Application Note

Protection Against Overvoltage Events, Miswiring, and Common Mode Voltages

ABSTRACT

With more systems demanding higher voltage operation, this creates new avenues for greater innovation and efficiency. However, this also comes with new risks related faults, transients, or other failure events that can bring a system to an abrupt halt. Having fault protection enabled devices in the signal chain not only prevents critical downstream devices from being damaged, but also allows for a robust system that will minimize any potential system down time. TI's fault protected multiplexers allow designers to utilize these high voltage nodes without having to fret about damaging events from taking down their systems for maintenance and repair.

This report will review common overvoltage and overstress events a system can experience and how the features of TI fault protected multiplexers and signal switches can combat these events.

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1 Overvoltage and Overstress Events and Effects

An overvoltage event can be defined as an event where the voltage seen at one or more of the device inputs exceeds the absolute maximum rating as defined in the data sheet. The traditional CMOS switch structure as shown in Figure 1-1 can help illustrate how an overvoltage event occurs.

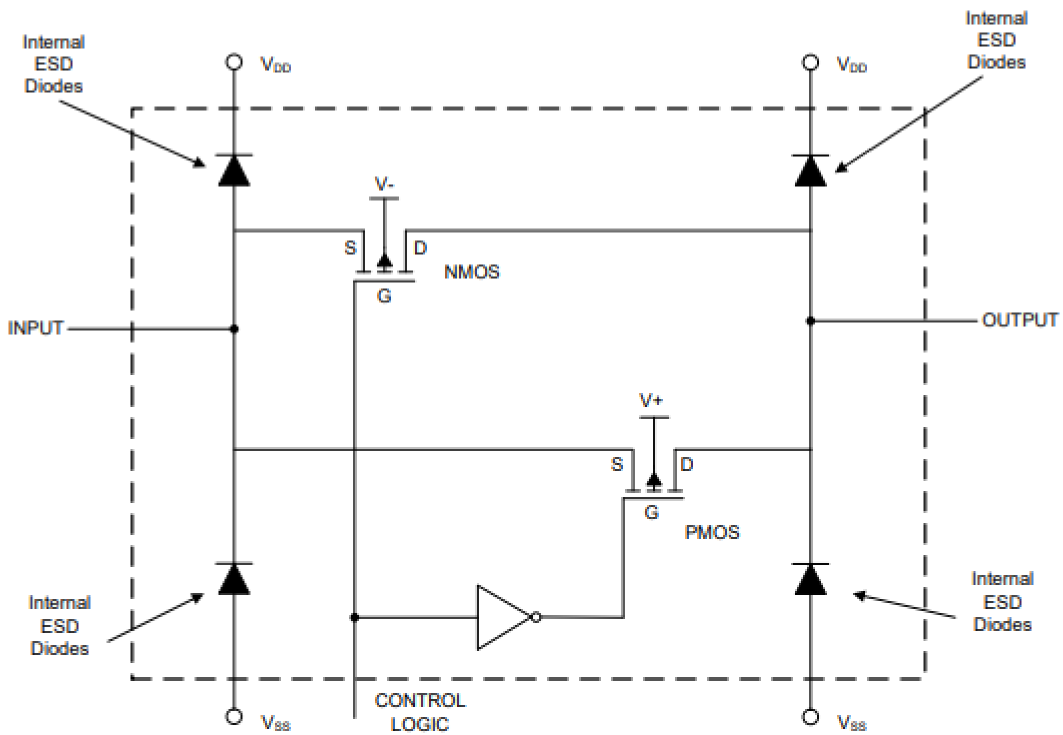

Figure 1-1. CMOS Switch Architecture

In many multiplexers and signal switches, there are ESD diodes tied between the input and the positive supply rail (VDD/VCC) and an ESD diode tied from the input to the negative supply rail or ground (VSS/GND). The purpose of these ESD diodes is to protect against ESD HBM and CDM events that can often be encountered during the manufacturing process or just in general handling of the device. Now, these diodes will begin conduction when they have a forward voltage drop of around 0.4V-0.7V and can sustain only a certain amount of current going through them for a limited amount of time. When an overvoltage event occurs, this will cause these diodes to turn on and begin conducting a very large current that will inevitably damage these diodes as there is normally no current limiting resistor in the path. Figure 1-2 is an illustration of such an overvoltage event:

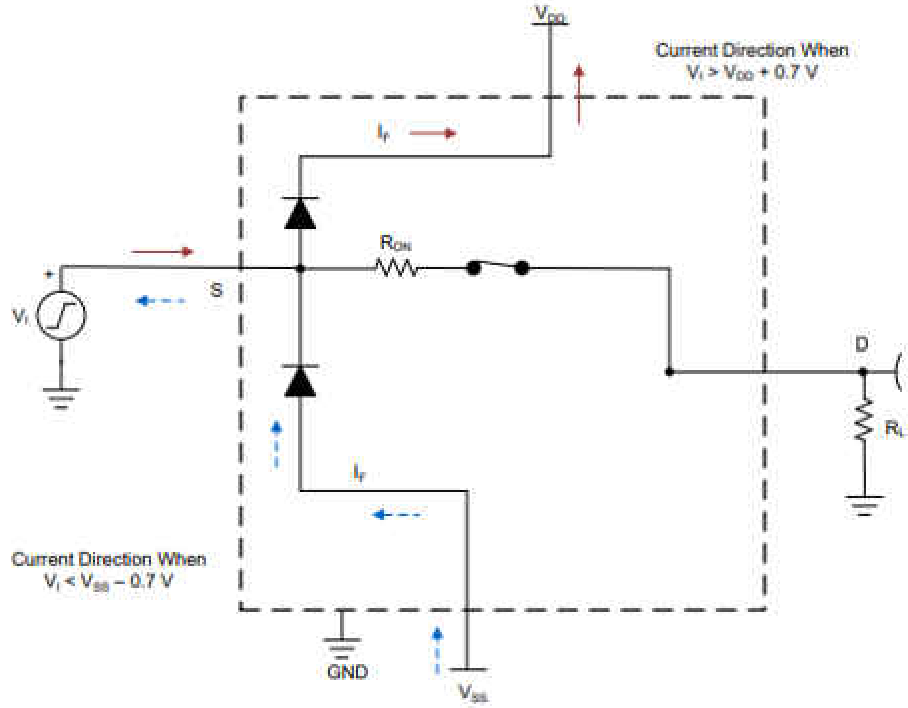

Figure 1-2. ESD Diode Conduction during Overvoltage Event

In addition, the device that is directly in the signal chain of the overvoltage event is not the only device at risk. Any devices that are also powered by the same supply rail or are referenced to the same ground can be affected as well. This phenomenon is known as backpowering. Backpowering can be described using the Figure 1-3.

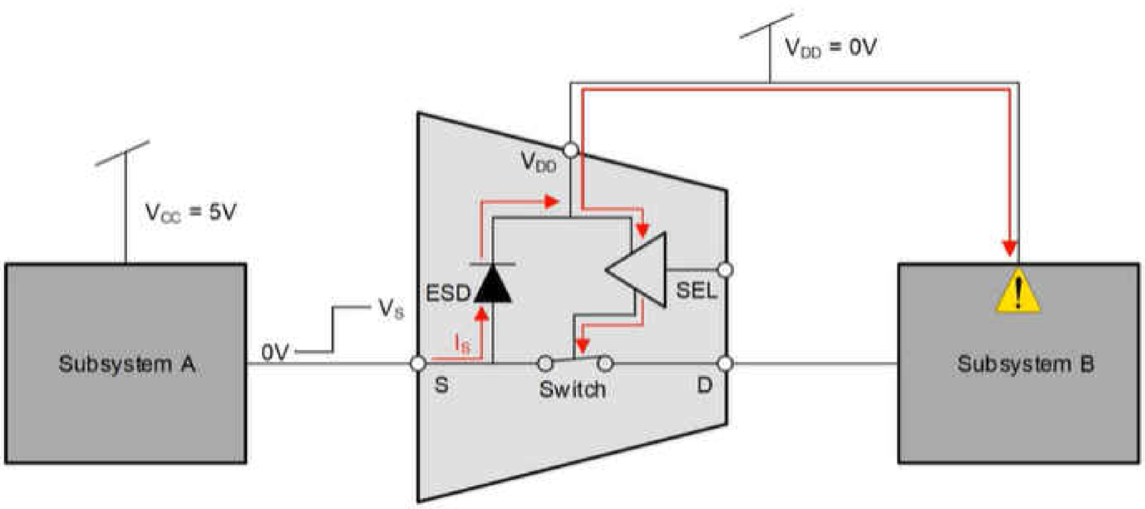

Figure 1-3. Backpowering during an Overvoltage Event

As shown in Figure 1-3, the overvoltage signal can be passed through the power rail to other devices downstream, potentially powering them up to a higher voltage than expected which can cause unexpected behavior in the system or can damage the devices.

Overstress events, like a hard short, can also introduce a potentially hazardous environment to the device as well. In most data sheets, there is a limited continuous current a multiplexer device can sustain before there is a risk to damaging the device. This risk is due to the power dissipation the device can handle and varies depending on the architecture of the switch, rated maximum voltage, package, and PCB design. Without any current limiting resistors or built-in current clamps to the device, these events can be particularly catastrophic to the system and can destroy multiple devices along the fault path.

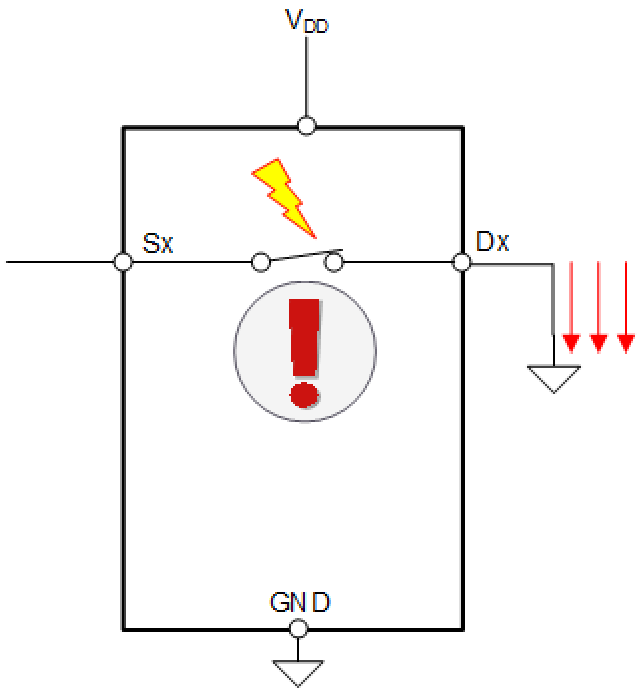

Figure 1-4. Short Circuit Fault

Lastly, ground shifting and common mode faults are other sources of possible system overstress. Ground shifting is when the circuit common reference is altered from its original or intended state and can be inadvertently introduced when there are large return currents flowing through the system (such as during an overcurrent event). Ideally, the system should have all the ground paths connected to one point (known as a star connection), however if not implemented, ground shifting can cause a significant impact on the system. Figure 1-5 is an example.

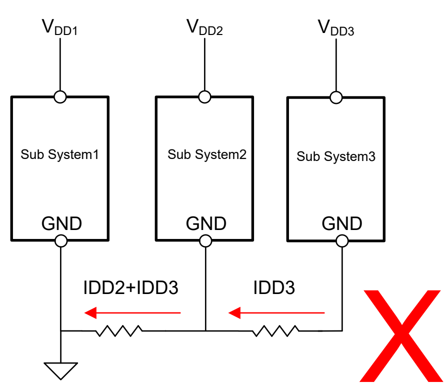

Figure 1-5. Improper Grounding and Effects

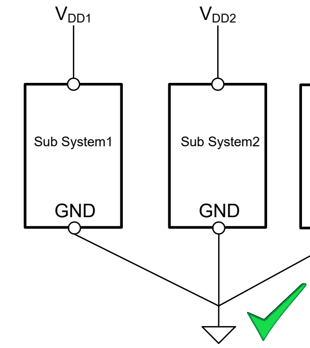

Figure 1-6. Star Connection

In the scenario above, it is evident that connecting each subsystem to ground at a different point can easily introduce differences in ground references between circuits. This is due to the fact that as the return current traverses through the return path, the different resistances and currents at each branch cause fluctuations in the ground reference of each circuit.

As stated previously, if the return current is large enough, it can shift the ground reference enough that it could cause the device to be exposed to an overvoltage event. Common mode faults are similar in which the ground reference suddenly changes to create an unsafe environment for the device, but occurs in a different way. Figure 1-7 illustrates an example.

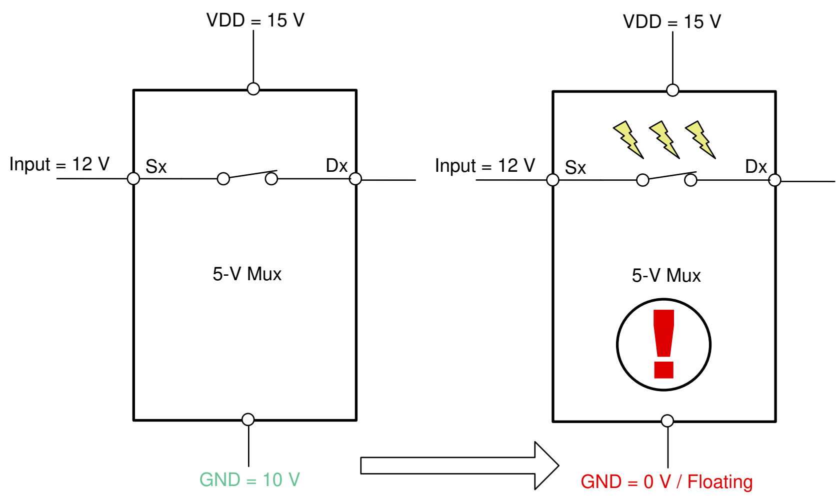

Figure 1-7. Common Mode Fault

Note that in this example, the GND is being referenced to 10 V and VDD is being referenced to 15 V, hence the device is operating as a 5 V device since that is what the device sees as a potential difference. Now, what happens if the 10V supply faults or gets shorted? This fault or short would cause the device to suddenly see the full 15 V and would cause a significant overvoltage event that would ultimately damage the device. While using ground shifting and common mode voltages can create great flexibility in a system, they are prone to these types of faults that can be catastrophic to the system if not implemented properly.

2 Multiplexer and Signal Switch Protection Against Fault Events

With all of these possibilities on the table, what can be done about it? The severity of these overvoltage and overstress events can cause real issues in many systems, however, TI offers a variety of multiplexers and signal switches that offer several built-in features that can protect against such events.

Overvoltage Fault Protection

One of the more common faults a system can experience is an Overvoltage Fault. Often caused from either a transient event, unstable power-up or power-down sequence, or a miswiring, this must to be given thorough consideration for every system. Fortunately, TI offers multiplexers and signal switches that include internal overvoltage protection circuitry that can handle such events.

As shown in Table 2-1 the Overvoltage Protection for these devices include the following features.

Table 2-1. Overvoltage Protection Features

Feature	Description
+/-60 V Overvoltage Protection	+/-60 V overvoltage protection in reference to ground
85 V Absolute Maximum Voltage Across Pins	85 V Between Source Pins and Supply Rails 85 V Between Source and Drain Pins
Overvoltage Programming	VFP and VFN pins that can be individually set to trip at a specific fault voltage.
Overvoltage Detection	When an overvoltage event is detected (VSource > VFP/VFN + VT OR VSource >VDD/VSS + VT), the channel experiencing the overvoltage event turns off and the Fault Flags (available on select devices) are set

While these attributes are common across TI's fault protected multiplexer family, each device implements these features slightly differently. Table 2-2 highlights some of these key differences and it is important to understand which would be best in each specific system.

Table 2-2. Fault Protected Mux Configurations

Device	Configuration	Fault Behavior		
		Trigger Supplies	Output Behavior	Flag
TMUX7308F/TMUX7309F	8:1x1/4:1x2	Primary (VDD/VSS)	Pull to Primary Supply	None
TMUX7411F/7412F/7413F	1:1x4	Primary (VDD/VSS)	Pull to Primary Supply	FF
TMUX7462F	1:1x4	Fault (VFP/VFN)	Pull to Fault Supply/Open	FF

Depending on the desired system performance, designers will need to determine how they would like to have the multiplexer handle the fault events. The TMUX7308F represents a subset of devices where it offers the most generic protection as it has the overvoltage detection set at anything above the given supply rail. For more control, devices similar to the TMUX7462F allows the designer to control exactly where they would like to have the multiplexer trip for an overvoltage event. The system examples Figure 2-1 and Figure 2-2 illustrate how to use these devices in different situations:

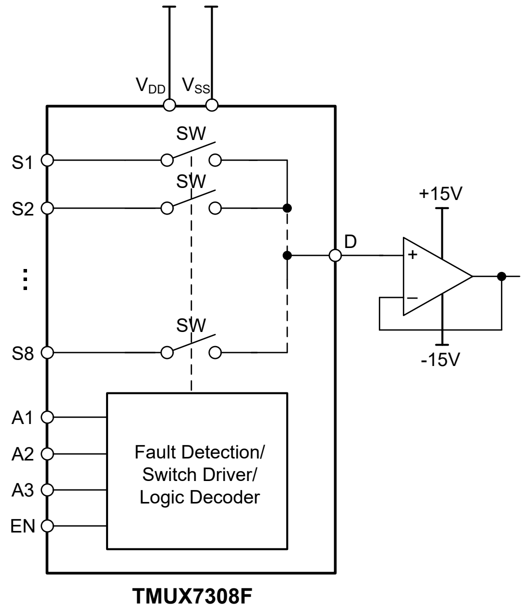

Figure 2-1. Main Supply Fault Control

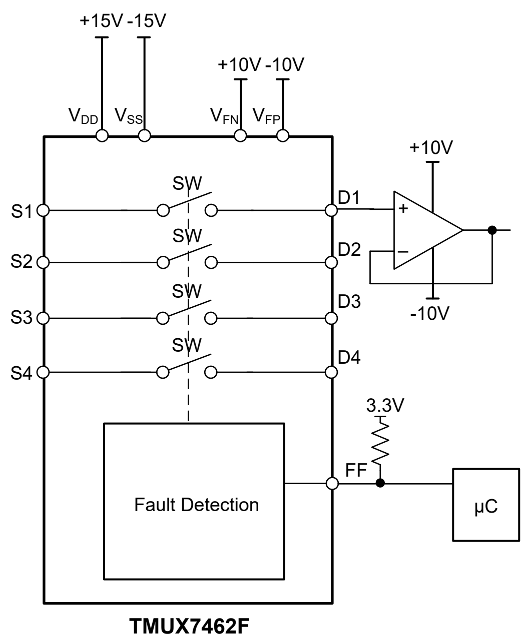

Figure 2-2. Secondary Supply Fault Control

When the downstream devices need to be protected to the same level as the fault protected multiplexer, the TMUX7308F is a sufficient solution here as it will protect up to the VDD/VSS rail voltage. If there is a need to customize the fault protected mux to protect against a certain threshold, the TMUX7462F allows the designer to set the exact trip voltage using the VFP/VFN pins in order to prevent downstream damage.

Other important considerations include the reporting of faults (using fault flag pins SF and FF) which is offered on some multiplexers and also the output behavior demonstrated when there is a fault. The output can be put into an open state or can be pulled to a supply rail. The TMUX7462F is unique as it has an addition DR (drain response) pin that lets the user dictate how to operate the state of the output during a fault event. If the DR pin is pulled low, it will be pulled to the supply that is exceeded. However, if pulled high or floated, it will become high impedance.

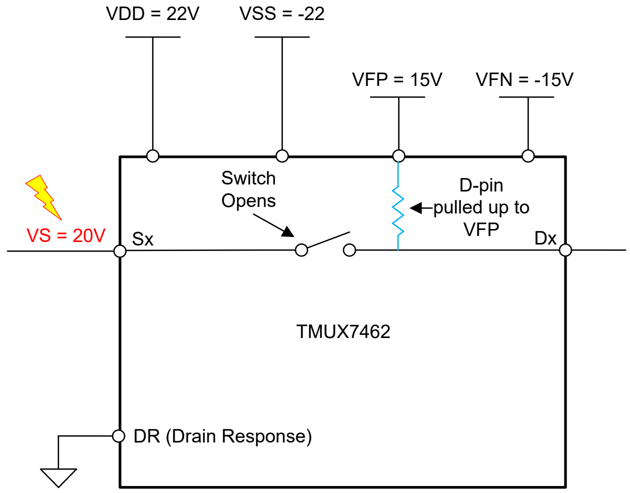

Figure 2-3. TMUX7462F Drain Response tied to GND

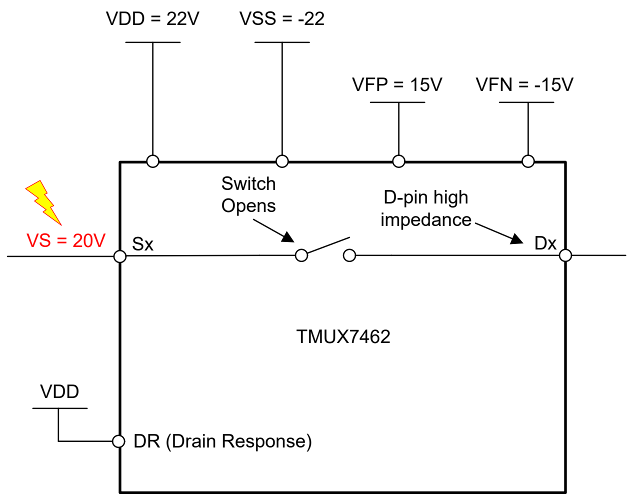

Figure 2-4. TMUX7462F Drain Response tied to VDD

The fault flags, SF (Specific Fault Flag) and FF (General Fault Flag) are often used in conjunction with a microcontroller to help report system faults. Both of these pins are open drain outputs and are asserted low when the multiplexer detects an event occurred. When the event occurs, the FF pin will be pulled low and report that one of the device inputs has encountered a fault. The SF pin, however, will be asserted low only when the fault affected channel is selected with the address pins. Like mentioned previously, some devices may either have one, both, or neither of these pins.

Powered-Off Protection

Another critical feature of these protection multiplexers it their inherent Powered-Off protection circuitry which allows the devices to sustain overvoltage events of up to +/-60V when the supplies are removed or at 0V. This provides relief from power sequencing difficulties as well as miswiring instances. Take the system Figure 2-5 shown as an example of all the possible miswiring combinations with just three inputs and the repercussions on the TMUX7219 device:

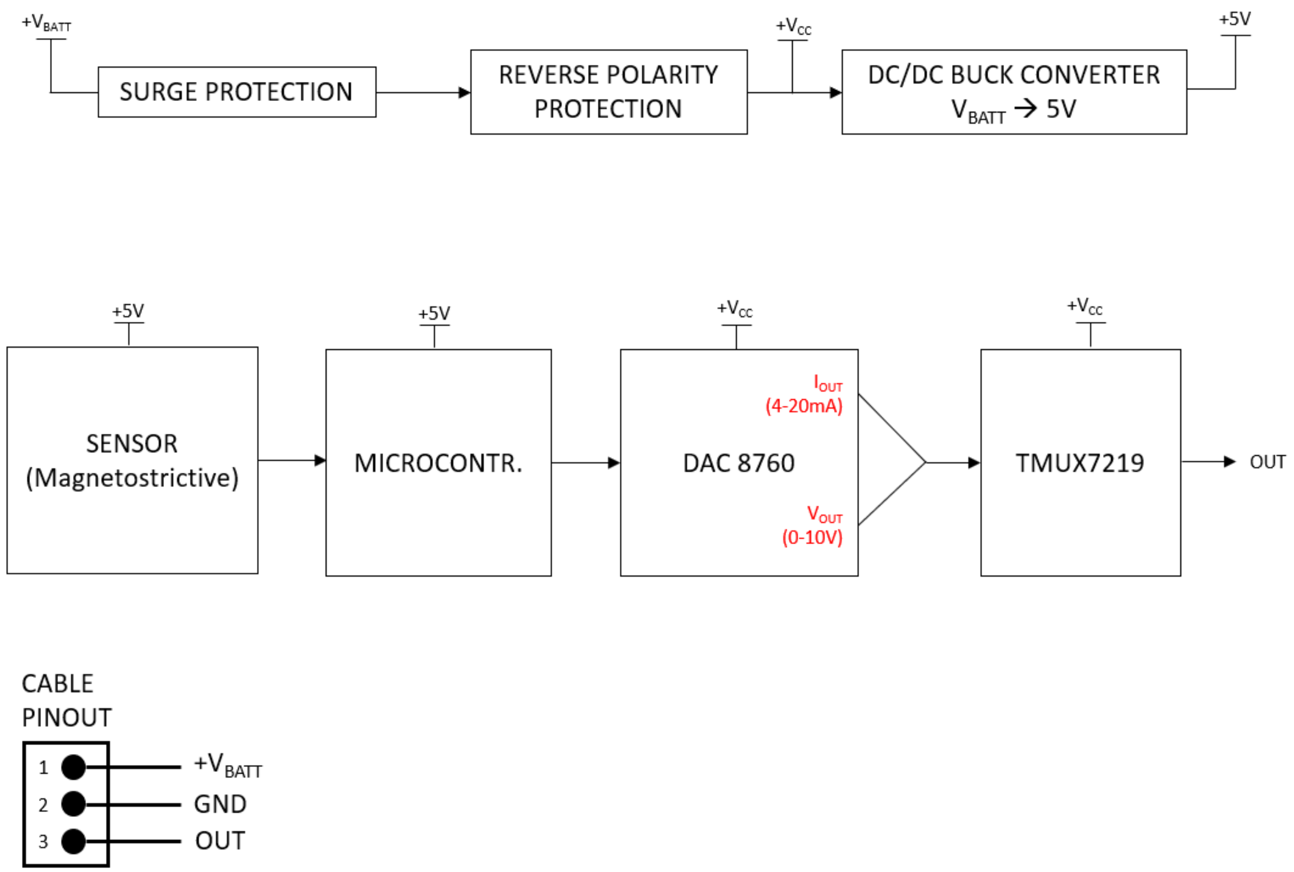

Figure 2-5. Miswiring on a Non-Fault Protected Device

Table 2-3. Miswiring Combinations

Combinations			Result
VCC	**D**	**GND**	
VBATT	OUT	GND	Operates without issue
VBATT	GND	OUT	GND pin/circuit is now floating or at the potential the OUT cable is connected to. This could be a problem depending what is on that side of the OUT cable. Remainder of circuit is OK.
OUT	VBATT	GND	VCC is now floating or at the potential the OUT cable is at. VBATT is now attached to the input and most likely at a higher potential than VCC, thus turning on the ESD protection diode and possibly back powering device
OUT	GND	VBATT	VCC is now floating or at the potential the OUT cable is at. VBATT is now attached to the GND and the input most likely has a lower potential than VBATT, thus turning on the ESD protection diode and causing current to flow, possibly damaging the device if no current limiting resistor is in place.
GND	VBATT	OUT	VCC is now grounded. GND is floating or at potential of OUT cable. Input is at VBATT which will cause the ESD diode to turn on and possibly back power the device.
GND	OUT	VBATT	VCC is now grounded. GND is at VBATT and input is floating or at potential of OUT cable. S pin voltage will be lower than GND, thus turning on ESD protection diode and allowing current to flow. Could cause damage if current is too high. Need current limiting resistor

Essentially, all of the situations except the correct wiring will pose some risk to the device and system if there is no implementation of a protection device that does not incorporate powered off protection. With this feature, all of these combinations are accounted for and can be protected against.

Current Limit Protection

While there are many sources that can cause an overvoltage event, the system also needs to take into consideration the possibility of an overcurrent event. The TI Fault Protection Multiplexer family has a unique architecture to help limit the current to a fixed amount while also keeping the device within its maximum junction temperature. Figure 2-6 is an example of TI versus a competitor device under the same shorted fault condition at 25C:

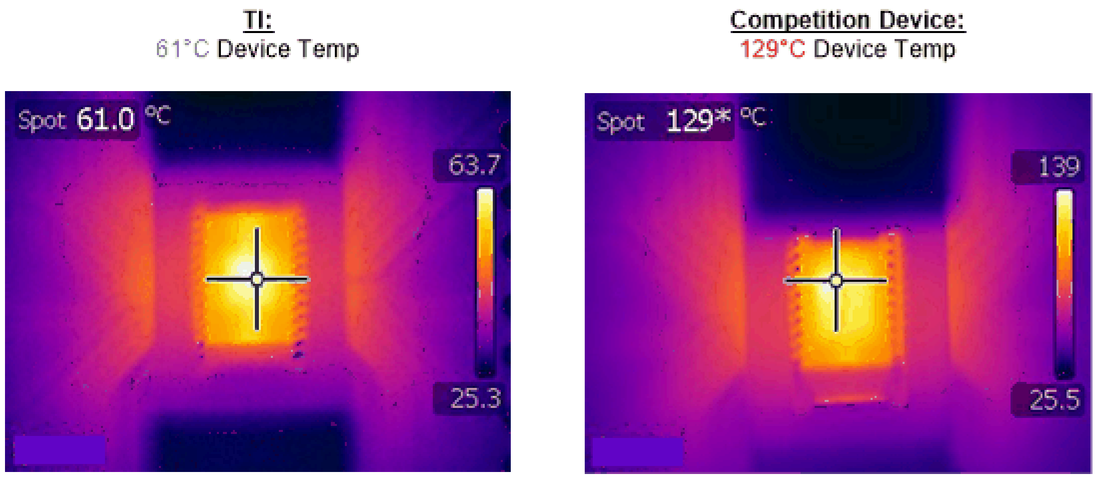

Figure 2-6. TI Device vs. Competitor Device

As the temperature is increased to 125C, the TI device under fault increases to 145°C which is still within the absolute maximum junction temperature of 150°C while the competition device can get up to 200°C. An important note is that these devices are not meant to be left in this shorted state indefinitely and the fault should be cleared as soon as possible. For information on the approximate current limit for each fault protected device, it can be estimated from the IDC parameter defined in each data sheet at the specified temperature.

Integrated vs. Discrete Solution

Even though some of these overvoltage and overstress situations can be addressed using external components, there are often significant drawbacks when doing so. Figure 2-7 is an illustration of the extra components that would be needed to replicate only some of the features boasted by the TI Fault Protected Multiplexer family.

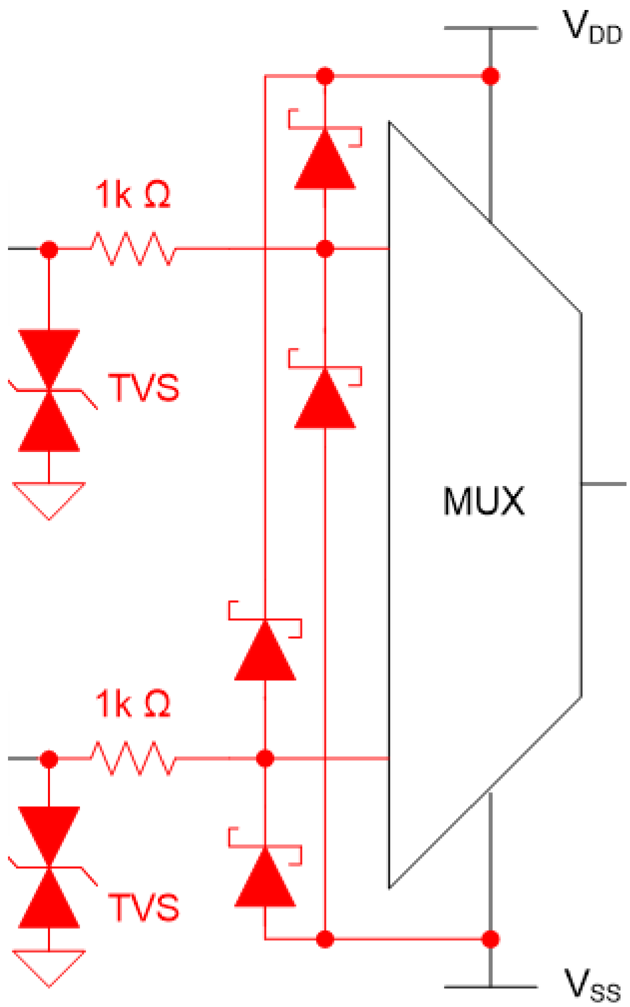

Figure 2-7. Mux without Integrated Fault Protection

TVS diodes on every input, Schottky or Zener diodes between the supply rails and the input, and current limiting resistors would be required to do just a subset of what the integrated solution can do. In addition, the system level repercussions are significant when implementing a discrete solution:

Table 2-4. Discrete Component Impact

Discrete Protection Drawback	System Level Impact
Series resistor increases the settling time of the signal	Limits switching speed of the multiplexer and slows down the system
Protection diodes introduce additional leakage current and parasitic capacitance	Impact system measurement accuracy and affect linearity
No protection in floating supply case	Impact system robustness during uncontrolled power sequencing events
Large number of components required	Add system cost and increase board size

3 Conclusion

Overvoltage and overstress events are a common problem faced in many systems, however, TI has a wide array of multiplexers that introduce significant robustness and protection features that can mitigate or completely eliminate these possibilities. Inherent overvoltage protection, powered-off protection, and current clamp capabilities that are prevalent in the TI fault protection multiplexers offer the resilience needed for systems to operate reliably and offer flexibility to tailor each system to handle these undesired events.

4 Resources

1. Texas Instruments, System-Level Protection for High-Voltage Analog Multiplexers application brief.
2. Texas Instruments, TMUX7462F data sheet.
3. Texas Instruments, TMUX7308F data sheet.
4. Texas Instruments, TMUX7412F data sheet.
5. Texas Instruments, TI Precision Labs - Switches and Muxes: Simplify Power Sequencing with Powered-Off Protection.
6. Texas Instruments, TI Precision Labs - Switches and Muxes: What is Overvoltage Protection?