Application Bulletin AB-17

Adding an Over-Voltage Crowbar to an RC5051 Converter: Design and Analysis

Summary

Adding an over-voltage crowbar circuit to an RC5051 converter can protect a processor in the event of a catastrophic converter failure. Both a low-cost and a high-performance crowbar are shown and their operation explained.

Analysis

A typical RC5051 converter for a processor, as shown in Figure 1, has excellent performance in regulating its output voltage to precisely the level required. The converter will almost never fail. However, it is this “almost” that is of importance here. Once in a very long time, something catastrophic may happen to the converter, causing the output voltage to rise above its regulation level. Examples of such catastrophic events include:

1. The high-side MOSFET, Q1, fails short, perhaps due to a voltage spike on its drain;
2. A short appears across certain traces, perhaps due to PCB burrs;
3. The inductor L2 shorts, perhaps due to a wire nick;
4. The high-side drive of the RC5051 fails high, perhaps due to an over-voltage on the VCCQP pin.

Any of these events may cause the voltage at the output of the converter to very quickly rise towards the input voltage, potentially damaging the processor or other load.

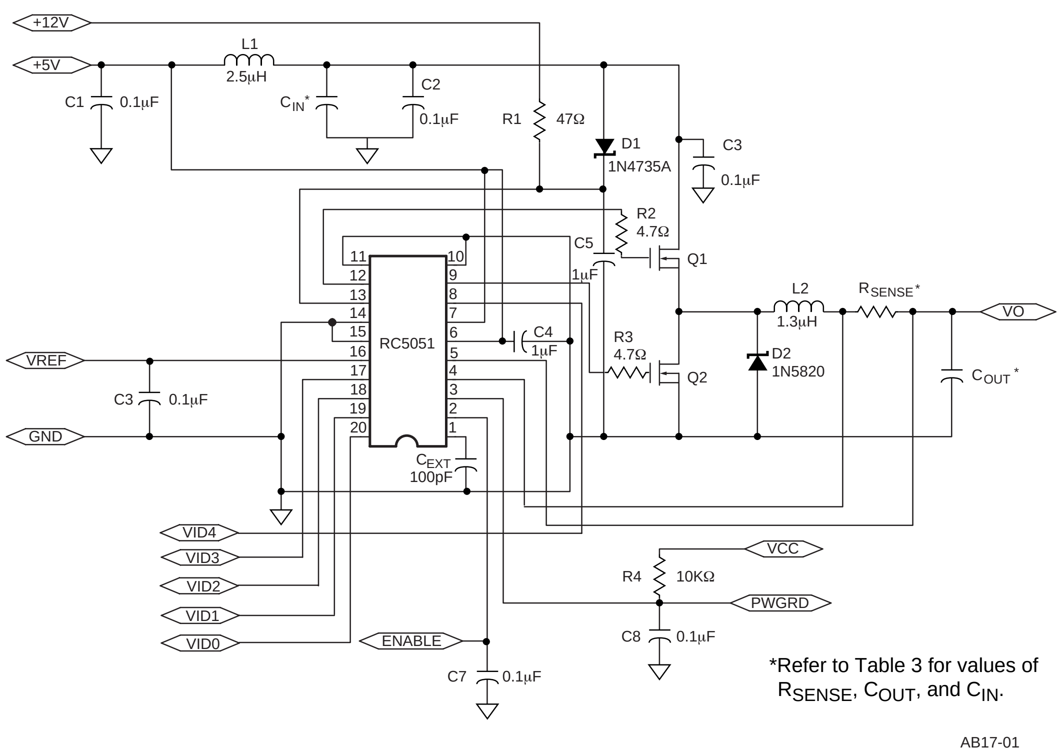

Figure 1. Typical RC5051 Converter for a Processor

An Inexpensive Crowbar

A crowbar circuit must be designed to clamp the output voltage of a converter when the voltage rises above a certain level, and it must not ever falsely activate. Furthermore, as will be seen in a moment, the rate of rise of the output voltage in the event of a failure can be extremely fast, and so the crowbar must respond in the shortest possible time. To some extent, these requirements conflict with the obvious requirement that the crowbar circuit must be inexpensive; in this section, a circuit is shown which is fast, reliable, and very inexpensive. However, it is not especially accurate, although adequate for many purposes. In the next section, a circuit will be shown in which the accuracy will be much improved, at somewhat higher cost.

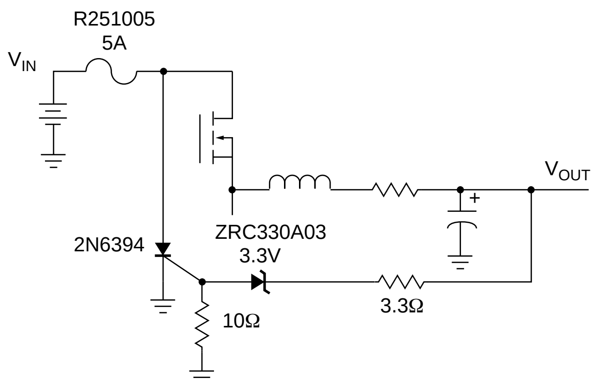

Figure 2. Inexpensive Crowbar Circuit

The crowbar circuit of Figure 2 works as follows. When the output voltage is in its normal range (either 2.8V or 2.0V) the zener is off; specifically, the leakage current through the zener times the resistance on the gate of the SCR gives an SCR gate voltage less than its minimum firing voltage (200mV for the SCR shown). When the output voltage goes high, the zener turns on, applying approximately (V_{OUT} – 3.3V) to the gate of the SCR. When this voltage exceeds the threshold (1.5V maximum for this SCR), the SCR fires within 2µsec, clamping the input voltage and pulling down the output voltage, and eventually blowing the fuse.

The maximum voltage that the output sees depends on how quickly the SCR fires. To see this, consider the scenario in which the high-side MOSFET shorts. The input voltage is applied directly to the inductor, so that the inductor current rises very quickly; for any non-rod core inductor, the core will quickly saturate, leaving effectively no inductance between the input and output voltages. Thereafter, the rate of rise of the output voltage is set by the parasitic resistance, composed of the fuse resistance, inductor resistance, and the sense resistor, and the output capacitance.

As an example, the resistance of the fuse shown is approximately 15mΩ; assume the inductor has about 5mΩ of winding resistance, and the sense resistor is 6mΩ. This gives a total series resistance from input to output of 26mΩ. If the output capacitance is a typical 10mF, the time constant is 260µsec. Assuming then that the voltage starts at 3.6V (3.3V zener, plus minimum gate threshold voltage of the SCR of 200mV, plus maximum gate current of 30mA * 3.3Ω), and the input is 12V, in 2µsec the output voltage increases to

$$V = 3.6V + 8.4(1 - e^{-2\mu sec/260\mu sec}) = 3.66V$$

Thus, this circuit clamps the output voltage at just above the voltage set by the zener plus the SCR gate threshold. However, if the firing time of the SCR were slightly longer, or the RC time constant somewhat less, clearly the voltage could rise quite considerably.

A Better Crowbar Circuit

The above analysis points out the one problem with the circuit of Figure 2, namely, the voltage at which crowbarring occurs is very dependent on the characteristics of the SCR gate threshold: the SCR is guaranteed to be off with 200mV on its gate, but not guaranteed to be on with less than 1.5V. The 1.3V spread means that designing the SCR to trip on at a minimum of 3.0V means that it *may* not turn on until 4.3V. The circuit shown in Figure 3 circumvents this problem by removing the variability of the SCR gate from the equation.

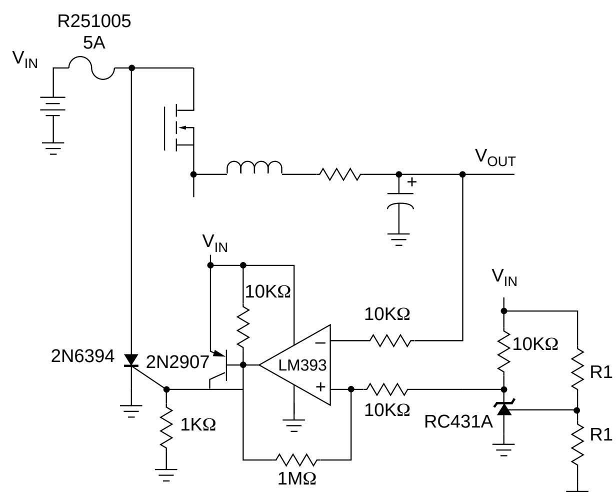

Figure 3. High Performance Crowbar Circuit

The circuit works by using a comparator to determine when the output voltage exceeds a level set by an adjustable voltage reference, the RC431A. The comparator turns on a PNP transistor, which then drives the gate of the SCR. Since the SCR in this circuit is driven from the input voltage, there is no longer any variability in the over-voltage trip point. However, there is a small additional delay in the propagation time of the comparator—for the part shown, about 1.3µsec additional.

Notes:

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