

Replacing Discrete Protection Components with Overvoltage Fault Protected Analog Switches

By Paul O'Sullivan

Abstract

The challenge of designing robust electronic circuitry often results in a design with a multitude of discrete protection components with associated cost, design time, and space additions. This article discusses fault protected switch architecture, along with the performance benefits and other advantages it offers vs. traditional discrete protection solutions. A new novel switch architecture and proprietary high voltage process that provides industry-leading fault protection along with the performance required for precision signal chains is discussed. ADI's new portfolio of fault protected switches and multiplexers (ADG52xxF and ADG54xxF) uses this technology.

Analog input protection for high performance signal chains is often a pain point for system designers. There is typically a significant trade-off between analog performance (such as leakage and on resistance) and the level of protection that can be offered by discrete components.

Replacing the discrete protection components with overvoltage protected switches and multiplexers can offer significant benefits in terms of analog performance, robustness, and solution size. The overvoltage protected component sits between sensitive downstream circuitry and the input that is exposed to external stresses. An example of this would be the sensor input terminal in a process control signal chain.

This article details the issues caused by overvoltage events, discusses traditional discrete protection solutions and the associated drawbacks, presents the solution offered by overvoltage protected analog switches including features and system benefits, and finally introduces the industry-leading portfolio of ADI fault protected analog switches.

Overvoltage Issues—Back to Basics

When the input signal applied to a switch exceeds the power supplies (V_{DD} or V_{SS}) by more than a diode drop, the ESD protection diodes within the IC become forward-biased and current flows from the input signal to the supplies, as shown in Figure 1. This current could damage the part and may trigger a latch-up event if the current is not limited.

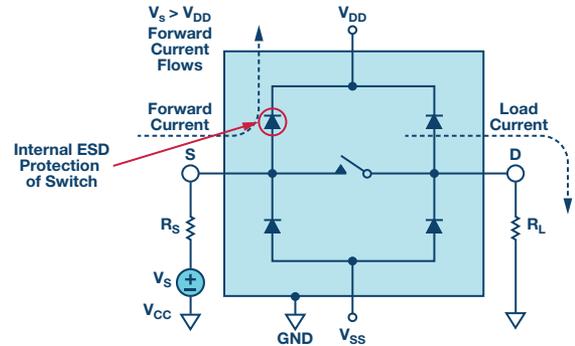
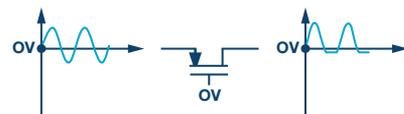


Figure 1. Overvoltage current path.

If the switch is unpowered, there are a couple of scenarios that could occur:

1. If the power supplies are floating, the input signal could end up powering the V_{DD} rail through the ESD diodes. In that case, the V_{DD} pin goes to within a diode drop of the input signal. This means the switch would effectively be powered, as would any other components using the same V_{DD} rail. This could lead to unknown and uncontrolled operation of devices in the signal chain.
2. If the power supplies are grounded, the PMOS device will turn on with negative V_{GS} so the switch will pass a clipped signal to the output, possibly damaging downstream components that would also be unpowered (see Figure 2). Note: if there are diodes to the supply, they will forward bias and clip the signal to +0.7 V.



- ▶ PMOS turns on with negative V_{GS}
- ▶ PMOS is ON so signal passes through to output

Figure 2. Overvoltage signal with power supply grounded.

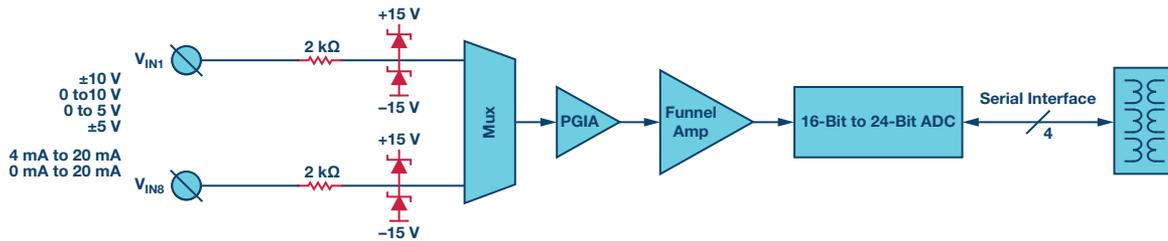


Figure 3. Discrete protection solution.

Discrete Protection Solution

Designers traditionally solve input protection issues with discrete protection components.

Large series resistors are used to limit the current during a fault, and Schottky or Zener diodes to the supply rails clamp any overvoltage signals. An example of such a protection scheme in a multiplexed signal chain is shown in Figure 3.

However, there are many disadvantages to using these discrete protection components.

1. The series resistor will increase the settling time of the multiplexer and slow down the overall settling time.
2. The protection diodes will introduce additional leakage current and varying capacitance that will impact the precision and linearity of the measurement.
3. There will be no protection in the floating supply condition as the ESD diodes to the supplies won't provide any clamping protection.

Traditional Switch Architecture

The diagram in Figure 4 gives an overview of a traditional switch architecture. The switch component (on the right hand side of Figure 4) has ESD diodes to each of the supply rails, at both the input and output side of the switch element. The external discrete protection components are shown here as well—the series resistor for current limiting and the Schottky diodes to the supplies for overvoltage clamping. There is often a requirement for a bidirectional TVS for additional protection in harsher environments.

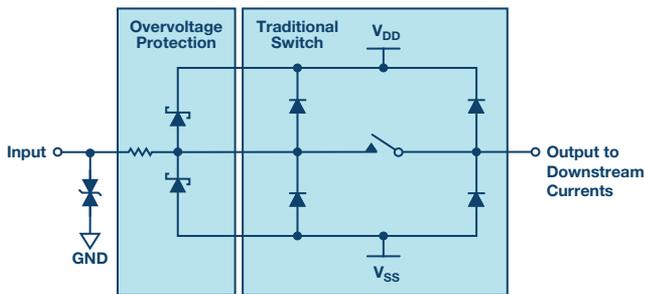


Figure 4. Traditional switch architecture with external discrete protection.

Fault Protected Switch Architecture

The fault protected switch architecture is shown in Figure 5. The ESD diodes at the input side are replaced with a bidirectional ESD cell, so the input voltage range is no longer limited by the ESD diodes to the supply rails. Therefore, the input can see voltages up to the limitation of the process (which is ± 55 V for the new fault protected switches from ADI).

The ESD diodes remain at the output side in most cases as there usually isn't a requirement for overvoltage protection from the output side.

The ESD cell at the input side can still provide excellent ESD protection. The ADG5412F overvoltage fault protected quad SPST switch that uses this type of ESD cell achieves a 5.5 kV HBM ESD rating.

There may still be a requirement for an external TVS or a smaller current limiting resistor for more stringent cases such as IEC ESD (IEC 61000-4-2), EFT, or surge protection.

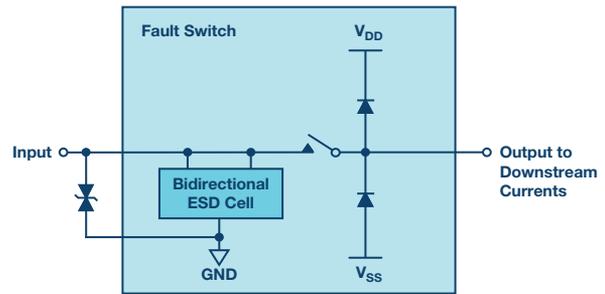


Figure 5. Fault protected switch architecture.

In the case of an overvoltage condition at one of the switch inputs, the affected channel turns off and the input goes high impedance. The leakage will remain low on the other channels, so the remaining channels can continue to operate as normal with minimal impact on performance. This allows for very little compromise between system speed/performance and overvoltage protection.

The fault protected switch can therefore greatly simplify the signal chain solution. The switch overvoltage protection removes the requirement for the current limiting resistors and Schottky diodes in many cases. The overall system performance is no longer limited by external discrete components that typically introduce leakage and distortion into a signal chain.

ADI Fault Protected Switch Features

The new portfolio of fault protected switches from ADI are built on a proprietary high voltage process that provides overvoltage protection up to ± 55 V in both the powered and unpowered states. These parts provide industry-leading performance for fault protected switches for precision signal chains.

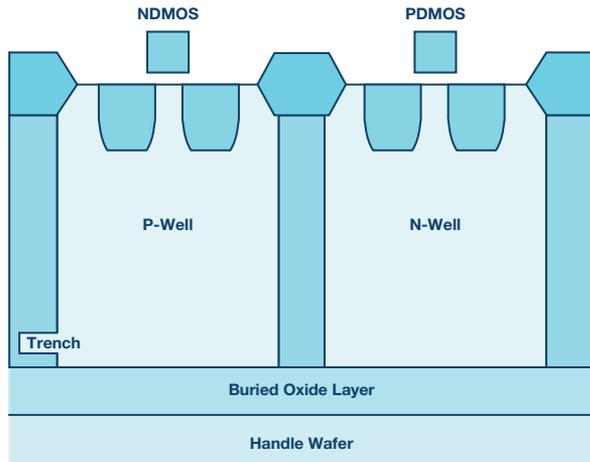


Figure 6. Trench isolated process.

Latch-Up Immunity

The proprietary high voltage process is also trench isolated. An insulating oxide layer is placed between NDMOS and the PDMOS transistors of each switch. Parasitic junctions, which occur between the transistors in junction-isolated switches, are eliminated and the result is a switch that is latch-up immune under all circumstances. The ADG5412F, for example, passes a JESD78D latch-up test of ± 500 mA for a 1 second pulse width, which is the most stringent test in the specification.

Analog Performance

As well as achieving industry-leading robustness (overvoltage protection, high ESD rating, known state at power-up without digital inputs present), the new ADI fault protected switches also have industry-leading analog performance. Switch performance as always is a trade off between low on resistance and low capacitance/charge injection. The choice of switch usually depends on whether the load is high impedance or low impedance.

Low Impedance Systems

Low on-resistance parts are usually used in low impedance systems, where the on resistance of the switch needs to be kept to a minimum. In low impedance systems, such as a power supply or gain stage, the on resistance and source impedance in parallel with the load can cause gain errors. Even though gain errors can be calibrated out in many cases, the variation of on resistance (R_{ON}) across signal range or between channels produces distortion that cannot be calibrated out. Therefore, low resistance circuits are more subject to distortion errors due to R_{ON} flatness and R_{ON} variation across channels.

The plot in Figure 7 shows the switch on resistance of one of the new fault protected switches across the signal range. As well as achieving very low on resistance, the R_{ON} flatness and matching between channels is also excellent. The parts have a patented switch driver design that guarantees a

constant V_{GS} voltage and delivers flat R_{ON} performance across the input voltage range. The trade-off is a slightly reduced signal range where optimal performance can be achieved, which can be seen from the shape of the R_{ON} plots. There can be significant system benefits because of this R_{ON} performance in applications sensitive to R_{ON} variation or THD.

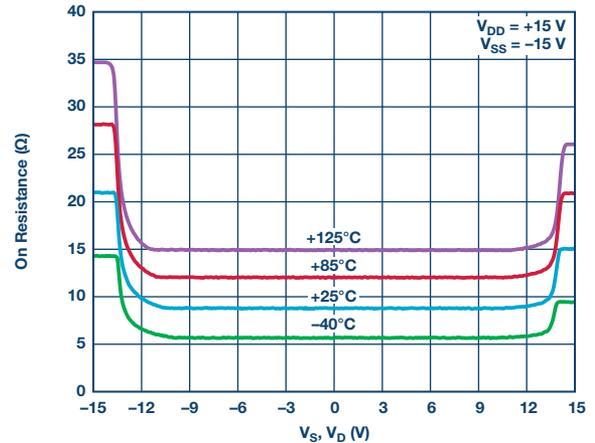


Figure 7. Fault protected switch on resistance.

The ADG5404F is the new latch-up immune, overvoltage fault protected multiplexer. Latch-up immune parts and overvoltage protected parts typically have higher on resistance and worse on-resistance flatness than standard parts. However, due to the constant V_{GS} scheme used in the ADG5404F design, the R_{ON} flatness is actually better even than the ADG1404 (industry-leading low on resistance) and ADG5404 (latch-up immune, but not overvoltage protected). In many applications, such as RTD temperature measurements, the R_{ON} flatness is actually more important than the absolute value of on resistance so the fault protected switch provides potential for increased performance in these systems.

The typical fault mode for a low impedance system is for the drain output to go open circuit in the case of a fault.

High Impedance Systems

Low leakage, low capacitance, low charge injection switches are most commonly used in high impedance systems. Data acquisition systems are typically high impedance due to amplifier loads on the multiplexer output.

- Leakage is the dominant source of error in high impedance circuits. Any leakage currents can lead to significant measurement errors.
- Low capacitance and low charge injection is also critical for faster settling. This allows for maximum data throughput in a data acquisition system.

The leakage performance of the new ADI fault protected switches is excellent. In normal operation the leakage current is in the low nA range, which is critical for accurate measurements in many applications.

Critically, the leakage performance is also very good even when one of the input channels is in fault. This means that measurements can continue on other channels until the fault

is fixed, thereby reducing system downtime. The overvoltage leakage current for the ADG5248F 8:1 multiplexer is shown in Figure 8.

The typical fault mode for a high impedance system is for the drain output to pull to the supply rail in the case of a fault.

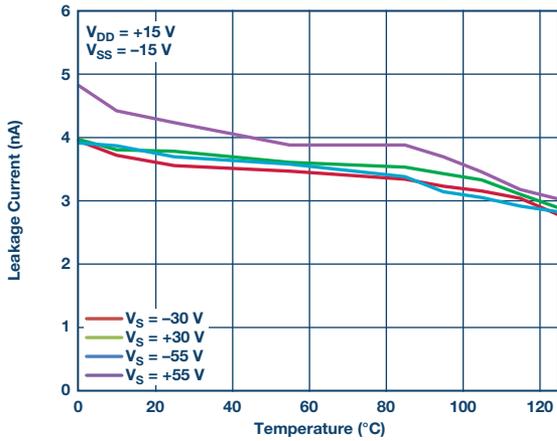


Figure 8. ADG5248F overvoltage leakage current vs. temperature.

Fault Diagnostics

Most of the new ADI fault protected switches also feature digital fault pins. The FF pin is a general fault flag, which indicates that one of the input channels is in fault. The specific fault pin (or SF pin) is a pin that can be used to debug which specific input is in fault.

These pins can be useful for fault diagnostics in a system. The FF pin first alerts a user to a fault. The user can then cycle through the digital inputs and the SF pin will identify which particular switch or switches are in fault.

System Benefits

The system benefits of the new portfolio of fault protected switches are captured in Figure 9. The benefits to a system designer are great, both in terms of ensuring optimal analog performance in a precision signal chain, and in terms of system robustness.

Features	System Benefits
Fault Protection ±55 V Overvoltage Protection	Prevents damage to downstream circuitry Reduces the need for discrete protection components
Fault Detection Digital Output Indicator for Fault Conditions	Alerts to source of fault Eliminates the need for complex fault detection software routines
High ESD Industry-Leading 5.5 kV HBM ESD	Eases board assembly Reduces ESD components
Precision Performance Low RON and RON Flatness Low Leakage Current	Prevents signal distortion Maximizes system performance

Figure 9. ADI fault protected switch—features and system benefits.

The benefits compared to discrete protection components are obvious and have been described in detail already. The proprietary high voltage process and novel switch architecture also gives the new range of ADI fault protected switches a number of advantages over competitor solutions.

- Industry-leading RON flatness for precision measurements
- Industry-leading fault leakage current to allow for continued operation on other channels not affected by a fault (10× better than competing solutions)
- Parts with secondary fault supplies for precision fault thresholds while still maintaining optimum analog switch performance
- Intelligent fault flags for system fault diagnostics

Application Examples

This first application example shown in Figure 10 is a process control signal chain, where a microcontroller is monitoring a number of sensors such as RTD or thermocouple temperature sensors, pressure sensors, and humidity sensors. In a process control application, the sensor may be connected at the end of a very long cable in a factory, with the potential for faults along the length of the cable.

The multiplexer in this case is the ADG5249F, which is optimized for low capacitance and low leakage. Low leakage is important for these type of small signal sensor measurements.

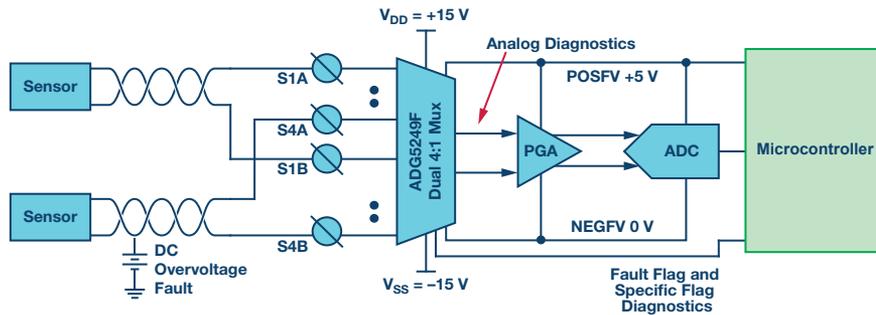


Figure 10. Process control application example.

Portfolio Summary

Table 1. Low On-Resistance Family of Fault Protected Switches

Product	Configuration	Fault Trigger Threshold	Output Fault Mode	Fault Flag
ADG5412F ADG5413F	Quad SPST	Primary supplies	Open circuit	General flag
ADG5412BF ADG5413BF	Quad SPST and bidirectional OVP	Primary supplies	Open circuit	General flag
ADG5462F	Quad-channel protector	Secondary supplies	Pull to secondary supply or open circuit (default)	General flag
ADG5404F	4:1 mux	Primary supplies	Pull to secondary supply or open circuit (default)	General and specific flags
ADG5436F	Dual SPDT	Primary supplies	Pull to secondary supply or open circuit (default)	General and specific flags

Table 2. Low Capacitance/Low Charge Injection Family of Fault Protected Switches

Product	Configuration	Fault Trigger Threshold	Output Fault Mode	Fault Flag
ADG5208F	8:1 multiplexer	Primary supplies	Pull to rails	None
ADG5209F	Differential 4:1 multiplexer	Primary supplies	Pull to rails	None
ADG5248F	8:1 multiplexer	Secondary supplies	Pull to secondary supplies	General and specific flags
ADG5249F	Differential 4:1 multiplexer	Secondary supplies	Pull to secondary supplies	General and specific flags
ADG5243F	Triple SPDT	Secondary supplies	Pull to secondary supplies	General and specific flags

The switch operates off $\pm 15\text{ V}$ supplies, while the secondary fault supplies are configured for 5 V and GND to protect the downstream PGA and ADC.

The main sensor signal passes through the multiplexer to the PGA and ADC while the fault diagnostics are sent directly to the microcontroller to provide an interrupt in the case of a fault. The user can therefore be alerted to a fault condition and can determine which of the sensors is in fault. A technician can then be sent out to debug the fault and if necessary replace the sensor or cable in fault.

Because of the industry-leading low fault leakage specification, the other sensors can continue to be monitored even while one of the sensors is down and awaiting replacement. Without such low fault leakage, a fault on one channel could make all of the other channels unusable until the fault is repaired.

The second application example in Figure 11 is a portion of a data acquisition signal chain where the ADG5462F channel protector would add value. In this case there is a PGA with $\pm 15\text{ V}$ supply rails, while the ADC downstream has as input signal range of 0 V to 5 V.

The channel protector sits between the PGA and ADC. It uses the $\pm 15\text{ V}$ supply rails as its primary supplies to achieve optimum on resistance, and uses 0 V and 5 V for its secondary supply rails. The ADG5462F will allow the signal to pass through in normal operation, but will clamp any overvoltage outputs from the PGA to between 0 V and 5 V to protect the ADC. Therefore, like the previous applications example, the signal of interest is biased in the flat R_{ON} region of operation.

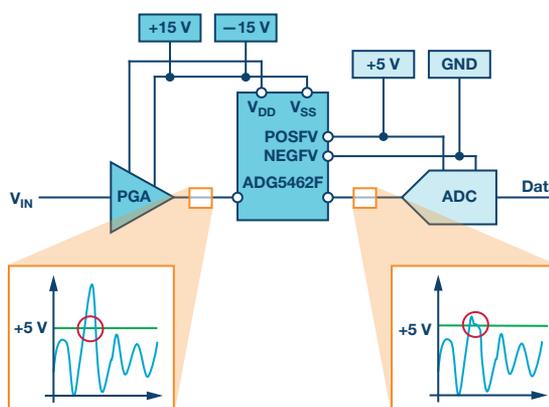


Figure 11. Data acquisition application example.

Summary

Replacing traditional discrete protection components with overvoltage protected switches and multiplexers can provide many system benefits in a precision signal chain. As well as saving board space, the performance benefits of replacing discrete components can be significant.

Analog Devices has a wide range of overvoltage protected switches and multiplexers. The latest families of fault protected devices are listed in Table 1 and Table 2. They are built on a proprietary high voltage and latch-up immune process and provide industry-leading performance and features for precision signal chains.



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