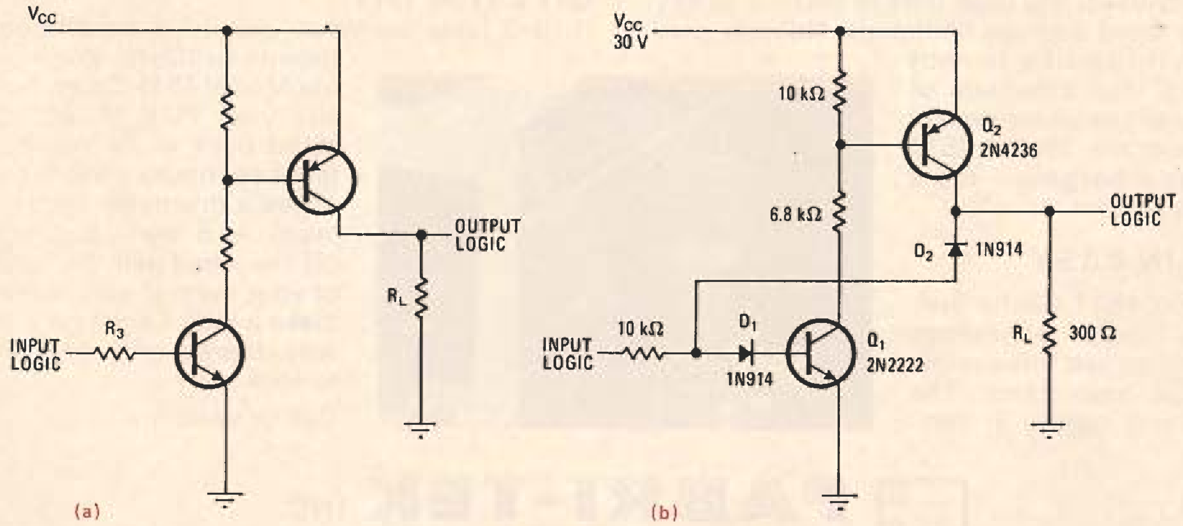
by P. R. K. Chetty
Indian Scientific Satellite Project, Bangalore, India

A level translator is used to interface between two circuits that operate at different logic levels. But the translating transistor (or level-up transistor) is often burned out when its load is accidentally short-circuited to ground. The addition of two diodes to the conventional level-up circuit can protect the transistor. Even a transistor that operates at 30 volts (as well as those meeting lower voltage requirements) can be safeguarded by the circuit modification described here.

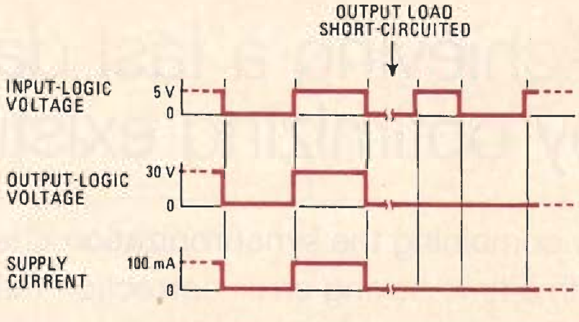
The conventional translation circuit (or logic level-up circuit) is shown in Fig. 1(a), and a modified version with two protection diodes added is shown in Fig. 1(b). The component values shown are chosen to provide a normal load current of about 100 milliamperes. In normal operation, when the input logic is high (logic 1), diode D_1 is forward-biased; Q_1 is turned on, and therefore Q_2 is turned on. Diode D_2 is reverse-biased, so the output-logic voltage across the load is nearly V_{CC}. When the input logic is low (logic 0), the transistors are turned off, and the output logic is zero.

If the output load is shorted to ground when the input is a logic 1, the anode of D_1 is above ground only by the amount of the forward-voltage drop through D_2. This voltage is not great enough to let Q_1 conduct because a voltage of at least two diode drops, V_{D1} and V_{BE}, would be required to turn on Q_1. Therefore Q_1 is turned off, and, as a result, transistor Q_2 is turned off too, which prevents it from conducting a destructive current straight to ground. The circuit remains shut down as long as the load is short-circuited, and it returns to normal operation when the short is removed.

Levels of input-logic voltage, output-logic voltage, and current from the high-voltage supply are shown in Fig. 2 for both normal operation of the circuit and the short-circuited-output condition. No current is drawn from the V_{CC} supply while the load is grounded. ☐



1. Protection. Conventional logic-level translator shown in (a) is modified by addition of two diodes in (b). Diodes protect translation transistor Q_2 from destructive current that would otherwise flow if load resistor were short-circuited. Diodes turn off both transistors, so no current is drawn from supply while load is shorted. In normal operation, load current of about 100 milliamperes is unaffected by diodes.



2. Waveforms. During normal operation of the logic-level translator, the output voltage and the current from the V_{CC} supply go on and off as the input logic goes high and low. If output load is short-circuited, diodes turn off transistors so that no currents flow.

Resettable electronic fuse consists of SCR and relay

by Russell Quong
Palos Verdes, Calif.

Most direct-current power supplies rely on a circuit breaker, current-sensing circuit, or fuse for current-overload protection, but this simple resettable-fuse circuit has advantages over all three. Built around a silicon controlled rectifier and a line relay, it is faster than a circuit breaker, less complex than most current-sensing circuits, and never in need of replacement.

How the circuit operates is evident from (a). Momentarily depressing S_1 closes the relay so that current flows from the supply to the load. In normal operation, the voltage across points PQ will be equal to the nominal supply voltage, and the normal operating voltage will appear across the relay winding. The relay and resistor R_2 are selected according to the dc supply voltage used and the relay's rated coil voltage, respectively.

Excessive current to the load causes a voltage drop across R_1 greater than 0.65 volt and switches on the SCR. The anode-to-cathode voltage of the SCR in the conducting region is approximately 2 v. This voltage, also across the relay coil, is far below the relay's holding voltage. Consequently, the relay opens, disconnecting the load from the supply. The relay may be reset by depressing S_1 again.

If a variable threshold point for SCR switching is desired, the SCR's gate can be connected to R_1 through potentiometer R_3. Resistor R_1 is calculated as before. ☐

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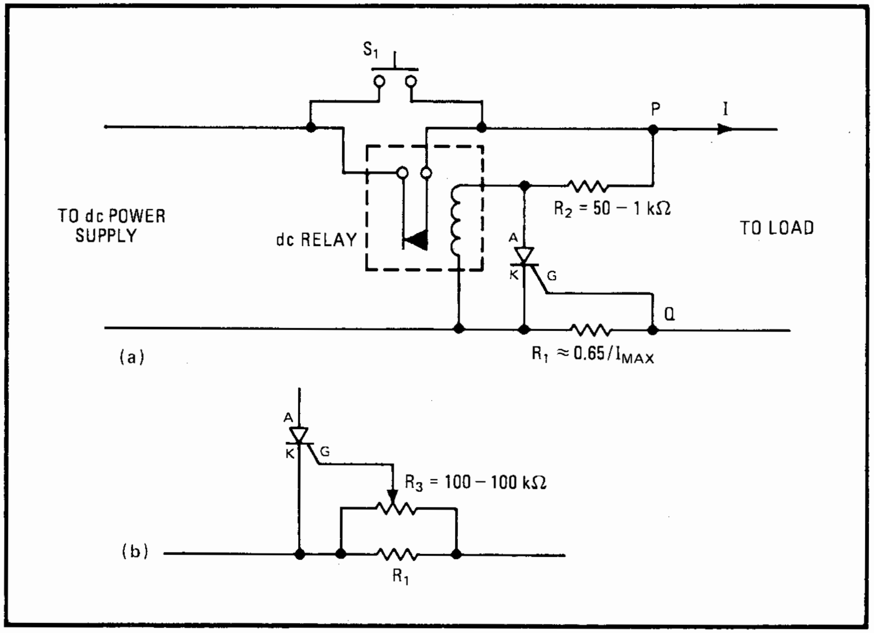


Electronic fuse. SCR and relay form resettable fuse for dc power supplies. When I_{max} is reached, SCR turns on, opening relay and disconnecting power from load. Depressing S_1 reinitializes circuit (a). SCR switching point may be adjusted with R_3 (b).

Voltage regulator protects logic pull-up transistors

by Stephen F. Moore
Resdel Engineering Corp., Arcadia, Calif.

A monolithic three-terminal voltage regulator and a Norton-type operational amplifier can provide excellent short-circuit protection—particularly for the transistor that's providing active pull-up at the output of a logic circuit.

All too often, transistors operated in this way are destroyed when the logic output is inadvertently shorted to ground. Sometimes, too, protecting these transistors is further complicated because the logic must be run at 28 volts. An easy solution would appear to be a current regulator. But most current limiters have one of two drawbacks—either they introduce an unacceptably large voltage drop, or they create excessive heat in biasing resistors.

A monolithic three-terminal voltage regulator, however, has neither defect. When the regulator is not overloaded, the voltage drop across the device is only about 1.5 V. When it is overloaded, the heat it creates remains within an acceptable range. Usually, the highest output voltage that one of these regulators can supply is 24 V. But, if the device's ground terminal is biased at 2 V (depending on the manufacturer's recommendations), the output of a 24-V regulator can be increased to 26.5 V.

When connected as shown, the regulator provides current limiting in two ways. Through its internal circuitry, it acts as a surge-current limiter of about 2 amperes. It also operates as a thermal-current limiter that reduces that output voltage when the current demand becomes excessive. This keeps the power dissipated in the regulator from exceeding the maximum allowable limit. Here, the thermal-current limiting will start at around 400 milliamperes.

Limiting the current available for the active-pull-up transistor will prevent the transistor from being destroyed as long as it is kept in saturation or in cutoff. A Norton amplifier allows both these conditions to be met—its current-sinking capability is greater than 30 mA, and it has an active pull-up in its output circuit. Because of the voltage drop across the regulator, this active pull-up creates a reverse bias on the transistor being protected, eliminating the need for the transistor's pull-up resistor. Also, a Norton amplifier will work reliably with a single-ended power supply at, as well as above, a supply voltage of 28 V.

The diode at the output of the circuit protects the transistor from overvoltages. For example, this diode will guard against an overvoltage caused by an inductive kickback that could forward-bias the base-collector junction of the transistor. ☐

Guarding against short circuits. An IC voltage regulator and a Norton amplifier keep this active-pull-up transistor from being permanently damaged if the input logic signal is mistakenly shorted to ground. The regulator provides both surge-current limiting and thermal-current limiting. The Norton amplifier keeps the transistor either fully saturated or fully cut off, and the output diode protects against overvoltages.

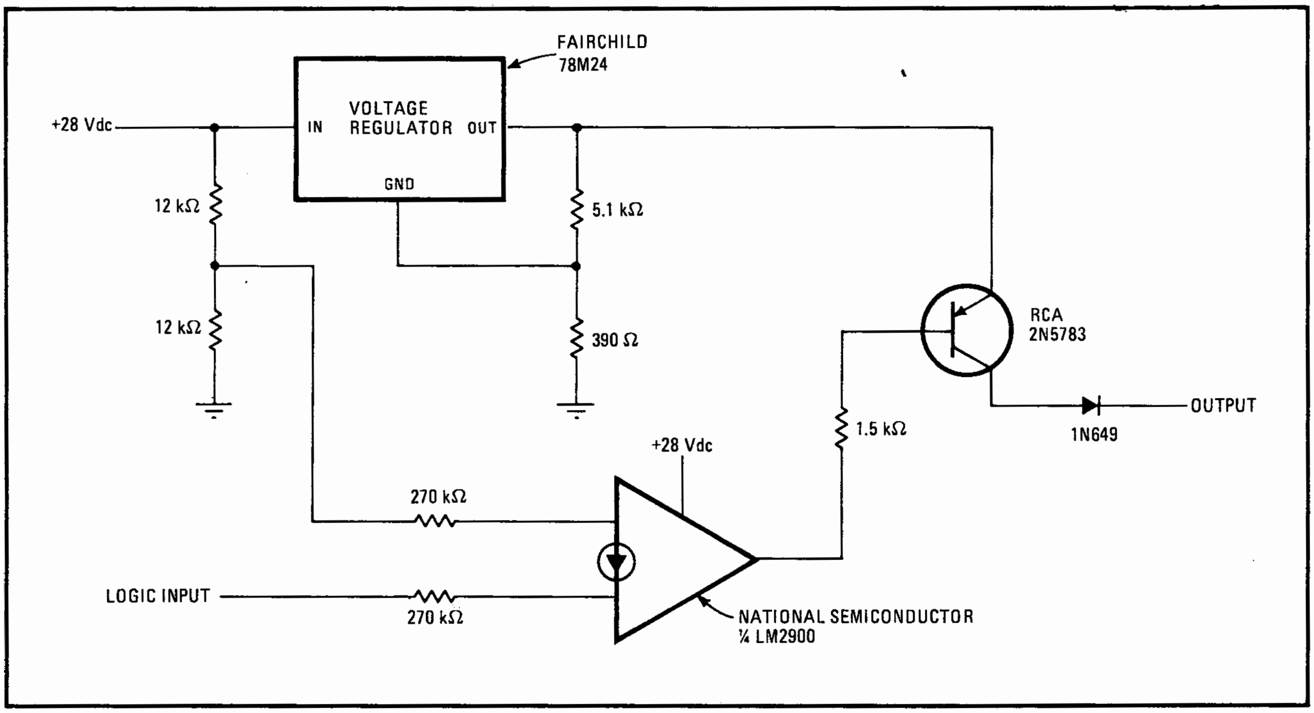
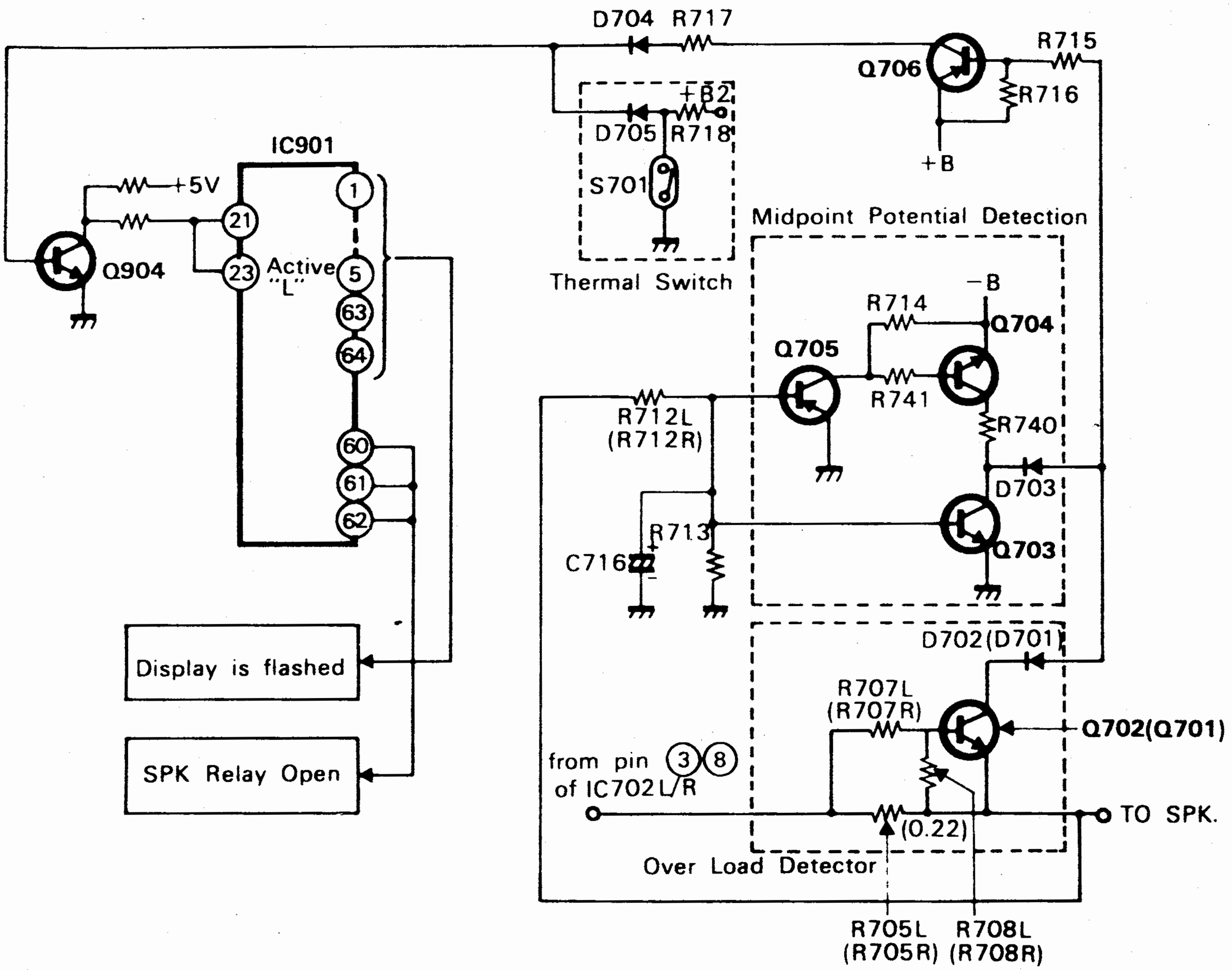


FIG. C4-1 OUTPUT PROTECTION BLOCK DIAGRAM



Current Protection
from a VCR

DESIGNERS NOTEBOOK

Overcurrent protection circuit is fast, fuseless

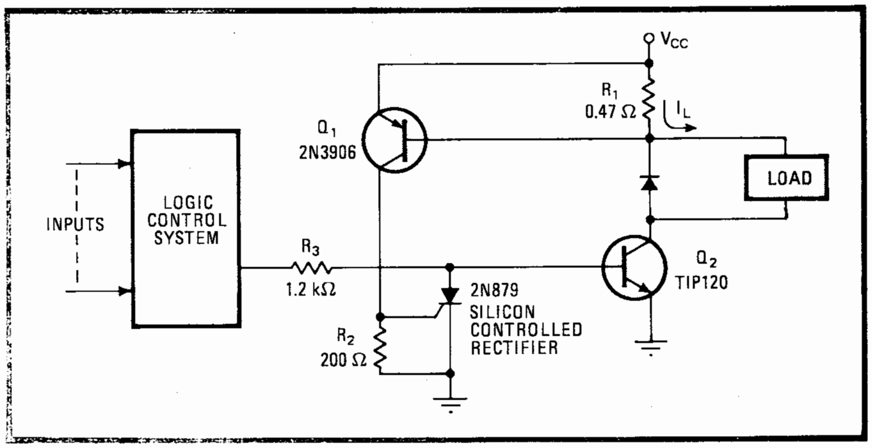
by Michael Maranzano, Engineering Manager
Locknetics Security Products, Hamden, Conn.

When loads are driven by power transistors, adequate overcurrent protection must be provided to prevent damage to the transistors. Fuses may be too slow to react compared to the I_t of the transistor.

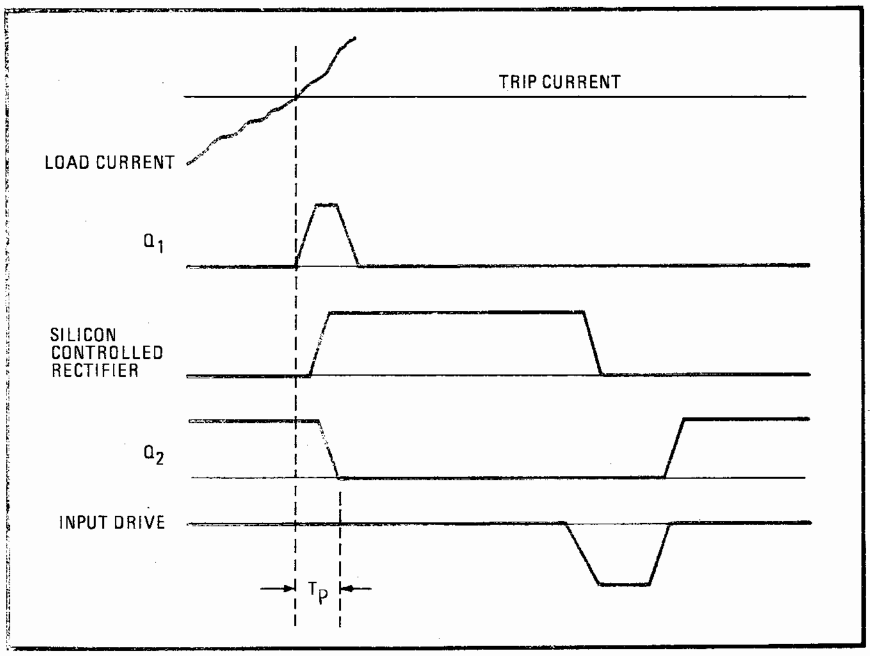
The circuit in Fig. 1 overcomes this difficulty by sensing the overcurrent and quickly grounding the power device's base to turn it off. The timing diagram in Fig. 2 shows the operation of the circuit. The output load current rises at an arbitrary rate until the voltage drop across R_1 turns transistor Q_1 on. The collector current now raises the voltage on the gate of the silicon controlled rectifier and fires it. When the SCR turns on, it shunts the base of Q_2 to ground and interrupts the current through R_1. Transistor Q_1 now is turned off. The SCR remains on as long as there is an input drive applied to base resistor R_3. By removing the input, the SCR turns off and the circuit is reset.

When the input is restored, the circuit will go through the cycle again if the output is still shorted or overloaded. It turns off in less than 10 μs after the trip current is reached. The value of R_1 determines the value of the trip current. The turn-off time depends on the transistors and the SCR's parameters.

There are two primary advantages of this design: No components need be replaced, and no separate reset buttons are required to restore power after a short or overload. By acting on the control logic to reenergize the load, the protection circuit resets and is ready to power the load again upon a new command. Resistor R_3 must be chosen so that it can provide enough holding current to keep the SCR on after it has fired. It also must be able to supply enough base current to drive Q_2 into saturation. This is especially important when the output device is a Darlington pair that requires little base current to enter saturation. This current must be larger than the holding current of the SCR, but its magnitude is not critical for good operation. Resistor R_2 is not critical either, provided it can raise the gate of the SCR above the triggering level. ☐



1. Protection circuit. Normally, Darlington power transistor Q_2 is on, providing load current. The logic-control system should provide a higher voltage than Q_2 requires for a good noise margin against transients. R_1 is chosen to vary the trip current. The diode protects against back electromotive force.



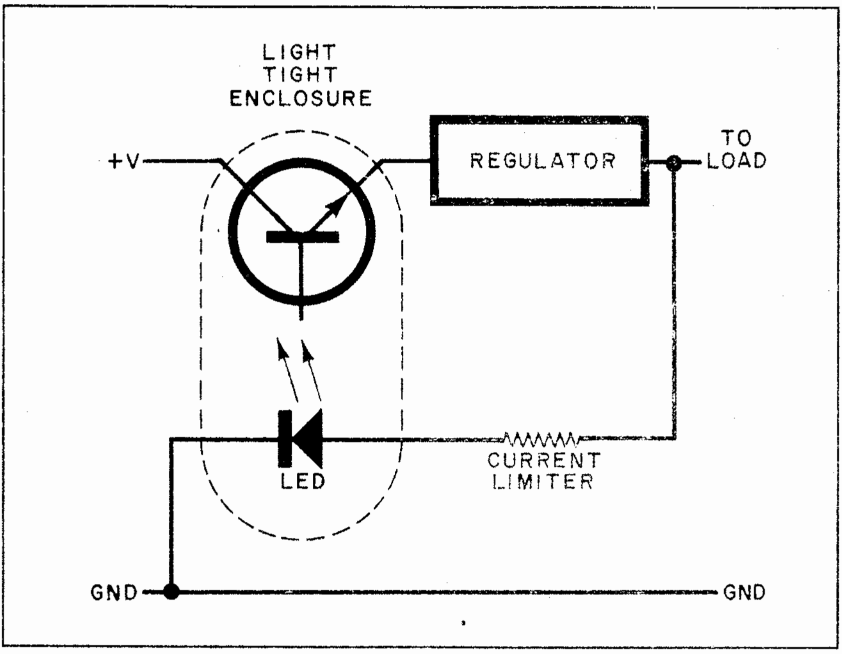
2. Timing it right. Transistor Q_1 turns on when the trip current is reached. The silicon controlled rectifier will fire when the gate reaches its threshold voltage, thereby shunting the base of Q_2 to ground. With Q_2 turned off, the current is interrupted through R_1. Interval Tp is the trip time.

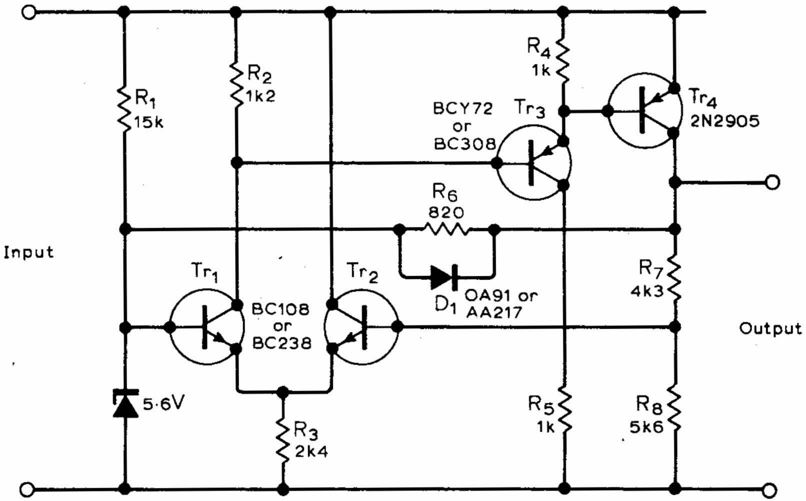
Protection Circuit. Being an avid dabbler in hardware, I have created my fair share of accidental short circuits. To save the cost of replacing relatively expensive voltage regulators and power supplies when I make such mistakes, I have recently concocted an automatic power-down protection circuit. A schematic is shown in the accompanying diagram.

The circuit is faster than a fuse and automatically "resets" itself when the short is removed. The normal regulated dc input line is opened, and a phototransistor or photoresistor (any type that can handle the current) is connected in series with the source and regulator. Between the output of the regulator (which can be almost any desired voltage) and ground is a LED and an associated current-limiting resistor, whose value depends on the dc voltage being monitored. The LED is placed physically close to the surface of the photosensitive device and the two are covered by a layer of black electrical tape to form a light-tight enclosure. As long as the regulator is delivering its rated output, the LED glows and causes the photo device to have a low resistance. Full current is thus allowed to flow.

If, for any reason, a short circuit occurs on the output side of the regulator, the LED goes dark, the resistance of the photo device increases, and the regulator shuts off. When the short is removed, the LED glows, and the regulator resumes operation.

Like most of the circuits I have discussed in this column, this one is basic, and the reader is urged to experiment with it. For example, if your power requirements are more than a simple photo device can handle, use a high-power npn transistor whose base is driven by the photo device, which, in turn, is controlled by the LED. In fact, not even the regulator is required since this protection circuit can be used as "plain vanilla" in series with the power lead. Once you get the idea of how the thing works, it's simple. So why not try your ideas.◇





Germanium diode for regulator protection

Power regulator protection is a perennial problem and this circuit offers a simple and economical solution. Under normal conditions, D_1 is reverse biased by the voltage across R_6 and does not affect the regulator operation. When the output is shorted, however, D_1 turns on and draws current through R_1 which removes the reference voltage across the zener diode. Because D_1 is a germanium type, Tr_1 is held off which also turns Tr_3 and Tr_4 off. When the short is removed, the circuit recovers and resumes normal operation.

D. E. O'N. Waddington,
St Albans,
Herts.

Foldback limiter protects high-current regulators

by A. D. V. N. Kularatna
Ratmalana, Sri Lanka

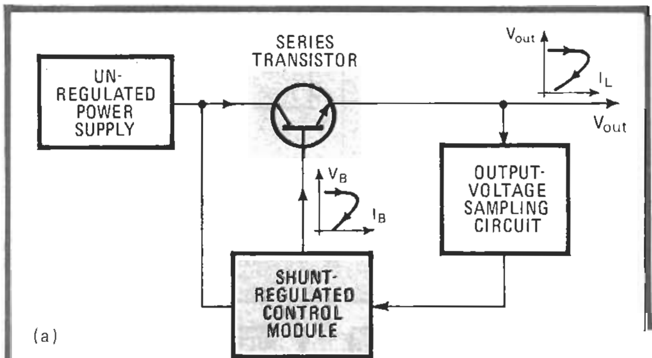
This circuit provides foldback protection for a series-regulated source that has to deliver high current. Because it requires no current-monitoring resistor, the circuit achieves wide dynamic response at good efficiency. It draws only 2% of maximum load current and its cost is reasonable.

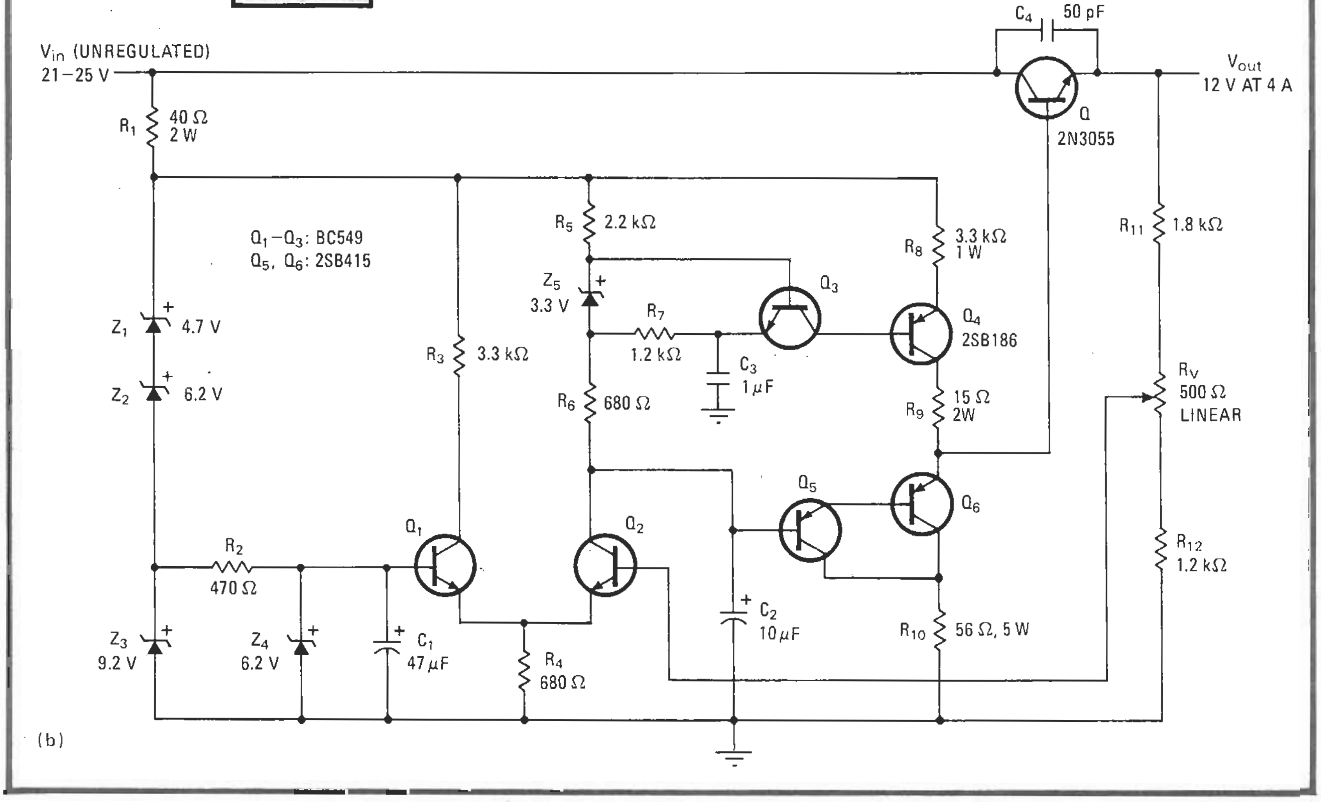
Here, a low-current shunt-regulated module (a) provides the overload protection. This module is configured into the conventional regulator system to work as a switch, in which role it quickly turns off a series-pass transistor when the load current exceeds some predetermined value.

The circuit details are explained with the aid of the diagram (b) for a representative regulator designed to deliver 12 volts at 4 amperes. Transistors Q_1 and Q_2 form a differential amplifier, which compares a 6.2-V reference to a potential derived from the 12-V output through potentiometer R_V. Shunt elements Q_5–Q_6 act to maintain the potential at the base of Q constant for any load condition by taking up the difference between the set and the actual base drive.

It is necessary that the current source Q_3-Q_4 be set to I_L/h_{fe} for proper tracking, where I_L is the maximum load current and h_{fe} is the current gain of Q. The value of the constant current, I, is $h_{fe\,Q4}(V_{Z5} - V_{be\,Q3})/R_7$, so that the current is most easily set by adjusting resistor R_7.

The module requires a current of 70 to 80 milliamperes under maximum load conditions. The short-circuit output current is less than 200 mA, because the drop in





High handling. Low-current shunt regulator (a) provides foldback limiting for high-current power sources at good efficiency and reasonable cost. Circuit (b) for 12-V regulator uses differential pair Q_1–Q_2 for detecting differences in reference and output voltage, Q_3–Q_6 for maintaining output potential by suitably controlling base drive to series pass transistor Q. Z_1–Z_3 minimize output ripple.

output voltage, switches transistor Q_2 off. The voltage across zener diode Z_5 is then reduced to a very low value, and this action in turn lowers the voltage at Q_6 and cuts down the base drive to Q.

Zener diodes Z_1–Z_3 were added to improve the ripple characteristics of the supply. As configured, the source has an output ripple of 6 mV peak to peak.

The shunt regulator module can be easily configured for any output voltage mainly by selecting the appropriate zener-diode values. □

Power-Supply Overload Protection

BY PETER STYS

IF you use a variable-output power supply, there is always a possibility of accidentally increasing its output beyond a load's capacity. In some instances, it will not matter. In others—say, with TTL ICs in the load—changing the output delivered from 5 to 10 volts would quickly "fry" the devices.

To ensure that the foregoing will not happen, add the overload protection circuit shown here to the supply's regulator. The circuit senses any sudden increase (or decrease) in output voltage, whereupon power to the regulator automatically shuts off. And it does this at any voltage within the supply's range! Moreover, the circuit also provides short-circuit protection by detecting the sudden drop in voltage.

How It Works. Normally, comparator *IC1B*'s noninverting (+) input is referenced below its inverting (−) input. Hence, the comparator sinks all of *SCR1*'s gate drive through *R2*. Now, when the voltage increases rapidly, the level at the noninverting input rises above that at the inverting input (which is delayed by *R7* and *C1*) and the comparator ceases sinking. At this point, *SCR1* fires and removes base drive from transistor *Q1*. In turn, this shuts off the regulator.

The same sequence of events applies to comparator *IC1C*, except that here the sensitivity is toward sudden decreases in voltage. If only overvoltage protection is desired, the *IC1C* circuit can be omitted.

Resistor networks *R8/R9* and *R10/R11* set tolerance margins for increases and decreases, respectively, in voltage within which any changes in voltage, no matter how rapid, will not trigger the circuit. The values of the resistors can be selected to suit the particular regulator being used to prevent false triggering. All resistance values depend on how steadily the output voltage is maintained under changes in load, how good the regulator's transient response is, etc.

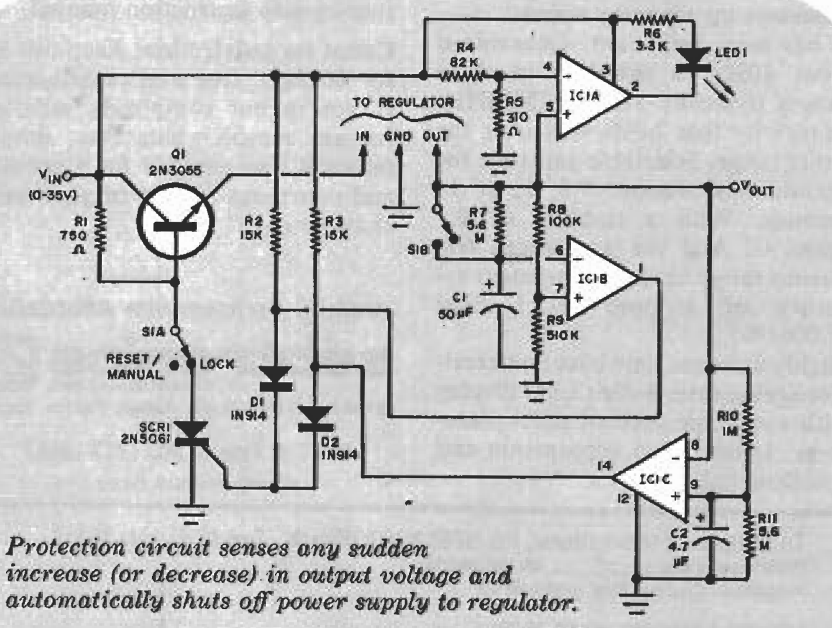
Networks *R7/C1* and *R10/C2* determine what will be the allowable rates of increase and decrease, respectively, of regulator voltage without triggering. If an external pass transistor already exists in the power supply's regulator circuit, its base can be shunted and *Q1* can be eliminated.

Light-emitting diode *LED1*, which can be any discrete red LED, simply indicates when an error has occurred in the preset output voltage and that power to the regulator has been shut down.

Switch *S1* is used for resetting the circuit if the protect system is tripped or for restoring variable output control capability when in the RESET/MANUAL position. This position interrupts current flow through *SCR1*. Setting *S1* to LOCK arms the automatic protect circuit. Manually adjusting the output potentiometer on the power supply will, therefore, trigger the circuit.

Construction. The simplest way to assemble and install the protective circuit is to use a piece of perforated board and solder clips. Alternatively, you can design a printed circuit board to accommodate all components except *Q1*, *LED1*, and *S1*. In either case, there is nothing critical about component placement and wire lengths. Also, it is a good idea to use a socket for *IC1*.

Mount *Q1* on the rear apron of the power supply, if possible, with an insulating socket and mica spacer. Use thermal-transfer paste between spacer and transistor and spacer and chassis. Then use an ohmmeter to make absolutely sure that *Q1*'s collector (case) is isolated from the chassis. If you cannot mount *Q1* on the rear apron, fabricate an aluminum L bracket large enough to hold the transistor, mount *Q1* on it as above, and bolt the assembly to the chassis. Mount *S1* and *LED1* on the front panel of the power supply. Use a small rubber grommet to hold the LED in place. Finally, interconnect all components and integrate them into the power supply's circuit, carefully following the schematic diagram. ◇



Protection circuit senses any sudden increase (or decrease) in output voltage and automatically shuts off power supply to regulator.

PARTS LIST

C1—50-µF, 35-volt electrolytic
C2—4.7-µF, 35-volt electrolytic
D1,D2—1N914 diode
IC1—LM339 quad comparator
LED1—Any discrete red light-emitting diode
Q1—2N3055 or similar transistor
R1—750-ohm 2-watt resistor
The following resistors are ½-watt, 5%:
R2,R3—15,000 ohms
R4—82,000 ohms
R5—310 ohms
R6—3300 ohms
R7,R11—5.6 megohms
R8—100,000 ohms
R9—510,000 ohms
R10—1 megohm
S1—Dpdt switch
SCR1—2N5061 or similar silicon controlled rectifier
Misc.—Printed-circuit board or perforated board and solder clips; socket for IC1; machine hardware; socket and mounting hardware for Q1; etc.

Cascaded regulators prevent pass transistor's burnout

by Christopher Tocci
Krohn-Hite Corp., Avon, Mass.

Cost-conscious designers are often tempted to squeeze every bit of available energy from a linear, voltage-regulated source that must deliver high output power, and the overheating and/or secondary breakdown that may result can cause component failures. In these cases, it will be less expensive to cascade several regulators so that no one element of any device, most notably the series-pass transistor, undergoes excessive electrical or thermodynamic strain. The design technique for achieving the n-cascade arrangement is described here.

The cascade connection of n regulators is shown in block form in (a). In general, if the following conditions are met, namely

$$V_{in} - V_1^o = V_2^o - V_1^o = \ldots\ V_{n\text{-}1} - V_o \qquad (1)$$

$$V_i^s = V_i^f \qquad (2)$$

$$V_i^f = {}^1\!/\!_2 V_i^o \qquad (3)$$

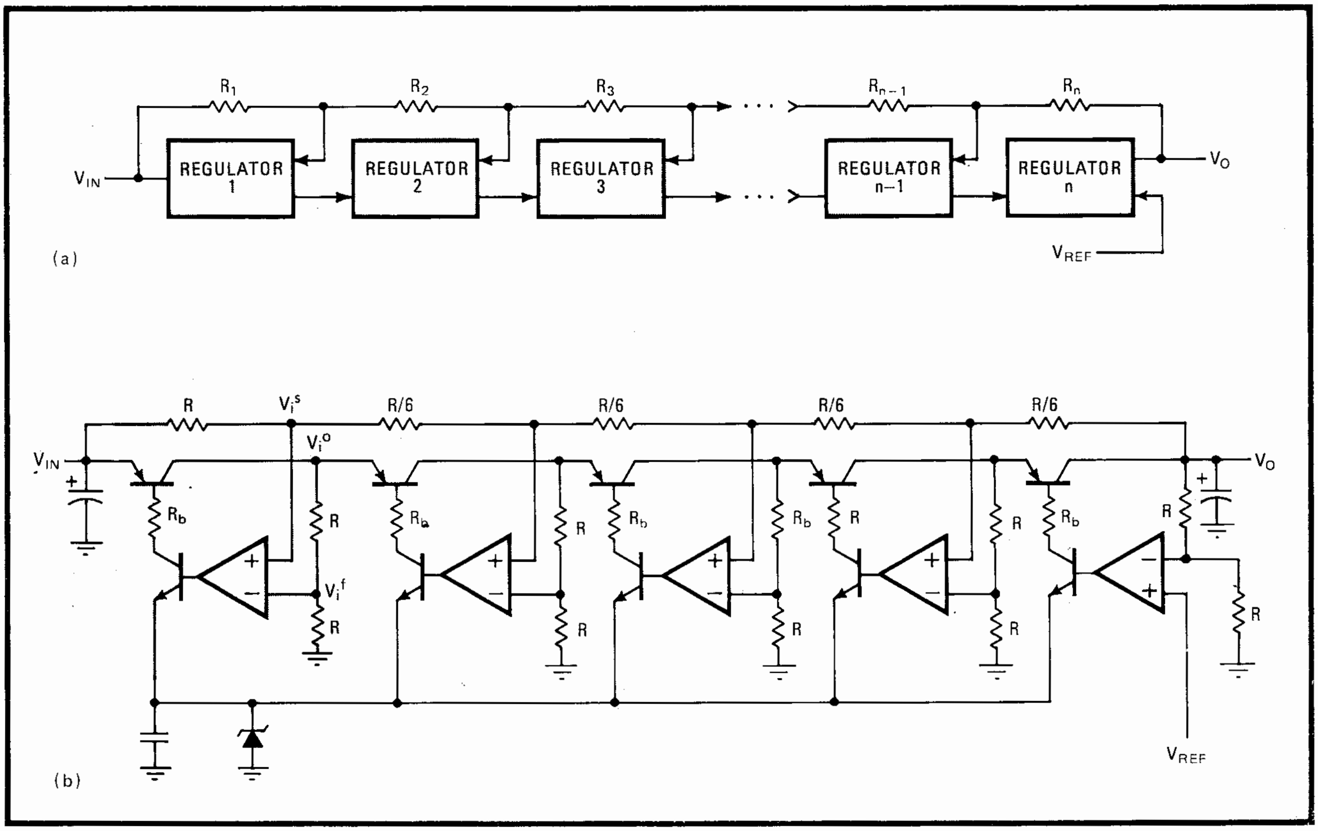
where

V_i^s = the resistor string voltage at the ith regulator
V_i^o = the local output voltage from the ith regulator
V_i^f = the local feedback voltage to the ith regulator

then $R_i = R/(n+1)$ for $i = 2, 3 \ldots n$, if $R_1 = R$. More importantly, it can be shown that the voltage across the series-pass transistor of each regulator becomes $V_i^o - V_{i+1}^o = (V_o + V_{in})/n$.

Equations 1 through 3 can be realized by connecting each regulator together as shown for a discrete five-stage unit in (b), where R is selected arbitrarily, within the limits of the technology (transistors, op-amps, etc) of the active elements used in the regulators. Under this arrangement, $V_o = 2\ V_{ref}$. The output voltage can be made variable over a greater range than 2:1 by appropriate selection of local feedback resistances. It is necessary that the op amps be of the type that can be operated from a single supply so that the feedback resistances R may be adjusted in order to attain the desired dynamic range.

Two problems are inherent in this design—the ripple generated at the nodes of the resistor string and the occurrence of oscillations due to unwanted feedback. The first problem is not a critical one because most of



Cooler. N-stage regulators (a) combine to equalize voltage drop across their respective series-pass transistors so that no device is destroyed by heat or breakdown, as may happen when high power is drawn through a single device. Design technique discussed in text is employed in discrete five-stage regulator (b). Supply ripple is eliminated at last stage. Oscillations are avoided with bypass capacitor in R/6 string.

the ripple will be eliminated by the last regulator, which derives its reference voltage from a stiff supply.

The second problem may be overcome by placing a large capacitor between the center of the resistor string and ground. Note that using too large a value of capacitance, however, will cause a turn-on lag that is excessive and that may create a low-frequency oscillation. □

Engineer's notebook is a regular feature in *Electronics*. We invite readers to submit original design shortcuts, calculation aids, measurement and test techniques, and other ideas for saving engineering time or cost. We'll pay $50 for each item published.

Calculator notes

Circuit breaker provides overcurrent and precise overvoltage protection

Anthony H Smith, Scitech, Bedfordshire, England

Requiring only a handful of inexpensive components, the circuit breaker in **Figure 1** responds to both overcurrent- and overvoltage-fault conditions. At the heart of the circuit, D_2, an adjustable, precision, shunt-voltage regulator, provides a voltage reference, comparator, and open-collector output, all integrated into a three-pin package.

Figure 2 shows a simplified view of the ZR431, D_1. The voltage appearing at the reference input is compared with the internal voltage reference, V_{REF}, nominally 2.5V. In the off state, when the reference voltage is 0V, the output transistor is off, and the cathode current is less than 0.1 µA. As the reference voltage approaches V_{REF}, the cathode current increases slightly; when the reference voltage exceeds the 2.5V threshold, the device fully switches on, and the cathode voltage falls to approximately 2V. In this condition, the impedance between the cathode and the supply voltage determines the cathode current; the cathode current can range from 50 µA to 100 mA.

Under normal operating conditions, D_2's output transistor is off, and the gate of P-channel MOSFET Q_4 goes through R_9, such that the MOSFET is fully enhanced, allowing the load current, I_{LOAD}, to flow from the supply voltage, $-V_S$, through R_6 into the load. Q_2 and current-sense resistor R_6 monitor the magnitude of I_{LOAD}, where Q_2's base-emitter voltage, V_{BE}, is $I_{LOAD} \times R_6$. For normal values of I_{LOAD}, V_{BE} is less than the 0.6V necessary to bias Q_2 on, such that the transistor has no effect on the voltage at the junction of R_3 and R_4. Because the input current at D_2's reference input is less than 1 µA, negligible voltage drops across R_5, and the reference voltage is effectively equal to the voltage on R_4.

In the event of an overload when I_{LOAD} exceeds its maximum permissible value, the increase in voltage across R_6 results in sufficient base-emitter voltage to turn on Q_2. The voltage on R_4 and, hence, the reference voltage now pull up toward V_S, causing D_2's cathode voltage to fall to approximately 2V. D_2's output transistor now sinks current through R_7 and R_8, thus biasing Q_3 on. Q_4's gate voltage now effectively clamps to the supply voltage through Q_3, and the MOSFET turns off. At the same instant, Q_3 sources current into R_4 through D_1, thereby pulling the voltage on R_4 to a diode drop below the supply voltage. Consequently, no load current flows through R_6 because Q_2, whose base-emitter voltage is now 0V, has turned off. As a result, no load current flows through R_6, D_2's output transistor latches on, and the circuit remains in its tripped state in which the load current is 0A. When choosing a value for R_6, ensure that Q_2's base-emitter voltage is less than approximately 0.5V at the maximum permissible value of the load current.

As well as responding to overcurrent conditions, the circuit breaker also reacts to an abnormally large value of the supply voltage. When the load current lies within its normal range and Q_2 is off, the magnitude of the supply voltage and the values of R_3 and R_4, which form a potential divider across the supply rails, determine the voltage at the reference input. In the event of an overvoltage at the supply voltage, the voltage on R_4 exceeds the 2.5V reference level, and D_2's output transistor turns on. Once again, Q_3 turns

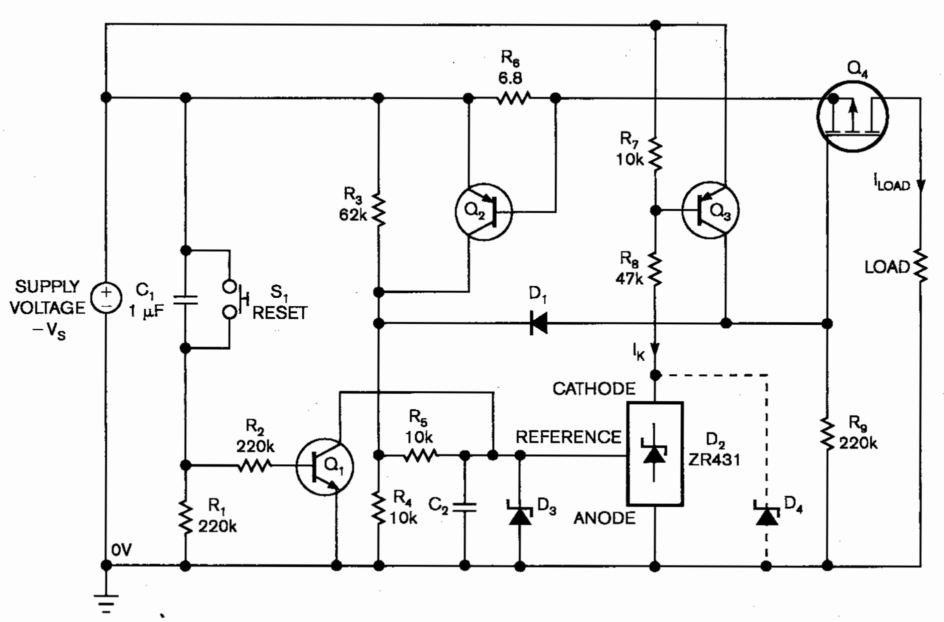


Figure 1 This circuit breaker provides both overvoltage and overcurrent protection. Other than the current flowing in R_3, R_4, and D_2's cathode, the circuit draws no current from the supply in its normal untripped state.

on, MOSFET Q_4 switches off, and the load becomes effectively isolated from the dangerous transient.

The circuit now remains in its tripped state until reset. Under these conditions, Q_3 clamps Q_4's gate-source voltage to roughly 0V, thereby protecting the MOSFET itself from excessive gate-source voltages. Ignoring the negligibly small voltage across R_5, you can see that the reference voltage is $V_S\times R_4/(R_3+R_4)$ in volts. Because D_2's output turns on when the reference voltage exceeds 2.5V, you can rearrange the equation as $R_3=[(V_{ST}/2.5)-1]\times R_4$ in ohms, where V_{ST} is the required supply-voltage trip level. For example, if R_4 has a value of 10 kΩ, a trip voltage of 18V would require R_3 to have a value of 62 kΩ. When choosing values for R_3 and R_4 to set the desired trip voltage, ensure that they are large enough that the potential divider will not excessively load the supply. Similarly, avoid values that could result in errors due to the reference-input current.

When you first apply power to the circuit, you'll find that capacitive, bulb-filament, motor, and similar loads having large inrush current can trip the circuit breaker, even though their normal, steady-state operating current is below the trip level that R_6 sets. One way to eliminate this problem is to add capacitor C_2, which slows the rate of change of the voltage at the reference input. However, although simple, this approach has a serious disadvantage in that it slows the circuit's response time to a genuine overcurrent-fault condition.

Components C_1, R_1, R_2, and Q_1 provide an alternative solution. On power-up, C_1 initially discharges, causing Q_1 to turn on, thereby clamping the reference input to 0V and preventing the inrush current from tripping the circuit. C_1 then charges through R_1 and R_2 until Q_1 eventually turns off, releasing the clamp at the reference input and allowing the circuit to respond rapidly to overcurrent transients. With the values of C_1, R_1, and R_2, the circuit allows approximately 400 msec for the inrush current to subside. Selecting other values allows the circuit to accommodate any duration of inrush current you apply to a load. Once you trip the circuit breaker, you can reset it either by cycling the power or by pressing S_1, the reset switch, which connects across C_1. If your application requires no inrush protection, simply omit C_1, R_1, R_2, and Q_1 and connect S_1 between the reference input and 0V.

When choosing components, make sure that all parts are properly rated for the voltage and current levels they will encounter. The bipolar transistors have no special requirements, although these transistors, especially Q_2 and Q_3, should have high current gain, Q_4 should have low on-resistance, and Q_4's maximum drain-to-source and gate-to-source voltages must be commensurate with the maximum value of supply voltage. You can use almost any small-signal diode for D_1. As a precaution, it may be necessary to fit zener diodes D_3 and D_4 to protect D_2 if extremely large transient voltages are likely.

Although this circuit uses the 431 device, which is widely available from different manufacturers, for D_2, not all of these parts behave in exactly the same way. For example, tests on a Texas Instruments (www.ti.com) TL-431CLP and a Zetex (www.zetex.com) ZR431CL reveal that the cathode current is 0A for both devices when the reference voltage is 0V. However, gradually increasing the reference voltage from 2.2 to 2.45V produces a change in cathode current ranging from 220 to 380 μA for the TL431CLP and 23 to 28 μA for the ZR431CL—roughly a factor of 10 difference between the two devices. You must take this difference in the magnitude of the cathode current into account when selecting values for R_7 and R_8.

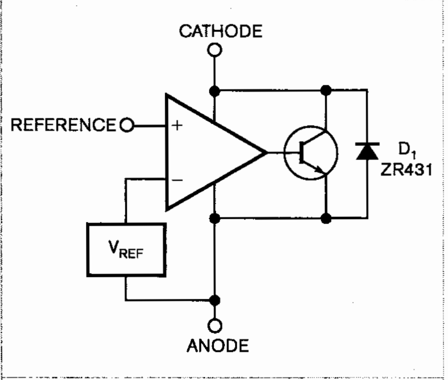


Figure 2 In this simplified view of the ZR431, the voltage at its reference input is compared with the internal voltage reference, which is nominally 2.5V.

The type of device you use for D_2 and the values you select for R_7 and R_8 can also have an effect on response time. A test circuit with a TL431CLP, in which R_7 is 1 kΩ and R_8 is 4.7 kΩ, responds within 550 nsec to an overcurrent transient. Replacing the TL431CLP with a ZR431CL results in a response time of approximately 1 μsec. Increasing R_7 and R_8 by an order of magnitude to 10 and 47 kΩ, respectively, produces a response time of 2.8 μsec. Note that the relatively large cathode current of the TL431CLP requires correspondingly small values of R_7 and R_8.

To set the overvoltage-trip level at 18V, R_3 and R_4 must have values of 62 and 10 kΩ, respectively. The test circuit then produces the following results: Using a TL431CLP for D_2, the circuit trips at 17.94V, and, using a ZR-431CL for D_2, the trip level is 18.01V. Depending on Q_2's base-emitter voltage, the overcurrent-detection mechanism is less precise than the overvoltage function. However, the overcurrent-detection accuracy greatly improves by replacing R_6 and Q_2 with a high-side current-sense amplifier that generates a ground-referred current proportional to load current. These devices are available from Linear Technology (www.linear.com), Maxim (www.maxim-ic.com), Texas Instruments, Zetex, and others.

The circuit breaker should prove useful in applications such as automotive systems that require overcurrent detection to protect against faulty loads and that also need overvoltage protection to shield sensitive circuitry from high-energy-load-dump transients. Other than the small current flowing in R_3 and R_4 and the current in D_2's cathode, the circuit draws no current from the supply in its normal, untripped state.**EDN**