Application Report
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Surge Stopping and Reverse Voltage Protection with the LM5069

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1 ABSTRACT

Many automotive and industrial applications require protection from a wide range of input supply insertion errors and voltage surges. Automotive voltage rails can exceed 40V during a load dump event, and at the same time, protection circuitry can encounter negative voltage surges below -24V during a reversal of the battery polarities. Several devices are available to block or clamp these events, however, a robust, high voltage programmable protection circuit, or "hot swap", such as the LM5069 can offer over-voltage, under-voltage, over-current protection as well as inrush control and power good flagging capability in one high voltage device. While other solutions lack reverse voltage protection or only disconnect on over-voltage / over-current events, the LM5069 circuits described here provide implementation for intelligent positive and negative surge suppression while protecting the corresponding MOSFETs. This paper discusses two configuration options for the LM5069 to achieve reverse voltage protection and over-voltage clamping while retaining the additional benefits of a hot swap controller.

2 PROTECTING AGAINST NEGATIVE VOLTAGES

Most engineers, at some point in time, have connected a power supply backwards to a circuit, and a majority of those engineers have discovered that in unprotected systems a huge amount of current will flow where it was not designed to. Ideally, the best solution to this problem would block all current in the reverse direction and have zero voltage drop when current flows in the forward direction. A diode in series with the supply voltage can provide an easy solution if the forward conduction power loss is minimal. A p-type MOSFET can provide reverse protection with minimal effort, however, the increased cost and on-resistance makes a p-type MOSFET less desirable than a comparable n-type. The common choice is an n-type MOSFET, driven with a controller, of which there are many options.

A high voltage hot swap such as the LM5069 is a natural fit to add a reverse-voltage blocking n-type MOSFET because of its inherent charge-pumped gate drive that is connected directly to the existing pass MOSFET. Figure 1 shows the standard evaluation board configuration for the LM5069, with the modifications for reverse input protection shown in red.

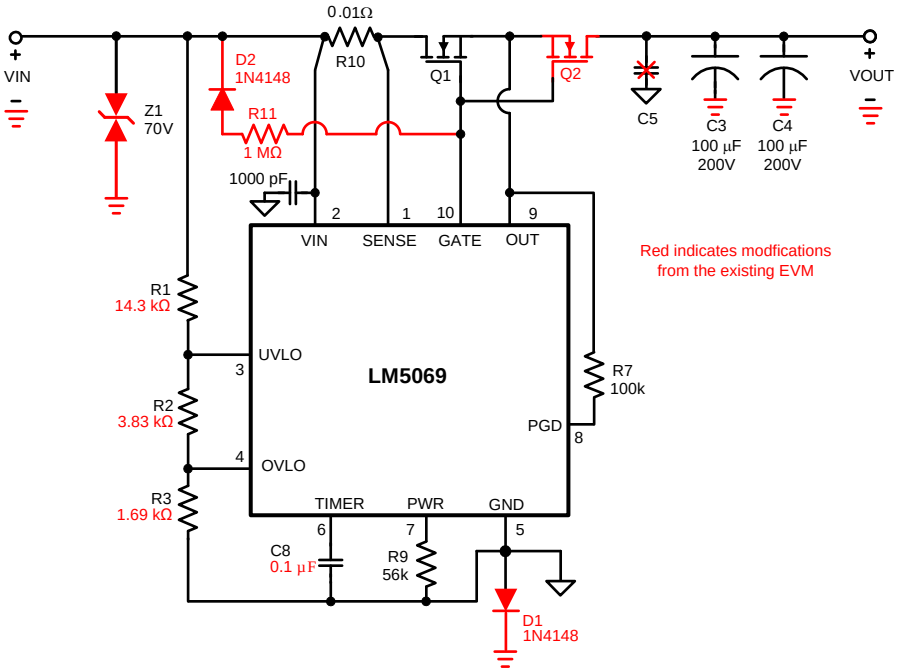

Figure 1. Reverse Voltage Blocking

2.1 Changes from the original EVM are listed below:

1. Q2 is necessary for reverse blocking when the input voltage is below the system ground.
2. D1 allows the GND pin of the LM5069 to track VIN when VIN is below the system ground.
3. D2 and R11 gives a path to VIN to discharge the GATE pin in the case that there is residual charge on the MOSFET gate after VIN goes negative. These components are only necessary if the input voltage can quickly transition from positive to negative.
4. R1, R2 and R3 were adjusted to give a 10V UVLO threshold and a 30V OVLO threshold.
5. Z1 changes from a unidirectional TVS (SMBJ70A) to a bidirectional TVS (SMBJ70CA)

Figure 2 shows the circuit response to a fast negative input transient. The high dv/dt of the input voltage creates current flow through the C_{OSS} capacitance of Q2 and also into the Gate node, however, the capacitance from gate to source and gate to drain of Q1 work to keep the V_{GS} voltage of both Q1 and Q2 below the threshold voltage. D2 and R11 can be used to drain any charge off of the Gate node in the case that the Gate was charged and the input voltage quickly transitions from positive to negative.

The reverse voltage blocking capability depends on the reverse breakdown voltage, $V_{(BR)DSS}$, of Q2. Both Q1 and Q2 were selected to be IRF3808, which has a $V_{(BR)DSS}$ of 75V.

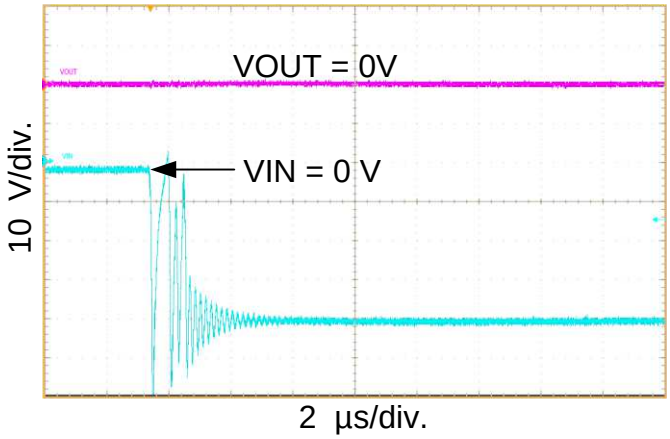

Figure 2. Negative Transient Input Voltage Response

3 STOPPING NEGATIVE AND POSITIVE SURGES

The UVLO and OVLO features of the LM5069 can be used to enable the pass MOSFET within a designed input voltage window. The circuit in Figure 1 is configured to enable the pass MOSFET by charging the GATE signal above the OUT node when VIN is greater than 9.3V and less than 29.3V. The forward voltage of D1 needs to be taken into account when calculating the UVLO and OVLO threshold voltages. This can be done by subtracting the diode forward voltage from the UVLO and OVLO thresholds when calculating R2 and R3 (R1 sets the hysteresis and is not influenced by the diode). See the modified calculations in Equation 2 and Equation 3.

$$R1 = \frac{V_{UVH} - V_{UVL}}{21\,\mu A} \quad (1)$$

$$R3 = \frac{2.5V * R1 * (V_{UVL} - V_D)}{(V_{OVH} - V_D) * (V_{UVL} - V_D - 2.5)} \quad (2)$$

$$R2 = \frac{2.5V * R1}{V_{UVL} - V_D - 2.5} - R3 \quad (3)$$

where

- V_{UVH} = Under-voltage Rising Threshold
- V_{UVL} = Under-voltage Falling Threshold
- V_{OVH} = Over-voltage Rising Threshold
- V_D = D1 forward voltage @ 1 mA

The results can be seen in Figure 3 for the given parameters:

- V_{UVH} = 10V
- V_{UVL} = 9.7V
- V_{OVH} = 30V
- V_D = 0.7V

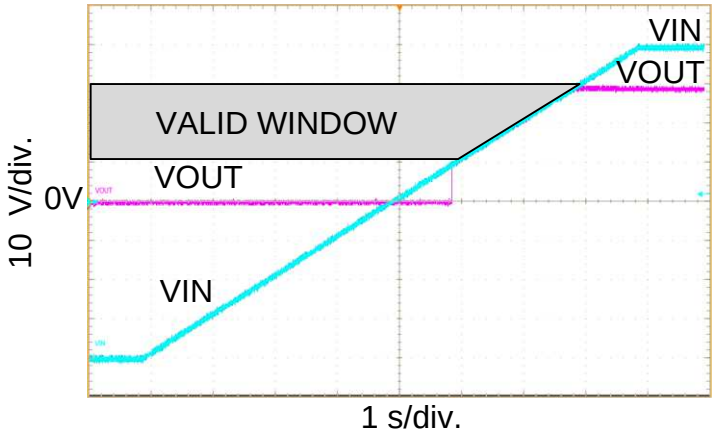

Figure 3. Valid Window using UVLO and OVLO

4 CLAMPING POSITIVE SURGES

The OVLO function of the LM5069 will shut off the pass FET when the voltage on the OVLO pin exceeds 2.5V. If there is no load on the output, the output voltage is maintained because there is no path for the output capacitors to discharge. However, if the output is loaded, the output voltage will quickly drop to zero.

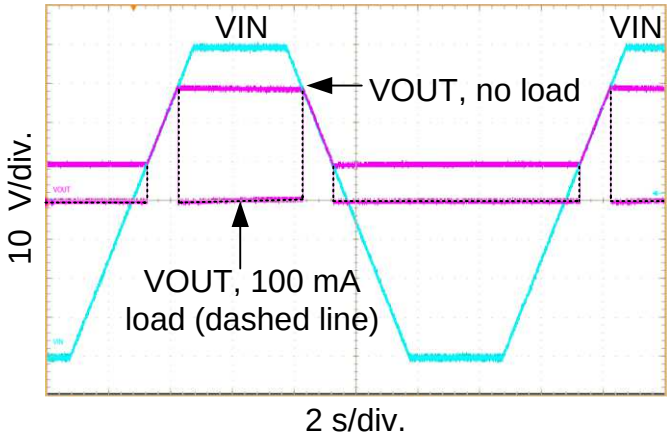

Figure 4. Output Response using UVLO and OVLO at no load and 100 mA load

In some cases, the system needs to “clamp” the output voltage such that the peak OVLO voltage is maintained during an over-voltage surge. This can be accomplished by using a zener diode with the cathode to the GATE pin and anode to the GND pin.

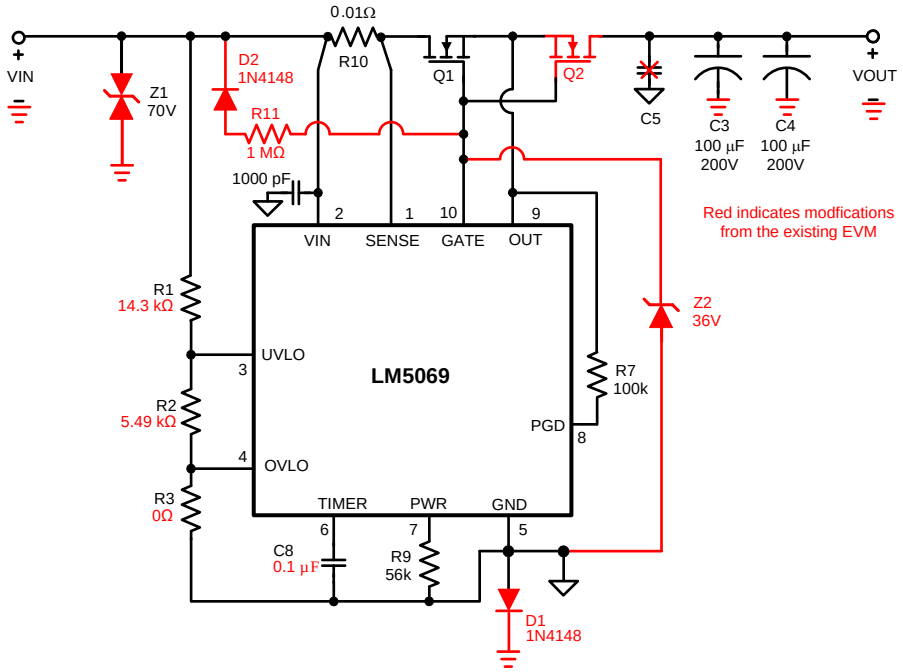

Figure 5. Output Voltage clamping with a zener on the gate

Figure 5 shows a circuit example of clamping an output voltage using a zener diode Z2 on the gate. When VIN rises up to the Z2 clamp voltage plus the threshold of Q1, the output voltage will rise until Q1 is forced to operate in a linear mode. At this point, the V_{GS} voltage of Q1 will be determined by the load current, which will be slighly higher than the threshold voltage of Q1. Q2 will maintain a relatively low V_{DS} voltage and have negligible influence on the output voltage. The output clamp voltage can be approximated as:

$$VOUT_{CL} = V_{Z2} + V_{D1} - V_{THQ1} \quad (4)$$

where

- $VOUT_{CL}$ = Clamped Output Voltage
- V_{D1} = D1 Forward Voltage @ 1 mA
- V_{Z2} = Z2 Clamp Voltage @ 20 µA
- V_{THQ1} = Q1 Threshold Voltage

Figure 6 shows the response of the circuit in Figure 5 with a 500 mA load on the output.

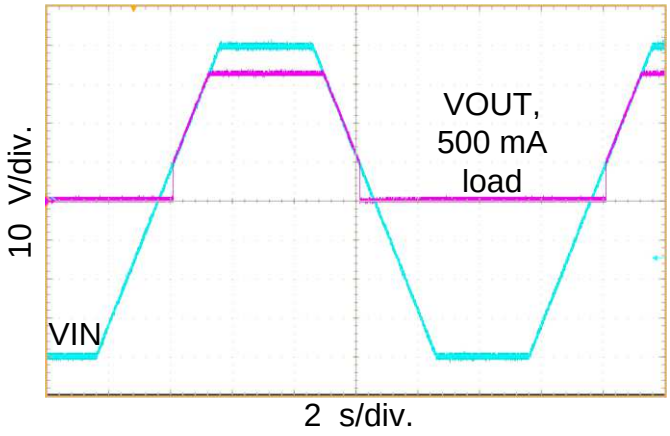

Figure 6. Output Voltage Clamped with Zener on Gate, 500 mA Load

An added benefit of using the LM5069 in an output voltage clamping circuit is that the MOSFET Q1 can be protected from exceeding the SOA. During the input surge event, the output voltage will remain constant. The power that is then absorbed by Q1 is the difference of the input and output voltages, multiplied by the load current. Many clamping solutions simply leave it up to the designer to ensure that the SOA of the MOSFET is not exceeded. However, the LM5069 provides a feature that will shut off the gate of Q1 when the programmed power limit is exceeded for a duration that lasts longer than the fault timer period. In Figure 5, the C8 will set the timer fault period, and R9 will set the SOA power limit. For this configuration, the timer fault period will last for 4.7 ms and the SOA power limit is configured to 45 W.

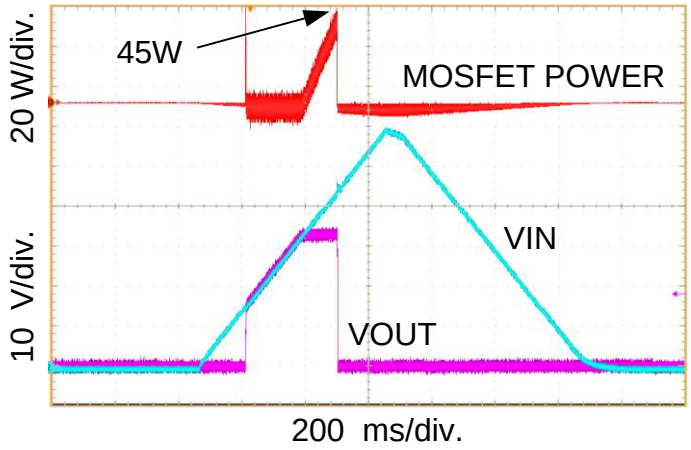

Figure 7. Output Voltage Response to SOA Power Limit, 4A Load

Figure 7 shows the output response when the SOA limit is exceeded with a 4A load. When the input voltage rises 11.25 V (45 W / 4 A) above the clamped VOUT voltage, the SOA protection circuitry is enabled. After 4.7 ms, the timer period will expire and the LM5069 will shut off Q1 and Q2, protecting Q1 from exceeding the SOA and subsequently failing.

Since transient protection solutions, such as those described, are used to ensure system reliability, ensuring the reliability of the protection circuit must be top priority. As demonstrated, LM5069 solutions provide robust protection in harsh environments, while protecting the pass elements (MOSFETS) that take the brunt of the outside world.

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