Application Note

Short to Battery Protection with TI Analog Switches and Multiplexers

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ABSTRACT

In the realm of automotive design, particularly in Electric Vehicle/Hybrid Electric Vehicle (EV/HEV) applications, there is an increasing necessity to make sure that I/O signals do not short to the battery voltage, often referred to as V_{BAT}. It is crucial to prevent damage resulting from a Short to Battery condition, which is of utmost importance in automotive environments where safety is paramount. The following application note dives into how Texas Instruments' analog switches and multiplexers can be leveraged to mitigate system damage by using a concept known as Short to Battery Protection.

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1 Introduction

In the automotive industry, particularly in EV/HEV applications, it is crucial to limit the effects that arise as a result of I/O signals shorting to the battery voltage, V_{BAT}. This is commonly referred to as Short to Battery protection. One way to achieve this protection is by implementing external diode and resistor networks as shown in Figure 1-1 to keep the input signals within the supply voltage. Alternatively, choosing a device with Injection Current Control circuitry as highlighted in Figure 2-1 eliminates the need for extensive external components to achieve such protection.

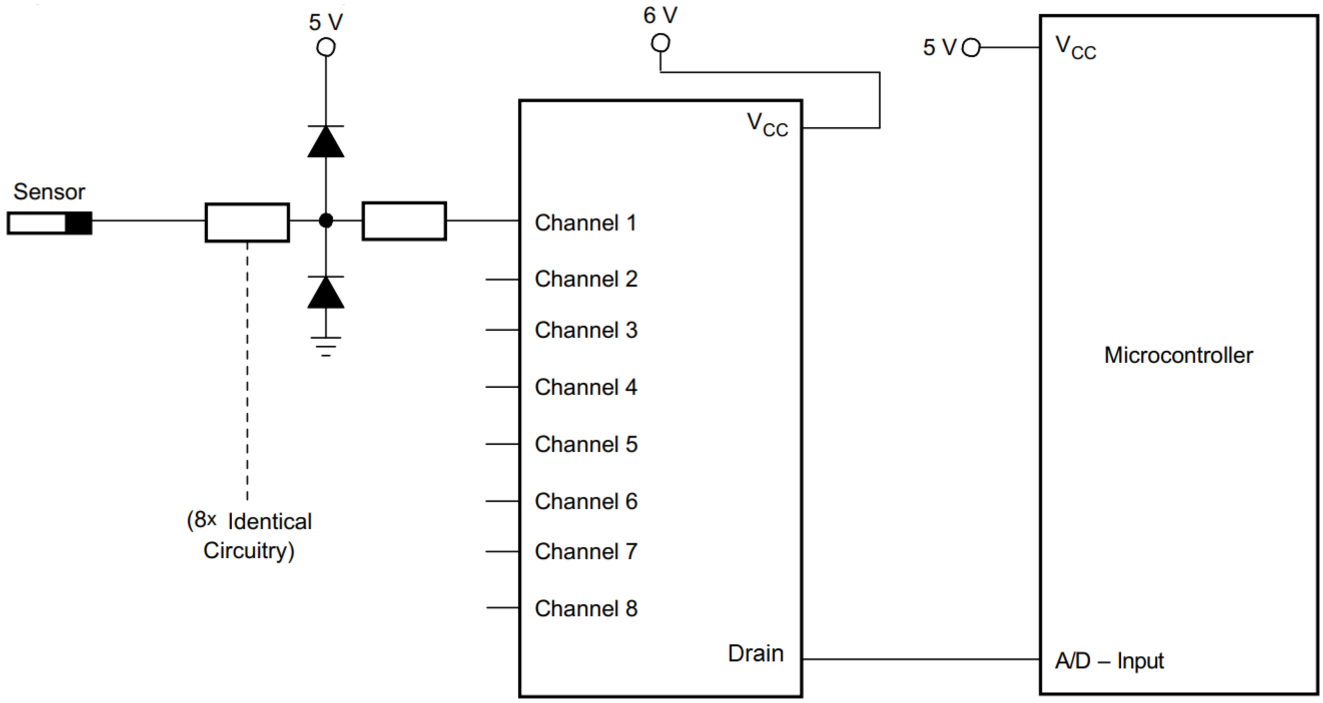

Figure 1-1. External Passive Components Implementation

2 Typical Application

Injection current is the current that is being forced into a pin by an input voltage (V_{IN}) higher than the positive supply (V_{DD} + ΔV) or the lowest potential (GND or V_{SS}). The current flows through the input protection diodes into whichever supply of the device that the V_{IN} signal is exceeding, potentially compromising the accuracy and reliability of the system. This current results in a ΔV_{OUT} at the output. A device with Injection Current Control can have a parameter in the data sheet referred to as Injection Current Coupling which is a ΔV_{OUT} spec that shows the maximum shift of the output voltage of an enabled signal path under various conditions. Injected currents can come from various sources depending on the application.

- Harsh environments and applications with long cabling, such as in factory automation and automotive systems, can be susceptible to injected currents from switching or transient events.
- Other self-contained systems can also be subject to injected current if the input signal is coming from various sensors or current sources.

When considering a device with the Injection Current Control feature to account for Short to Battery conditions it's important to understand how this feature works. The internal injection current control circuitry allows you to have a signal on the disabled paths without affecting the enabled path. In fact, these signals can even exceed the supply voltages. This circuitry, as shown in Figure 2-1, also provides protection against currents injected into the disabled paths, a feature not typically supported by standard CMOS switches. Moreover, TI offers switches like TMUX1308-Q1 and TMUX1309-Q1 that lack internal diode paths to the supply pin, thereby eliminating the risk of damaging components connected to the supply pin or unintentionally powering the system supply rail.

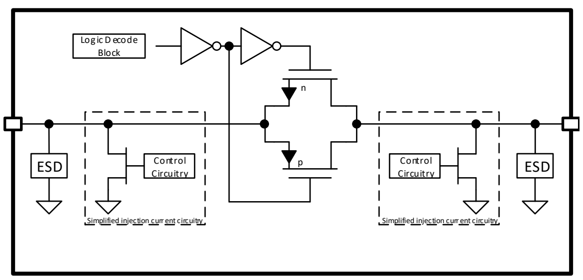

Figure 2-1. Current Injection Control Circuitry

The Injection Current Control circuitry is independently controlled for each source or drain pin (Sx or D). The control circuitry for a particular pin is enabled when that input is disabled by the logic pins and the injected current causes the voltage at the pin to be above VDD or below the lowest potential. The injection current circuit includes a FET to shunt the undesired current to GND in the case of overvoltage or injected current events. For example, each injection current circuit in the TMUX1308-Q1/TMUX1309-Q1 is rated to handle up to 50mA; the device, however, can support a maximum current of 100mA at any given time into all of the switch inputs combined. Limiting injected current into the device is as simple as adding a series limiting resistor to the signal path. This resistor can be calculated using Ohms Law (V=IR).

The limiting resistor can be efficiently used to help your system survive short to battery conditions. Let's take a look at an example utilizing the TMUX1308-Q1, which demonstrates several common use cases of implementing a series limiting resistor to survive such conditions.

We begin with the following setup to explore our first scenario with channel S7 selected and channel S0 experiencing a Short to Battery condition.

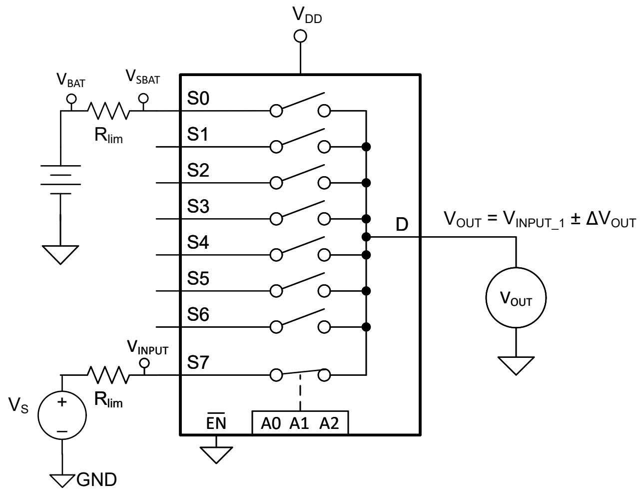

Figure 2-2. Channel S7 Selected, Channel S0 Experiencing a Short-to-Battery Condition

In this use case, we take a look at a layout of the TMUX1308-Q1 experiencing a Short to Battery condition on an unselected channel, S0, while channel S7 is selected. Using a 12V battery as an example, a quick calculation using the I_S/I_D spec of 25mA shows that an approximate R_{LIM} value of 480Ω can be needed for the channel to limit enough current such that the device is still within recommended operating conditions. In practice, this value can slightly vary depending on system design. In these experiments, we also were concerned about keeping V_{SBAT} at a value of 5.6V to provide headroom for the absolute maximum ratings of the device. For example, a value of 470Ω was seen to be sufficient enough to limit the current while maintaining a V_{SBAT} voltage within absolute maximum ratings. Note that choosing too large of an R_{LIM} can substantially limit current flow, but also provide a smaller ΔV_{OUT}. Choosing too small of an R_{LIM} can damage the device by allowing too much current to flow.

Table 2-1 indicates values of ΔV_{OUT}, V_{SBAT} and minimum R_{LIM} for various V_{BAT} cases when considering a maximum allotment of 25mA for I_S/I_D per the data sheet.

Table 2-1. R_{Lim} Values for 25mA Through the Switch

V_{BAT}	R_{LIM}	ΔV_{OUT} (typ)	V_{SBAT}
12V	470	< 10 uV	5.6V
19V	750	< 10 uV	5.6V
24V	1K	< 10 uV	5.6V
36V	1.5K	< 10 uV	5.6V
48V	2K	< 10 uV	5.6V
60V	2.4K	< 10 uV	5.6V

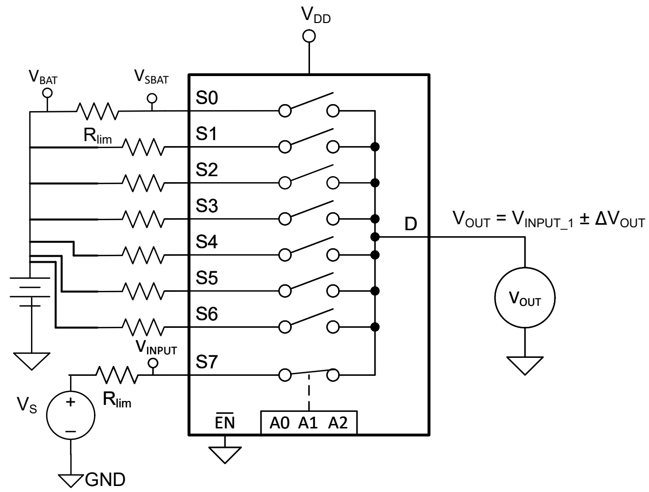

Figure 2-3. All Unselected Channels Experiencing a Short-to-Battery Condition

We then evaluate the scenario of seeing a Short to Battery condition on all unselected channels at the same time. Table 2-2 indicates values when considering a maximum allotment of 12.5mA for I_S/I_D. This is due to taking the I_{INJ} spec of 100mA and dividing by 8 to represent all channels. If you have the potential to see Short to Battery on all channels at the same time, then 12.5mA is the limiting factor. In practice, values can slightly vary depending on system design. In these experiments, we also cared about keeping V_{SBAT} at a value of 5.6V to provide headroom for the absolute maximum ratings of the device. Here again, choosing too large of an R_{LIM} can substantially limit current flow, but also provide a smaller ΔV_{OUT}. Choosing too small of an R_{LIM} can also damage the device.

Table 2-2. R_{Lim} Values for 12.5mA Through the Switch

V_{BAT}	R_{LIM}	ΔV_{OUT} (typ)	V_{SBAT}
12V	1K	< 10 uV	5.6V
19V	1.5K	< 10 uV	5.6V
24V	2K	< 10 uV	5.6V
36V	3K	< 10 uV	5.6V
48V	3.9K	< 10 uV	5.6V
60V	4.7K	< 10 uV	5.6V

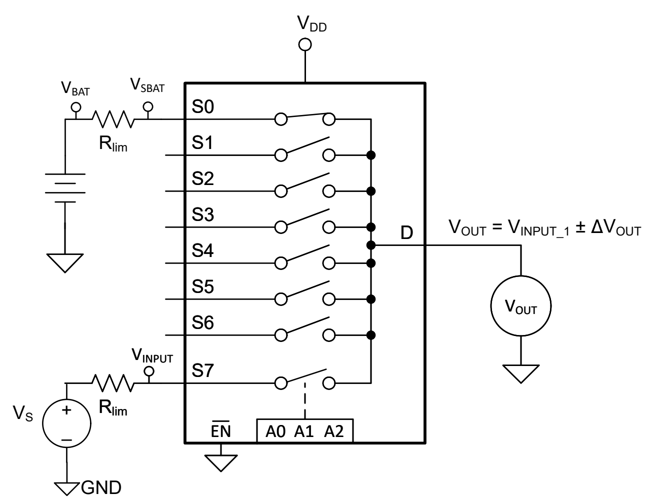

Figure 2-4. Short-to-Battery Condition Only on a Single Selected Channel

We then evaluate the scenario of a Short to Battery occurring when the switch is closed using a 5V supply. As such, input voltage needs to be limited to 6V. Table 2-3 indicates values of R_{LIM} needed to keep the voltage of a selected channel under 6V using a standard 5V V_{DD} for all short to battery cases. Choosing too large of an R_{LIM} can decrease ΔV_{OUT} while substantially limiting current flow. Choosing too small of an R_{LIM} can also damage the device.

Table 2-3. R_{Lim} Values for <6V Through the Switch

V_{BAT}	R_{LIM}	ΔV_{OUT} (typ)	V_{SBAT}
12V	1.6K	< 10 uV	5.9V
18V	3K	< 10 uV	5.9V
19V	3.3K	< 10 uV	5.9V
24V	4.7K	< 10 uV	5.9V
36V	10K	< 10 uV	5.9V
48V	13K	< 10 uV	5.9V
60V	15K	< 10 uV	5.9V

Note that if using a lower supply voltage, the R_{Lim} values can change for the best current flow. Always be aware of electrical characteristics in the data sheet such that proper operation of the device is designed for.

3 Summary

In conclusion, Short to Battery protection is a critical need in automotive applications where a design needs to account for various I/O signals shorting to your battery voltage. In this application note we studied what Short to Battery protection is, how Current Injection affects it and how a device with Current Injection Control can help add robustness to your automotive system. Next, several use cases were observed using a 5V supply. By choosing a TI analog switch or multiplexer that has Injection Current Control and no internal diode path to supply you can add flexibility to your system while also making sure of safety and quality.

4 References

- Texas Instruments, *TMUX13xx-Q1 Automotive 5-V, Bidirectional 8:1, 1-Channel and 4:1, 2-Channel Multiplexers with Injection Current Control*, data sheet.
- Texas Instruments, *Precision Labs: Prevent Crosstalk with Injection Current Control*
- Texas Instruments, *FAQ: How does Injection Current Control Work in TI Analog Multiplexers & Switches*, E2E™ design support forum.

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