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10 A Electronic Fuse Enables Compact Overcurrent Protection for 48 V Power Supplies

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Abstract

Traditionally, fuses are used for overcurrent protection. However, fuses are bulky in size, are slow to respond, have a wide trip current tolerance, and require replacement after one or a few trips. This article describes a compact, low profile, and fast 10 A electronic fuse that overcomes these passive fuse shortcomings. The electronic fuse provides overcurrent protection on up to 48 V DC power supply rails.

Introduction

To minimize system downtime caused by electrical failures, power supplies in high availability or 24/7/365 systems need protection from overloads and short circuits in the board they power up. Overcurrent protection for a supply is essential when it powers multiple subsystems or boards such as RF power amplifier arrays or backplane-based servers and routers. Quickly disconnecting the faulting subsystem from the shared power supply bus allows the remaining subsystems to continue operating without rebooting or going offline.

Traditional overcurrent protection (OCP) relies on fuses, but they suffer from bulky size, slow response, wide tolerance, and requiring replacement after one or a few trips. Integrated circuit OCP solutions for DC power supplies, known as electronic circuit breakers or electronic fuses, overcome these fuse disadvantages. To save board space and resemble the simplicity of a passive fuse, electronic fuses include the power MOSFET switch along with the control circuit in the same package.

Surge Stopper with Internal Power MOSFET

A surge stopper is an integrated circuit device that controls an N-channel power MOSFET placed in the power path between a DC power supply (for example, 12 V, 24 V, or 48 V) and the system electronics needing protection from input voltage and load current surges. Built-in output current and output voltage limiting enables a surge stopper to shield load electronics from high voltage input surges and protect the power supply from downstream overloads and short circuits. An adjustable timer activates during voltage or current surge limiting events, allowing continuous system operation, without powering off, for brief fault transients. If the fault persists beyond the timer duration, the system is disconnected from the power supply.

The LTC4381 is the first surge stopper with an internal power MOSFET. It operates with supply voltages up to 72 V while consuming just 6 µA of quiescent current. The internal power MOSFET's 100 V drain source breakdown voltage (BV_{DSS}) and 9 mΩ on resistance ($R_{DS(ON)}$) allow up to 100 V input surges and 10 A applications. The LTC4381 has four options that offer a choice of fault retry behavior and fixed or adjustable output clamp voltage.

48 V, 10 A Electronic Fuse Circuit

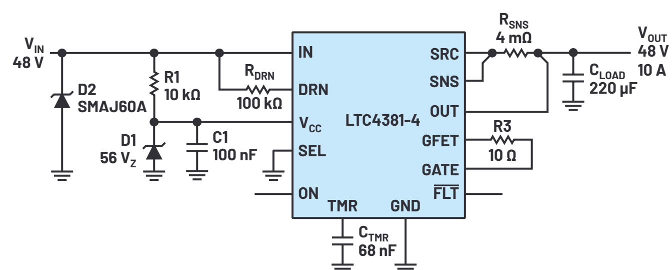

Figure 1. A 48 V, 10 A electronic fuse with an LTC4381.

The LTC4381's surge stopper functionality can be easily extended to work as an electronic fuse. Figure 1 shows the LTC4381-4 in a 48 V, 10 A electronic fuse application, which protects the power supply from an overload or short circuit at the output. During normal operation, the output V_{OUT} is connected to the supply input V_{IN} through the internal power MOSFET and external sense resistor, R_{SNS}. When the R_{SNS} voltage drop exceeds the 50 mV current limit threshold during an output overload or short circuit, the TMR pin capacitor voltage starts ramping up from 0 V and the internal MOSFET shuts off when the TMR voltage reaches 1.215 V (more on this later). The 4 mΩ R_{SNS} sets the typical overcurrent threshold to 12.5 A (50 mV/4 mΩ) and the minimum threshold to 11.25 A (45 mV/4 mΩ), providing sufficient margin to the 10 A load current.

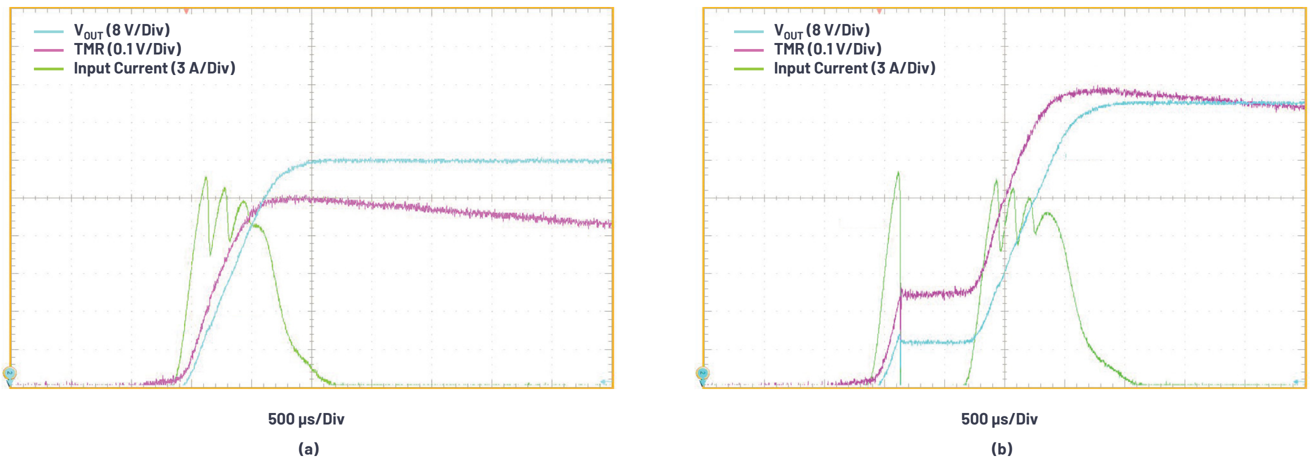

Figure 2. The LTC4381 10 A fuse circuit starting up a 220 µF load capacitor with (a) 48 V (left) and (b) 60 V (right) supplies.

Due to the parasitic inductance of the trace or cable back to the supply, the input voltage spikes significantly above the normal operating voltage whenever the internal MOSFET switch is turned off while current is flowing. Zener D1 protects the LTC4381 V_{CC} pin's 80 V absolute maximum rating, while D2 protects the internal 100 V MOSFET from avalanching. D1 also sets the output clamp to 66.5 V (56 V + 10.5 V) in case D2 is not used. R1 and C1 filter V_{IN} spikes and dips. If there is capacitance close to the LTC4381 limiting voltage spikes to below 80 V, then the V_{CC} pin can be directly connected to V_{IN}. In this case D1, D2, R1, and C1 could be eliminated.

With 10 A flowing through the internal MOSFET during normal operation, the LTC4381's initial voltage drop is 90 mV, and power dissipation is 900 mW. However, this power dissipation raises the LTC4381 package temperature to about 100°C on a DC2713A-D evaluation board at room temperature ambient, doubling the $R_{DS(ON)}$ and raising the voltage drop to 180 mV. The 4 mΩ sense resistor drops another 40 mV at 10 A. More copper area can be spent, especially on the SNS node, to lower the LTC4381 temperature rise. For reference, the DC2713A-D SNS node uses 2.5 cm^2 of 2 oz. copper, spread evenly across the board's two outer layers.

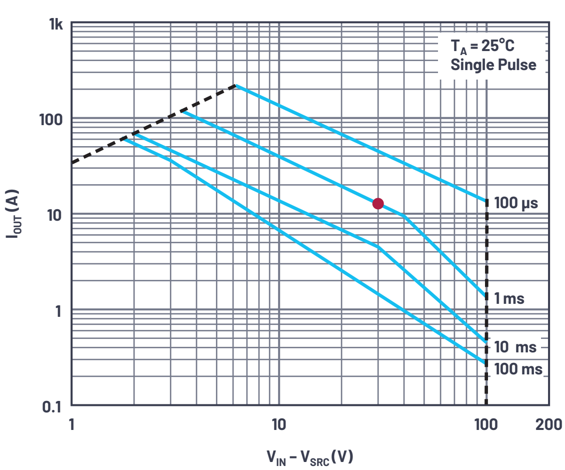

Figure 3. The LTC4381 MOSFET's safe operating area.

Start-Up Behavior

After the ON pin is released from ground, the Figure 1 circuit starts up a 220 µF load capacitor, as shown in Figure 2, for 48 V and 60 V supplies. 60 V is assumed to be the upper limit of the 48 V supply's operating range. 220 µF is the maximum load capacitor that can be charged up safely by this 10 A circuit, assuming no extra load current during startup. If the 220 µF capacitor is charged up to 60 V at the 12.5 A current limit, the inrush time is 220 µF × 60 V/12.5 A = 1.06 ms. The LTC4381 MOSFET's safe operating area (SOA) graph, as shown in Figure 3, reveals that it can survive 12.5 A and 30 V for 1 ms. 30 V is used since it is the average input-to-output differential voltage, which starts at 60 V and ramps down to 0 V.

Since there is no GATE pin capacitor to slow down its ramp rate, the output charges up within 2 ms, and the inrush current peaks at 17 A—shooting past the current limit threshold—before being brought under control (see Figure 2). The LTC4381 has a 50 mV current limit sense threshold, or 12.5 A with a 4 mΩ sense resistor when the voltage at the OUT pin is >3 V , but it increases to 62 mV or 15.5 A when the voltage at the OUT pin is <1.5 V as shown in Figure 4. This graph also indicates that the output can get stuck at 2 V (and TMR times out) if an electronic load current drops more than 20 mV (5 A for 4 mΩ) across the sense resistor during startup.

The waveforms in Figure 2 show that the inrush current pulses instead of being regulated due to the missing 47 nF gate capacitor required for loop stability. In fact, the current shuts off for around 0.5 ms during the 60 V inrush. The LTC4381 TMR pull-up current is proportional to the power dissipation in the internal MOSFET. Hence, TMR ramps up during start-up inrush even if the current is below the current limit threshold. The gate capacitor has been deliberately omitted to afford a small TMR capacitor that still allows a successful startup for the 220 µF load capacitor. A small TMR capacitor protects the MOSFET during a short-circuit fault, which will be discussed in the next section.

68 nF is the smallest TMR capacitor that keeps the TMR voltage rise to around 0.7 V during the 60 V startup. For instance, choosing 47 nF for the TMR capacitor lets TMR reach 1.15 V during a 60 V startup, which is very close to the 1.215 V gate off threshold. A 0.7 V peak TMR target voltage is chosen to provide adequate margin from its 1.215 V gate off threshold while accounting for these tolerances: ±50% for the TMR pull-up current ($I_{TMR(UP)}$ specification in the LTC4381 data sheet), ±10% for the TMR capacitor, and ±3% for the 1.215 V TMR gate off threshold ($V_{TMR(F)}$ specification).

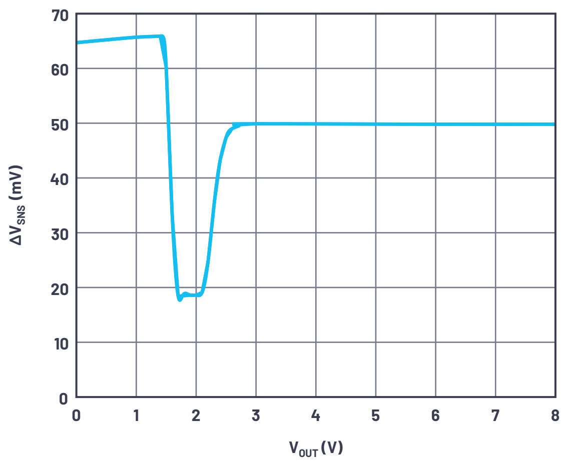

Figure 4. The LTC4381 current limit vs. output voltage.

Table 1 lists the recommended TMR capacitor for a maximum load capacitor to limit the TMR voltage rise to around 0.7 V during a 60 V startup.

Table 1. Recommended C_{TMR} for $C_{LOAD(MAX)}$.

$C_{LOAD(MAX)}$	C_{TMR}
12 μF	10 nF
47 μF	22 nF
90 μF	33 nF
140 μF	47 nF
220 μF	68 nF

Output Short-Circuit Behavior

The main purpose of the Figure 1 circuit is to protect the upstream power supply from downstream overcurrent faults such as overloads and short circuits, either during startup or normal operation. Figure 5 shows the LTC4381 starting up its MOSFET in the presence of a short circuit at the output. The gate voltage (blue curve) ramps up. When it exceeds the 3 V threshold voltage, the MOSFET turns on, and current (green curve) starts flowing. Due to the output short and the lack of a gate capacitor, the MOSFET current ramps up quickly, exceeding the 15.5 A current limit threshold at 0 V output, and peaks at 21 A before the LTC4381 reacts to pull down the MOSFET gate and shut off the current flow. The current excursion above 15.5 A lasts for less than 50 μs. Due to the brief power dissipation in the MOSFET, the TMR voltage (red curve) ramps up by about 200 mV. Since TMR is far below the 1.215 V gate off threshold, the gate turns on again, leading to another spike of current. With each spike of current, the TMR voltage steps up closer to 1.215 V.

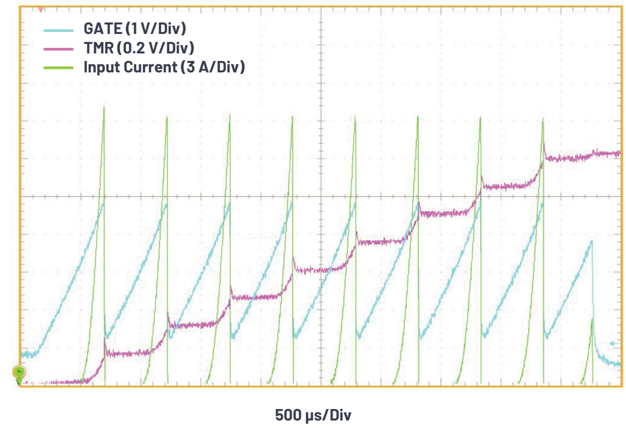

Figure 5. The LTC4381 starting up a 48 V supply into an output short circuit.

After a few such current spikes, the TMR voltage hits the 1.215 V gate off threshold and the MOSFET is kept off. The TMR now enters a cool-down cycle, and the LTC4381-4 doesn't let the MOSFET turn on again until the cool-down cycle completes. For a 68 nF TMR capacitor, the cool-down cycle is 33.3 × 0.068 = 2.3 s long, per Equation 8 in the LTC4381 data sheet. Since the LTC4381-4 retries automatically, the same pattern of current spikes and cool-down cycle will repeat indefinitely until the output short is removed. The pattern repeats if the output short circuit occurs during normal operation—that is, when the output is already up. Note that an LTspice® simulation does not exhibit the Figure 5 behavior unless 4 μH of input rail inductance is added.

Conclusion

The LTC4381's internal power MOSFET provides a compact circuit for an electronic fuse or circuit breaker for up to 48 V, 10 A systems. Design time spent in choosing a power MOSFET is eliminated. The LTC4381 MOSFET's SOA is production tested and guaranteed for each device, a guarantee that is not available with discrete MOSFETs. This helps build a robust solution to protect the expensive electronics in servers and network equipment.

Due to the absence of the loop-stabilizing GATE capacitor, the 10 A circuit discussed in this article has some unique behaviors that should be kept in mind. Specifically, these are the lack of the traditional dV/dt controlled inrush current and the pulsing currents during a short-circuit event. However, these are brief transient events, lasting less than a few milliseconds. Input bypass capacitance can help prevent any resulting disturbances on the 48 V supply, especially if it is being shared with other boards—for example, on a backplane. In the latter case, the load capacitance of the adjacent boards also serves the same purpose as input bypass capacitance.

About the Author

Pinkesh Sachdev is a senior applications engineer in the Cloud Power Group at Analog Devices. He received his B.Tech. degree from the Indian Institute of Technology, Mumbai, India, and his M.S. degree from Stanford University, both in electrical engineering. He can be reached at pinkesh.sachdev@analog.com.

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