

Improving Power Supply Reliability with IC Power Regulators

Three-terminal IC power regulators include on-chip overload protection against virtually any normal fault condition. Current limiting protects against short circuits fusing the aluminum interconnects on the chip. Safe-area protection decreases the available output current at high input voltages to insure that the internal power transistor operates within its safe area. Finally, thermal overload protection turns off the regulator at chip temperatures of about 170°C, preventing destruction due to excessive heating. Even though the IC is fully protected against normal overloads, careful design must be used to insure reliable operation in the system.

SHORT CIRCUITS CAN OVERLOAD THE INPUT

The IC is protected against short circuits, but the value of the on-chip current limit can overload the input rectifiers or transformer. The on-chip current limit is usually set by the manufacturer so that with worst-case production variations and operating temperature the device will still provide rated output current. Older types of regulators, such as the LM309, LM340 or LM7800 can have current limits of 3 times their rated output current.

The current limit circuitry in these devices uses the turn-on voltage of an emitter-base junction of a transistor to set the current limit. The temperature coefficient of this junction combined with the temperature coefficient of the internal resistors gives the current limit a $-0.5\%/^{\circ}\text{C}$ temperature coefficient. Since devices must operate and provide rated current at 150°C, the 25°C current limit is 120% higher than typical. Production variations will add another $\pm 20\%$ to initial current limit tolerance so a typical 1A part may have a 3A current limit at 25°C. This magnitude of overload current can blow the input transformer or rectifiers if not considered in the initial design—even though it does not damage the IC.

One way around this problem (other than fuses) is by the use of minimum size heat sinks. The heat sink is designed for only normal operation. Under overload conditions, the device (and heat sink) are allowed to heat up to the thermal shut-down temperature. When the device shuts down, loading on the input is reduced.

Newer regulators have improved current limiting circuitry. Devices like the LM117 adjustable regulator, LM123, 3A, 5V logic regulator or the LM120 negative regulators have a relatively temperature-stable current limit. Typically these devices hold the current limit within $\pm 10\%$ over the full -55°C to $+150^{\circ}\text{C}$ operating range. A device rated for 1.5A output will typically have a 2.2A current limit, greatly easing the problem of input overloads.

Many of the older IC regulators can oscillate when in current limit. This does not hurt the regulator and is mostly dependent upon input bypassing capacitors. Since there is a large variability between regulator types and manufacturers, there is no single solution to eliminating oscillations. Generally, if oscillations cause other circuit problems, either a solid tantalum input capacitor or a solid tantalum in series with 5Ω to 10Ω will cure the problem. If one doesn't work, try the other.

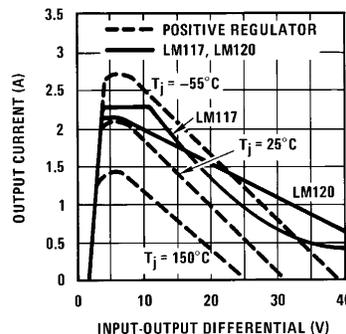
Start-up problems can occur from the current limit circuitry too. At high input-output differentials, the current limit is decreased by the safe-area protection. In most regulators the

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decrease is linear, and at input-output voltages of about 30V the output current can decrease to zero. Normally this causes no problem since, when the regulator is initially powered, the output increases as the input increases. If such a regulator is running with, for example, 30V input and 15V output and the output is momentarily shorted, the input-output differential increases to 30V and available output current is zero. Then the output of the regulator stays at zero even if the short is removed. Of course, if the input is turned OFF, then ON, the regulator will come up to operating voltage again. The LM117 is the only regulator which is designed with a new safe-area protection circuit so output current does not decrease to zero, even at 40V differential.

This type of start-up problem is particularly load dependent. Loads to a separate negative supply or constant-current devices are among the worst. Another, usually overlooked, load is pilot lights. Incandescent bulbs draw 8 times as much current when cold as when operating. This severely adds to the load on a regulator, and may prevent turn-on. About the only solutions are to use an LM117 type device, or bypass the regulator with a resistor from input to output to supply some start-up current to the load. Resistor bypassing will not degrade regulation if, under worst-case conditions of maximum input voltage and minimum load current, the regulator is still delivering output current rather than absorbing current from the resistor. Figure 1 shows the output current of several different regulators as a function of output voltage and temperature.



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FIGURE 1. Comparison of LM117 Current Limit with Older Positive Regulator

When a positive regulator (except for the LM117) is loaded to a negative supply, the problem of start-up can be doubly bad. First, there is the problem of the safe-area protection as mentioned earlier. Secondly, the internal circuitry cannot supply much output current when the output pin is driven more negative than the ground pin of the regulator. Even with low input voltages, some positive regulators will not start when loaded by 50 mA to a negative supply. Clamping the output to ground with a germanium or Schottky diode usually solves this problem. Negative regulators, because of different internal circuitry, do not suffer from this problem.

DIODES PROTECT AGAINST CAPACITOR DISCHARGE

It is well recognized that improper connections to a 3-terminal regulator will cause its destruction. Wrong polarity inputs or driving current into the output (such as a short between a 5V and 15V supply) can force high currents through small area junctions in the IC, destroying them. However, improper polarities can be applied accidentally under many normal operating conditions, and the transient condition is often gone before it is recognized.

Perhaps the most likely sources of transients are external capacitors used with regulators. Figure 2 shows the discharge path for different capacitors used with a positive regulator. Input capacitance, C1, will not cause a problem under any conditions. Capacitance on the ground pin (or adjustment pin in the case of the LM117) can discharge through 2 paths which have low current junctions.

If the output is shorted, C2 will discharge through the ground pin, possibly damaging the regulator. A reverse-biased diode, D2, diverts the current around the regulator, protecting it. If the input is shorted, C3 can discharge through the output pin, again damaging the regulator. Diode D1 protects against C3, preventing damage. Also, with both D1 and D2 in the circuit, when the input is shorted, C2 is discharged through both diodes, rather than the ground pin.

In general, these protective diodes are a good idea on all positive regulators. At higher output voltages, they become more important since the energy stored in the capacitors is larger. With negative regulators and the LM117, there is an internal diode in parallel with D1 from output-to-input, eliminating the need for an external diode if the output capacitor is less than 25 μF .

Another transient condition which has been shown to cause problems is momentary loss of the ground connection. This charges the output capacitor to the unregulated input voltage minus a 1–2V drop across the regulator. If the ground is then connected, the output capacitor, C3, discharges through the regulator output to the ground pin, destroying it. In most cases, this problem occurs when a regulator (or card) is plugged into a powered system and the input pin is

connected before the ground. Control of the connector configuration, such as using 2 ground pins to insure ground is connected first, is the best way of preventing this problem. Electrical protection is cumbersome. About the only way to protect the regulator electrically is to make D2 a power zener 1V to 2V above the regulator voltage and include 10 Ω to 50 Ω in the ground lead to limit the current.

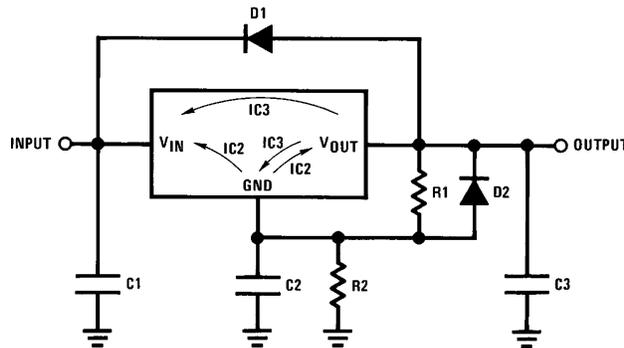
LOW OPERATING TEMPERATURE INCREASES LIFE

Like any semiconductor circuit, lower operating temperature improves reliability. Operating life decreases at high junction temperatures. Although many regulators are rated to meet specifications at 150°C, it is not a good idea to design for continuous operation at that temperature. A reasonable maximum operating temperature would be 100°C for epoxy packaged devices and 125°C for hermetically sealed (TO-3) devices. Of course, the lower the better, and decreasing the above temperatures by 25°C for normal operation is still reasonable.

Another benefit of lowered operating temperatures is improved power cycle life for low cost soft soldered packages. Many of today's power devices (transistors included) are assembled using a TO-220 or TO-3 aluminum soft solder system. With temperature excursions, the solder work-hardens and with enough cycles the solder will ultimately fail. The larger the temperature change, the sooner failure will occur. Failures can start at about 5000 cycles with a 100°C temperature excursion. This necessitates, for example, either a large heat sink or a regulator assembled with a hard solder, such as steel packages, for equipment that is continuously cycled ON and OFF.

THERMAL LIMITING GIVES ABSOLUTE PROTECTION

Without thermal overload protection, the other protection circuitry will only protect against short term overloads. With thermal limiting, a regulator is not destroyed by long time short circuits, overloads at high temperatures or inadequate heat sinking. In fact, this overload protection makes the IC regulator tolerant of virtually any abuse, with the possible exception of high-voltage transients, which are usually filtered by the capacitors in most power supplies.



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FIGURE 2. Positive Regulator with Diode Protection Against Transient Capacitor Discharge

One problem with thermal limiting is testing. With a 3-terminal regulator, short-circuit protection and safe-area protection are easily measured electrically. For thermal limiting to operate properly, the electrical circuitry on the IC must function and the IC chip must be well die-attached to the package so there are no hot spots. About the only way to insure that thermal limiting works is to power the regulator, short the output, and let it cook. If the regulator still works after 5 minutes (or more) the thermal limit has protected the regulator.

This type of testing is time consuming and expensive for the manufacturer so it is not always done. Some regulators, such as the LM117, LM137, LM120 and LM123, do receive an electrical burn-in in thermal shutdown as part of their testing. This insures that the thermal limiting works as well as reducing infant mortality. If it is probable that a power supply will have overloads which cause the IC to thermally limit, testing the regulator is in order.

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