Comparator switches regulator for foldback current limiting

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The three-terminal regulator, while easing the design of regulated power supplies, does limit the adjustability of their output parameters. Here is a circuit that couples a comparator with a National LM317 adjustable, three-terminal power regulator to provide independent control of output voltage and current limiting.

The power supply shown in the figure was designed as a 9-to-16-volt, 20-ampere bench regulator for automotive transceiver applications. It therefore employs high-power regulating transistors, but the technique of comparator-controlled current limiting in the output is adaptable to any power range. In this case, the current limit of the supply can be set from 1 to 20 A, independent of the output-voltage setting.

The circuit employs a foldback type of current limiting; that is, once the current limit is exceeded, the output voltage drops nearly to zero. The LM311 comparator,

monitoring the current flow, switches the supply into the limiting mode.

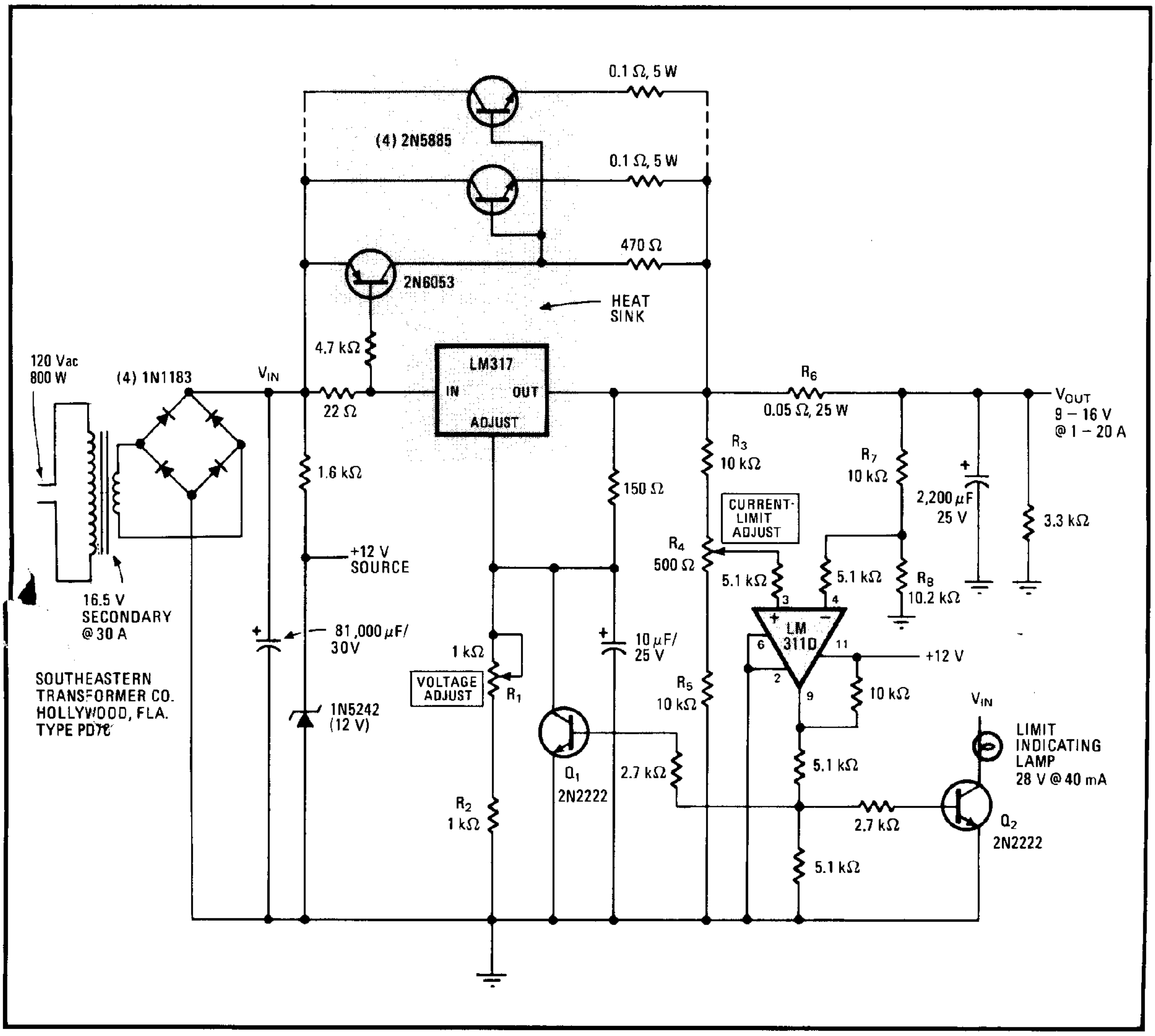
The output of the comparator goes high whenever the voltage drop across the current-sense resistor, R_6, exceeds the bias level set by the limit control, R_4. A high level at the output of the comparator turns on transistor Q_1, which in effect shorts out the voltage-adjusting resistors R_1 and R_2, thus dropping down the output voltage.

The design has an inherent hysteresis: in the limiting state, just enough current flows through the sensing resistor R_6 to keep the comparator turned on. Therefore the circuit does not oscillate as many other limiting regulators do—the output voltage remains near zero until the overload is removed. The action of the comparator also provides automatic recovery from the foldback point, since the circuit cannot latch in the current-limiting mode.

Transistor Q_2 turns on an incandescent lamp to indicate the limiting state. Since the value of the current-sensing resistor R_6 is not critical, the device may be replaced with the internal resistance of a 0- to 20-A meter, if desired.

The dial of the current-limiting control can be calibrated with known output loads at a set output voltage. Control of the limiting function is primarily dictated by the biasing resistors surrounding the comparator, R_3-R_8. Designs for output voltages and currents in other ranges may employ the same basic configuration of regulator and comparator, with only the biasing components needing to be changed.

The LM317 adjustable regulator, available in either TO-3 or TO-220 packages, is capable of driving loads up to 1½ amperes without the aid of power-transistor followers. In the supply shown, five power transistors—four 2N5885s and a 2N6053—are required to handle the 20-A loads. All power transistors and diodes, as well as the regulator, must have adequate heat sinking. □



Foldback current-limiting supply. This supply, which has an output voltage adjustable from 9 to 16 V and provides independent current limiting from 1 to 20 A, uses a comparator to drop output voltage when the current limit set by potentiometer R_4 is exceeded.

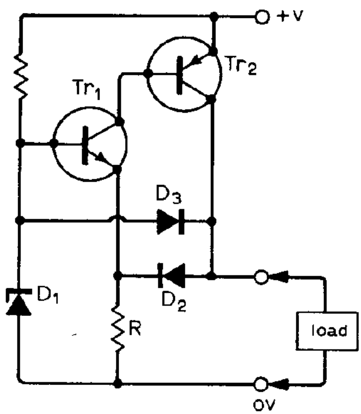
Circuit Ideas

Foldback in current-limited supply

A simple and useful addition to the current-limiting supply of A. E. T. Nye (*WW* June 1973, page 285) is a diode which will provide current foldback with overload conditions.

The diode D_3 is added between the zener point and the load. This normally has a small reverse voltage across it, and does not affect the operation of the circuit until current limiting occurs (see Nye for mechanism) and the load voltage starts to drop. It will then become conducting, diverting current from the zener diode, reducing the zener point voltage and hence the load voltage further. At high output current settings (output current limit is set by R: high means currents above the β maximum for Tr_2) a current foldback action occurs. As the load resistance is reduced below that which produces limiting the output current decreases progressively until at short circuit the output current is only that flowing through the zener bias resistor and D_3. At low current settings, the output is immediately bootstrapped down to the zener resistor current, but will bootstrap itself up again with a small increase in load resistance.

Foldback limiting characteristics are of course preferable to crowbar or fuse protection because the circuit is self-starting as



soon as the overload is removed. They are also usually preferable to current-limiting characteristics as they produce shutdown of both the power supply and any driven circuit, avoiding the worst case of heat dissipation on short-circuit.

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Current "Foldback" Protects Power Supply & Load

BY JEROME MAY

How a 723 IC can be used for both load and supply regulation.

WHILE MOST modern power supplies are designed to protect themselves against overloads and short circuits, the protection often doesn't go far enough. In many modern projects—particularly those involving computers—the load on the power supply can cost a great deal more than the supply itself. A practical power supply for modern projects, then, should protect both itself and the load. With an inexpensive 723 precision voltage regulator IC and a handful of components, you can build such a "full-protection" power supply.

Unlike most other regulator IC's, the 723 can be programmed to automatically drop the output current to a small fraction of maximum under overload and short-circuit conditions. This "foldback" current is similar to conventional current limiting up to the maximum current rating of the supply. But while a conventional current limiter will keep right on pumping maximum current into the load, the foldback circuit will go to maximum and then signal the series-pass transistor in the 723 to drop the output current to a mere fraction of its capability.

The actions of both conventional and foldback limiting are graphically illustrated in Fig. 1. Note the downward slope of the short-circuit current, I_{SC}, for the foldback characteristic as opposed to the zero slope of the line for conventional current limiting.

The functional diagram of the 723 is shown in Fig. 2. Pin designations on the diagram are for the dual in-line (DIP) configuration of this IC. Below the diagram are the pin designations for the round (TO-100) configuration of this IC. Some of the IC's more important maximum specifications are: 40 V from +V and V_C to −V; 150 mA maximum current for internal series-pass transistor; 900 mW DIP (800 mW round) maximum power dissipation; 0.001-μF frequency-compensation capacitor; 0.03% regulation at load; input-output voltage differential, 30 V minimum. On the TO-100, pin 5 is connected to the case.

Regulation Differences. A basic current limiter using a 723 is shown in Fig. 3. This circuit can be programmed to operate in either a low- (2-to-7-) or high- (7-to-35-) volt range by proper selection of voltage-divider resistors *R1* and *R2*. (Note: To avoid confusion during calculations, two *R1-R2* divider networks are shown. The resistor values calculated will be the same in both divider networks.)

If only the high-voltage range is desired, switch *S1* goes to HI, and V_{REF} goes to the noninverting, or +, input of the error amplifier in the 723 through a 5000-ohm resistor (*R4*). The output current of the IC is sensed by *R3* and fed to the *Q2* current sense amplifier in the 723. When the potential across *R3* exceeds about 0.7 volt, *Q2* diverts any increase in base current from the error amplifier to *Q1* inside the IC. This limits the available current from the 723 to the IC's rated maximum. Unfortunately, if the load resistance goes to zero, this maximum current will still be pumped into the load.

Now, consider the foldback modification shown in Fig. 4. (This circuit is identical to the Fig. 3 circuit except that *R5* and *R6* have been added as shown.) The ratio of *R5/R6* shifts the operating point of *Q2* inside the 723 so that, when the voltage drop across *R3* biases on *Q2*, any increase in the drop across *R3* (beyond the point at which the transistor first starts to conduct) diverts increasing current away from the base of the 723's *Q1* transistor. Thus, the output current "folds back" after the maximum programmed current is obtained. Note, however, that because a finite voltage drop is required to keep the 723's *Q2* transistor conducting, the output current can never go to zero; it simply folds back to a small fraction of the maximum current the IC can deliver.

Calculations. To program a 723 for the current-foldback regulator, first determine values for *R1* and *R2* to fix the output voltage. To determine the foldback current ("knee" in Fig. 1), *R3* is calculated after selecting convenient values for *R5/R6*.

If the output is to be less than 7 volts, the *R1A-R2A* divider network goes directly to the 723's V_{REF} input with *S1* in the LO position as shown in Fig. 3. The basic formula from which to work is $V_O = V_{REF}\ R2A/(R1A + R2A)$, from which we obtain $R1A = R2A(V_{REF} - V_O)/V_O$ and $R2A = V_O R1A/(V_{REF} - V_O)$. Assume that the desired V_O = 5 volts and that V_{REF} = 6.2 volts. Select an arbitrary value of several thousand ohms—say, 10,000 ohms — for *R2A*. Therefore, $R1A = 10{,}000(6.2 - 5)/5 = 2400$ ohms. Hence, for a 5-volt output, the values of *R1A* and *R2A* should be 2400 and 10,000 ohms, respectively.

Should you desire an output of greater than 7 volts, *S1* should be set to HI, which bypasses *R1A* and *R2A* by switching in *R4* and placing the *R1B-R2B* divider in the circuit. The basic for-

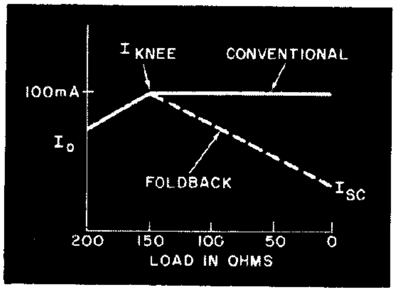

Fig. 1. Dashed line shows downward slope of short-circuit current for the foldback characteristic.

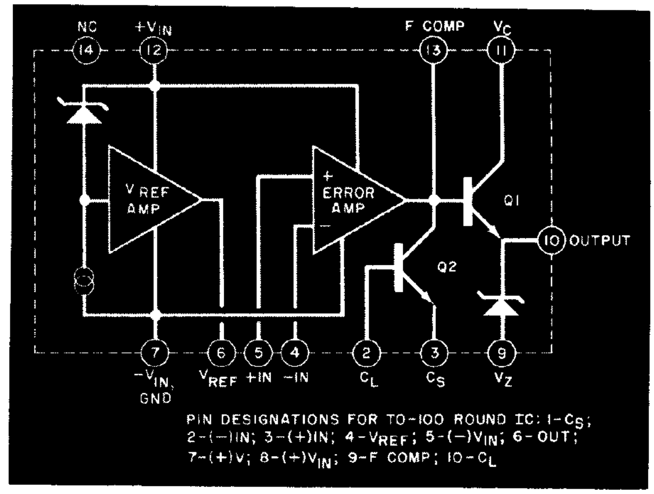

Fig. 2. Functional diagram of the DIP 723. Pin designations for TC-100 are also given.

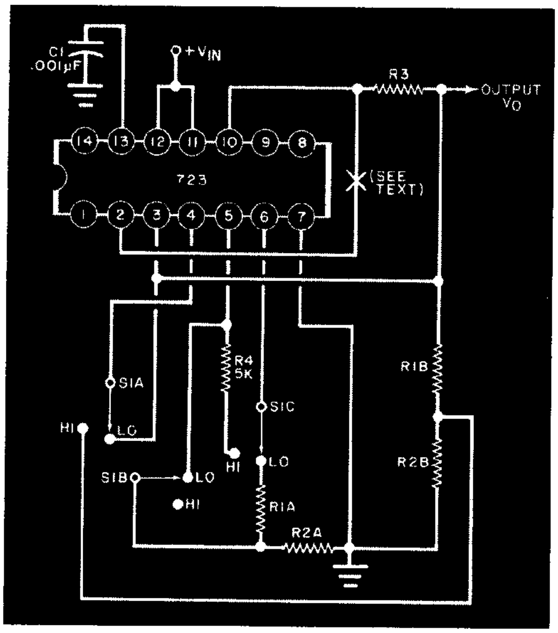

Fig. 3. Basic current limiter can operate in either a low (2 to 7 volts) or high (7 to 35) range by proper selection of resistors R1 and R2. See Fig. 4 for added circuit at point "X".

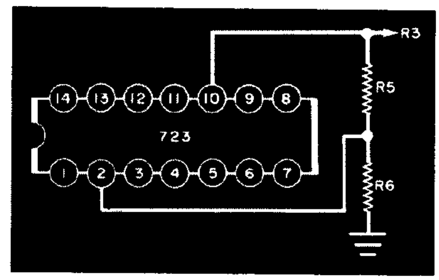

Fig. 4. Voltage divider at "X" in Fig. 3 shifts operating point.

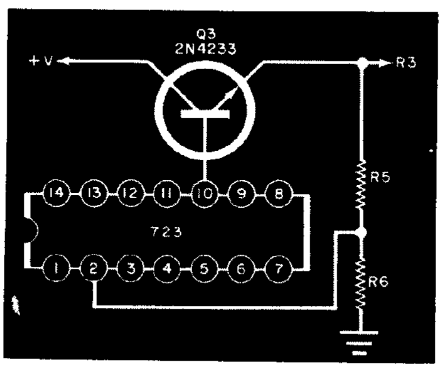

Fig. 5. Use of an npn series-pass transistor to increase capacity.

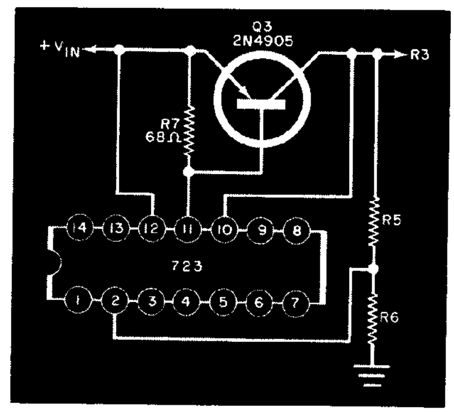

Fig. 6. If a pnp transistor is used as series-pass element, add a bias resistor.

mula here is $V_O = V_{REF}(R1B + R2B)/R2B$. Therefore, $R1B = R2B(V_O - V_{REF})/V_{REF}$ and $R2B = V_{REF}\,R1B/(V_O - V_{REF})$. This time, let us assume that the output is to be 15 volts and that V_{REF} remains the same at 6.2 volts. Again arbitrarily selecting a value of 10,000 ohms for *R2B*, *R1B* = 10,000 (15 − 6.2)/6.2 = 14,193 ohms.

Now, select the maximum current the supply is to deliver to the load. For example, assume that at V_O = 15 volts, you want an I_{MAX} of 100 mA. Now, select values for *R5* and *R6* (Fig. 4 shows how these components connect into the basic circuit). Assume that *R5* and *R6* have values of 1000 and 10,000 ohms, respectively. (Note: The smaller the ratio of *R5/R6*, the lower will be the resistance for *R3* to provide the required limiting. Bear in mind that the short-circuit current will be reduced for larger values of *R3*.)

From the equation $I_{MAX} = [V_O R5 + 0.7(R5 + R6)]/R3R6$, we obtain $R3 = [V_O R5 + 0.7(R5 + R6)]/I_{MAX}R6$. Therefore, R3 = [15(1000) + 0.7(1000 + 10,000)]/(0.1 × 10,000) = 22.7 ohms. Since the formula for short-circuit current is $I_{SC} = 0.7(R5 + R6)/R3R6$, I_{SC} = 0.7(1000 + 10,000)/(22.7 × 10,000) = 35 mA. This is about a third of the actual current the 723 supply is designed to deliver. The short-circuit current can be reduced, but then new values of the ratio R5/R6 will have to be selected to determine the 100-mA foldback point.

A current of 35 mA at 15 volts is a hefty half-watt to dissipate on an IC chip. Therefore, a better approach to the design of the supply would be to use an external series-pass transistor with adequate heat-sink protection. The circuit utilizing an npn series-pass transistor (*Q3*) is shown in Fig. 5. If all you have available is a pnp transistor, you can use it, along with an additional bias resistor (*R7*), as shown in Fig. 6. In either case, if the circuit is to be used to power a particular project, be sure the transistor's voltage, current, and power dissipation figures are capable of accommodating the load at full power. ◇