Application Report
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Stopping Reverse Current Flow in Standard Hot Swap Applications

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ABSTRACT

This report provides a solution to stop reverse current flow in hot swap controller applications. The proposed circuit uses an inexpensive operational amplifier to sense the condition of the output voltage exceeding the input voltage, and subsequently disable the hot swap controller, stopping the flow of reverse current (current flow from the output (load) into the input (supply)). The device used for testing this method is the LM5069, configured to provide hot swap control of input voltages from 11V to 22V to a load capacitor of 220 µF. A schematic of the solution and results are provided.

INTRODUCTION

Hot Swap controllers have become popular choice for system protection at the front end of many power supplies. They help increase reliability by providing inrush current protection, over- and under-voltage control, current limit, and circuit breaker functionality. However, most hot swap controllers do not provide any protection from reverse current flow (current flow from the load to the input supply). Maintaining the charge stored on the load capacitance in the event of an input supply collapse or removal is critical in many applications, such as Solid State Drives (SSD). In these applications, reverse current flow results in unnecessary energy loss from the load capacitance. A diode can easily provide this function but consumes power during forward current flow. This paper offers a solution for the reverse current flow problem with the addition of a FET and a low-cost operation amplifier to the standard hot swap configuration.

BLOCKING REVERSE CURRENT WHEN THE HOT SWAP IS DISABLED

Adding a single FET in series to the standard pass FET blocks reverse current flow when the gate of the pass FET is off. Figure 1 shows a standard hot swap circuit using the LM5069, with the addition of a reverse blocking FET (Q2) that is oriented with the source connected to the pass FET (Q1) source. The gates are tied together such that when the GATE pin is low, the pass FET stops current flow from the input to output and the blocking FET stops current flow from output to input.

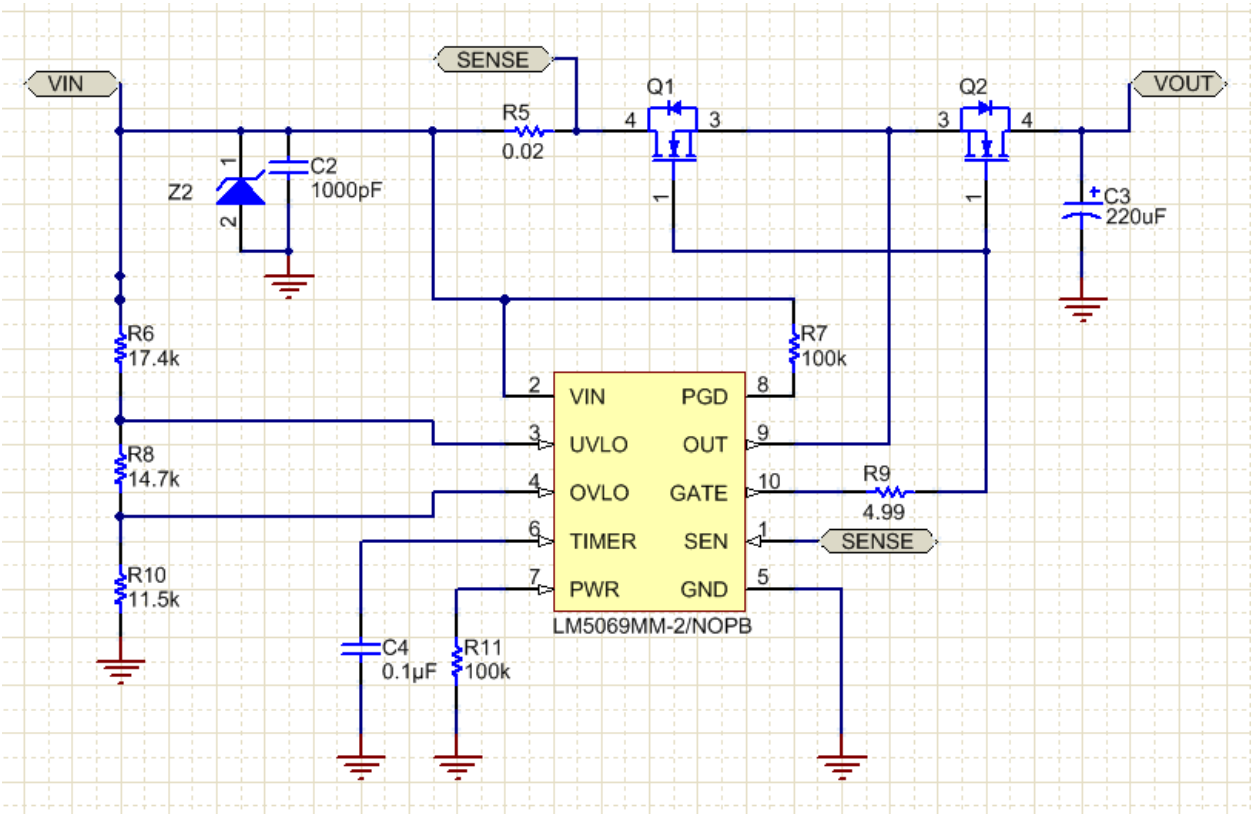

Figure 1. Reverse Current Blocking with the LM5069 When Device is Disabled

This addition can provide reverse current blocking in situations where the load can encounter positive voltages while the hot swap controller is in its insertion delay period, or if it has been shut off during a fault condition. The problem with this solution, though, is that once the gate is enabled, the hot swap controller does not react to a negative sense voltage. Therefore, if the input supply is lowered or removed, there is no mechanism to stop the flow of current from VOUT to VIN, and VOUT will track VIN until the hot swap controller's under-voltage threshold (UVLO) is crossed. Additionally, any external voltage impressed on the load can result in large current flow from the load to the input, limited only by the on-resistance of the pass FET, the sense resistance, and the internal impedance of the input supply.

BLOCKING REVERSE CURRENT WHEN THE HOT SWAP IS ENABLED

Active reverse current protection can easily be incorporated into the standard hot swap configuration with the use of a low-cost operational amplifier, the additional FET, and a handful of passive components. The premise is simple: detect a negative voltage from the input to the output, and disable the hot swap such that the gate of both the pass FET and the blocking FET are low. This condition can be maintained until the output falls back down to the input voltage or the system is disabled. The circuit in Figure 2 provides this function: when VOUT goes 3.5 mV above VIN, the operational amplifier U1 will swing its output from the negative rail created by Z1 to the positive rail, or VIN. When this happens, the transistor connected to the UVLO and OVLO resistor network will shut off. This causes the UVLO voltage to fall to ground, and the LM5069 in turn shuts off the gates of the pass and blocking FETs. This shut down state is reversed when the output voltage decreases to equal the input voltage, at which point the output of U1 will go to the negative rail and enable the hot swap.

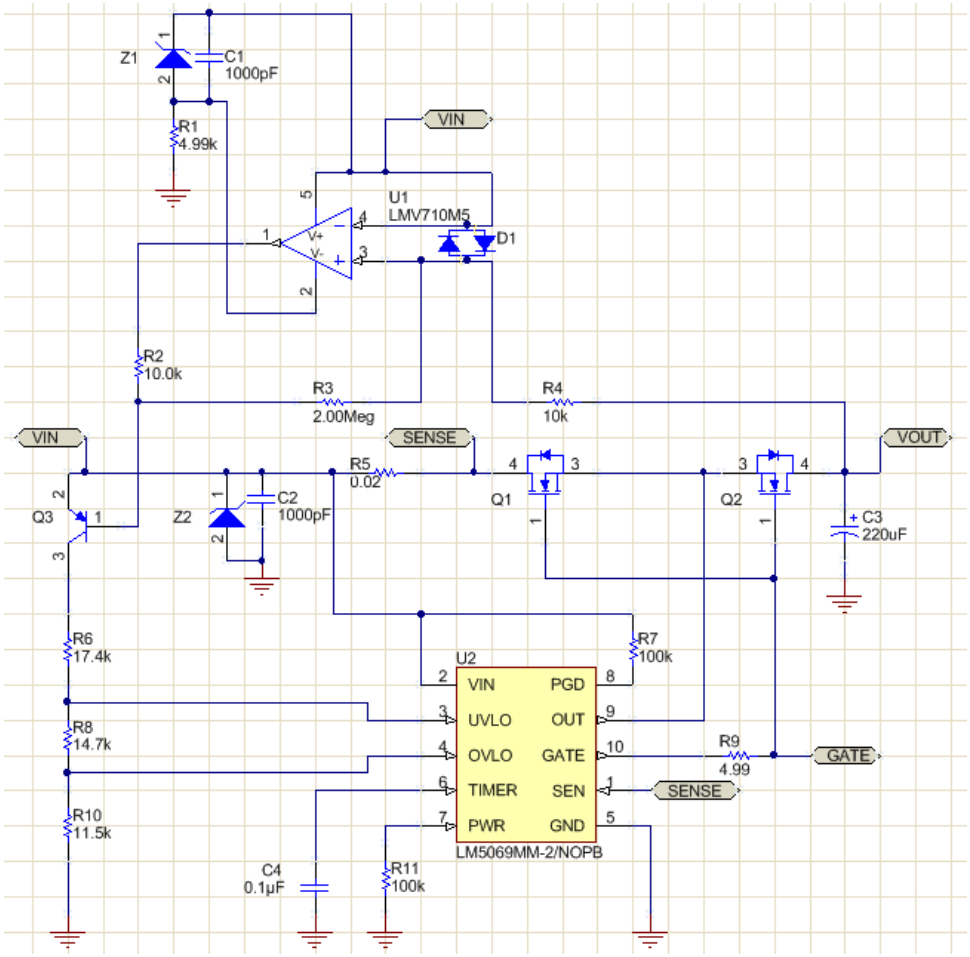

Figure 2. Active Reverse Current Blocking Circuit implemented with the LM5069

Some application considerations are necessary to properly select components in the design. The Zener diode Z1 is used to create a voltage rail for U1 that floats below VIN. To ensure that U1 maintains the appropriate operational voltage range, the resistor R1 should be sized such that enough current is pulled through Z1 to create an adequate negative bias voltage for U1 and also allow for the bias current for U1. Resistors R3 and R4 should be selected so that the voltage at which the reverse current detection is triggered is sufficiently higher than input voltage to allow for input offset voltage deviation on the amplifier to avoid an artificial trip of the blocking circuitry. In this application, the maximum input offset voltage specification of U1 is 3.5 mV, so a feedback resistor (R3) value of 2 MΩ, along with an input resistor of 10 kΩ (R4), was selected to give an offset of 3.5 mV. Any low supply voltage operational amplifier with a common mode range and output voltage range specified up to the positive rail can be selected.

RESULTS

Results are shown in figures 3 and 4. The test circuit in figure 3 shows a voltage source back-driving the output of the hot swap circuit. In figure 4(a), the response can be seen when the reverse blocking circuitry is disabled: There is an initial current surge (shown as IB) to charge the output capacitor, then current flows continuously from output to input, pulling up VIN in the process. Figure 4(b) shows the response when the reverse blocking circuitry is enabled: There is still a surge of current to charge the output capacitor, however, the LM5069 is disabled when VOUT >VIN + 3.5 mV. This turns off Q2, and blocks any additional flow of current from VOUT to VIN. VOUT will stay at the back-drive voltage, and VIN stays at the nominal unloaded input voltage.

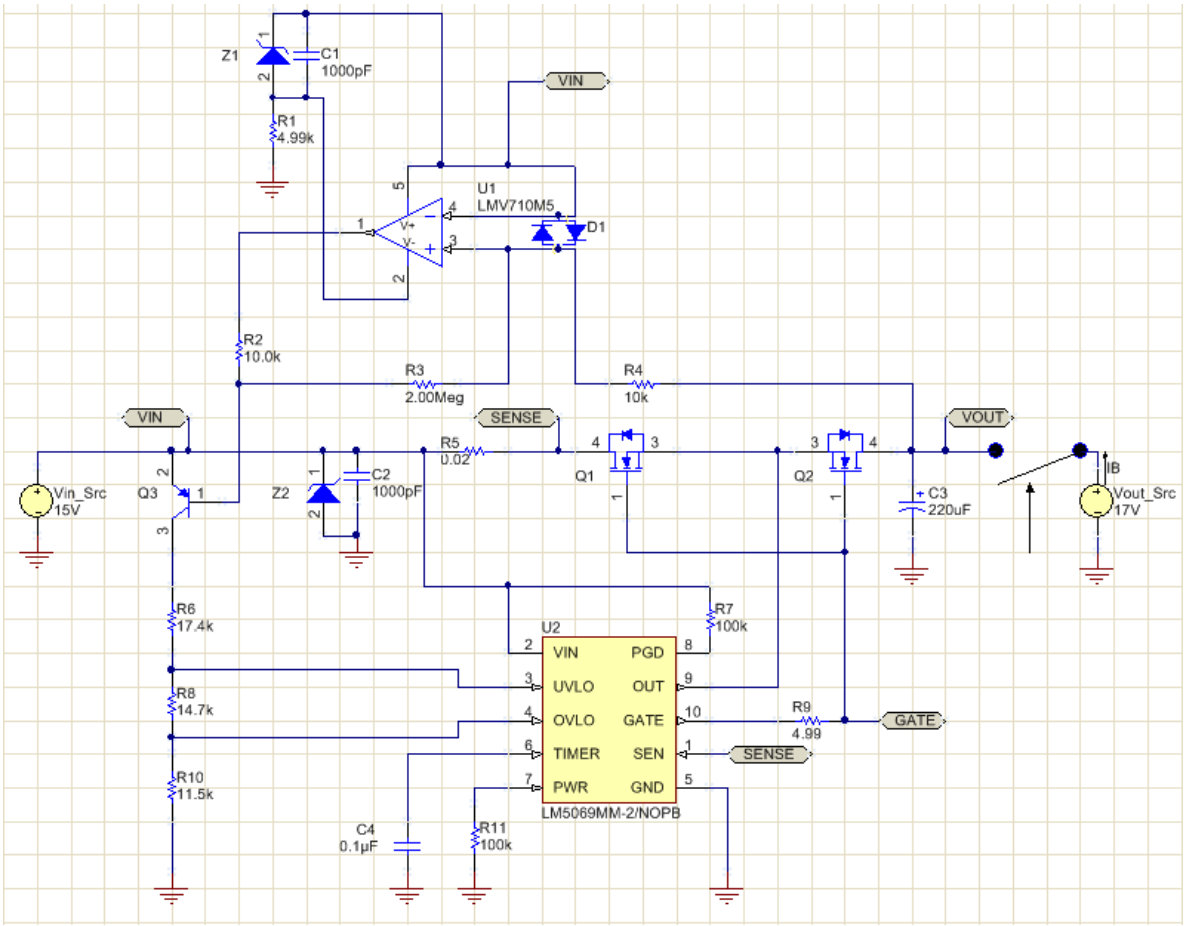

Figure 3. Standard Hot Swap with Reverse Current Blocking Circuitry Test Circuit

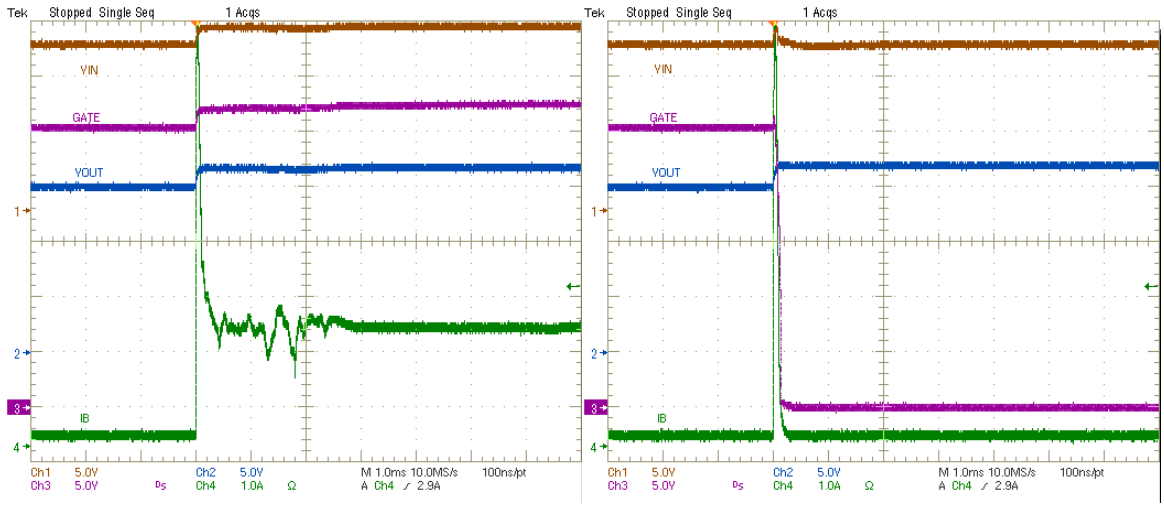

Figure 4. Hot swap Gate Response with the Reverse Blocking Circuitry Disabled (a) and Enabled (b)

CONCLUSION

A simple, inexpensive circuit addition to the standard hot swap controller configuration has been proposed to add active reverse current blocking capability. This functionality can be useful in applications that already use a hot swap and cannot tolerate current flow from the output to the input. While the response to reverse current conditions is not as fast as what is possible with a stand-alone diode, it offers improved efficiency due to minimal voltage drop during forward current flow.

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