

Power-Off Protected Data Acquisition Signal Chain Using Fault-Protected CMOS Switches

CIRCUIT FUNCTION AND BENEFITS

When signals come from remotely located sources, there is an increased likelihood that damaging faults can occur. Overvoltage conditions may occur due to systems with poorly designed power supply sequencing or where hot-plug insertion is a requirement. Transient voltages due to poor connections or inductive coupling may damage components if not protected. Faults can also occur due to power supply failures or in cases where there is a loss of the power connection while switch inputs remain connected to analog signals. Significant damage may result from these fault conditions, which can mean expensive repairs.

The circuit shown in Figure 1 provides protection to a data acquisition signal chain using a low on-resistance [ADG4612](#) quad SPST with power off protection. The data acquisition system is composed of the [ADA4000-1](#) low cost, precision JFET input op amp followed by an [AD7476](#) low power, 12-bit, 1 MSPS SAR ADC. The [ADG4612](#) provides low cost protection against loss of power while input signals are still present, as well as overvoltage fault protection up to 16 V. The extra board area required for the [ADG4612](#) is minimal because the device is available in a 3 mm × 3 mm LFCSP as well as a 16-lead TSSOP. The [ADG4612](#) provides protection for four separate data acquisition channels without requiring any additional discrete components.

CIRCUIT DESCRIPTION

Table 1. Devices Connected/Referenced

Product	Description
ADG4612	Low on-resistance quad SPST switch with power-off protection
ADA4000-1	Low cost, precision JFET input op amp
AD7476	12-bit, 1 MSPS SAR ADC in a 6-lead SOT-23

Figure 1 shows a single channel, fault-protected data acquisition signal chain that is made up of the [ADG4612](#), [ADA4000-1](#), and [AD7476](#). The key to protecting the data acquisition board is the protection features of the [ADG4612](#). The switch is in the isolation mode when no power supplies are present, that is, when V_{DD} is floating or $V_{DD} \leq 1\text{ V}$ or when the input signal, either V_S or V_D , is greater than V_{DD} supply plus a threshold voltage (V_T). Under these condition, the switch inputs are high impedance inputs, ensuring that no current flows that can damage the switch or downstream circuitry. The negative supply rail, V_{SS} , can be floating or 0 V to -5.5 V . The ground pin must be connected to the ground potential.

The inputs of downstream components, such as the [ADA4000-1](#) or [AD7476](#), should be limited to within the supply rails so that, when power supplies are lost or input signals exceed the supply rails, these signals are blocked.

In the off condition, input signal levels of up to 16 V are blocked (assuming $V_{SS} = 0\text{ V}$). The switch also turns off when the analog input signal level exceeds V_{DD} by the threshold voltage, V_T ($\sim 1.2\text{ V}$).

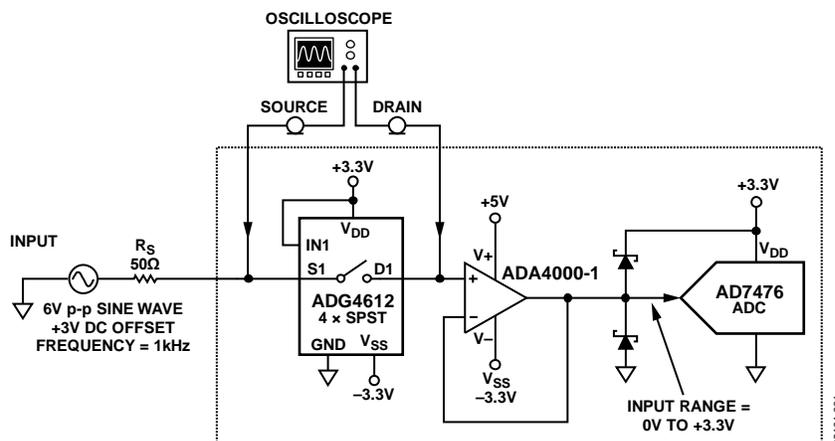


Figure 1. Fault Protected Data Acquisition Signal Chain Circuit (Simplified Schematic: All Connections and Decoupling Not Shown)

For standard CMOS analog switches, power supply requirements are specified in the product data sheet and should be adhered to in order to guarantee optimal part performance and operation. However, due to power supply failures, voltage transients, improper sequencing, and system or user faults, it is not always possible to meet data sheet recommendations.

The source, drain, and logic terminals of standard CMOS switches have ESD protection in the form of clamping diodes to the supplies. This is illustrated in Figure 2. These diodes vary in size depending on the process but are generally designed to be small to minimize leakage current. In normal operation, the diodes are reversed biased and do not pass current. When forward biased, they are not rated to pass currents greater than a few mA and can be damaged if this current is exceeded. Whenever an analog switch input voltage exceeds the supplies, the diodes become forward biased and large currents can flow, meaning that the switch can be damaged, even if the supplies are turned off. Furthermore, the damage caused by a fault is not limited to the switch but can also affect downstream circuitry such as the ADA4000-1 because applying a signal to an unpowered ADA4000-1 exceeds the absolute maximum rating of the device.

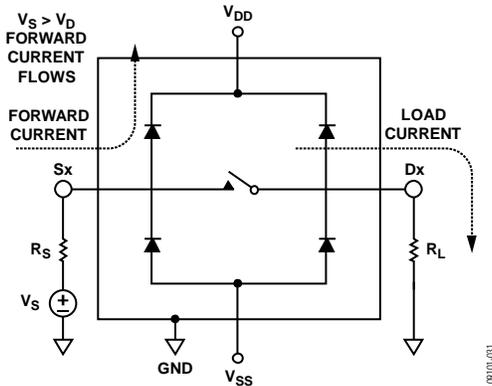


Figure 2. ESD Protection on Standard Analog CMOS Switches

The waveform in Figure 3 shows the performance of a standard analog switch when a signal is applied while the supplies are floating. A 6 V p-p sine wave with a 3 V dc offset is applied to the analog inputs, which in turn supply the power through the internal ESD diodes powering up the switch and any other components connected to the same V_{DD} supply. The input signal passes through the switch and is present at the ADA4000-1 inputs, thereby exceeding the maximum ratings of the ADA4000-1.

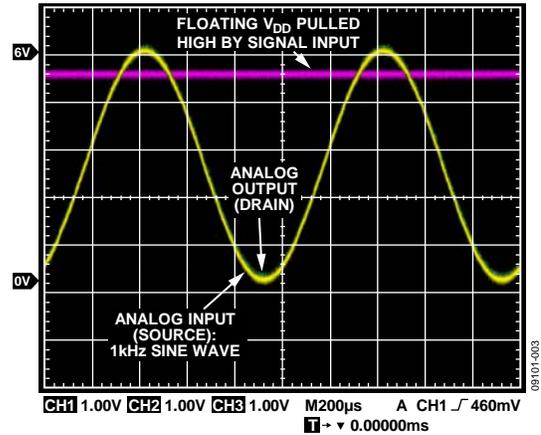


Figure 3. Standard Analog Switch with No Power Supply

Another limitation with standard CMOS switches is that, when analog signals exceed the power supplies, V_{DD} and V_{SS}, the supplies are pulled to within a diode drop of the fault signal. Internal diodes become forward biased, and currents flow from the input signal to the supplies. The fault signal can also pass through the switch and damage parts downstream as shown in Figure 4.

If the absolute maximum ratings of the devices are exceeded, the long-term reliability may be affected.

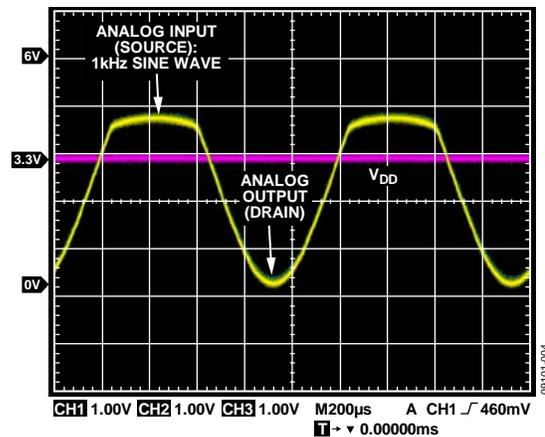


Figure 4. Standard Analog Switch with Overvoltage Condition

The [ADG4612](#) eliminates the effects of the faults previously shown. There are no internal ESD diodes from the analog or digital inputs to V_{DD} or V_{SS} . Instead, the [ADG4612](#) uses other protection components to protect against ESD events. This means that there is no low impedance path to the supplies during loss of power conditions or overvoltage faults. If signals are present on the [ADG4612](#) inputs before power is present, the switch enters isolation mode, which means that the inputs have high impedance paths to V_{DD} , GND, and the output. This prevents current flow and protects the device as well as downstream circuitry from damage.

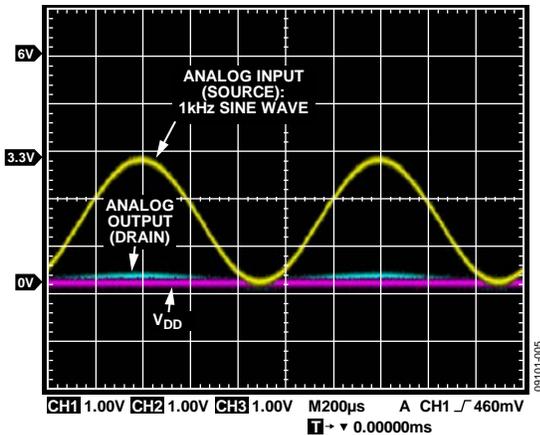


Figure 5. [ADG4612](#) with No Power Supply

Figure 6 shows the result of an overvoltage fault on the analog inputs. In this case, a 6 V p-p sine wave with a 3 V dc offset is applied to the [ADG4612](#), which is powered from ± 3.3 V supplies. When the analog input exceeds V_{DD} by a threshold voltage, V_T (~ 1.2 V), the switch enters isolation mode, thereby preventing the fault from damaging downstream circuitry.

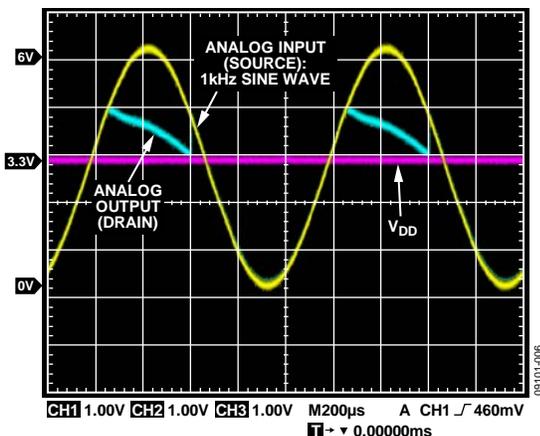


Figure 6. Overvoltage Condition on the [ADG4612](#)

The combination of the [ADG4612](#), [ADA4000-1](#), and [AD7476](#) shown in Figure 1 provides a data acquisition circuit that is robust to fault conditions such as loss of power with signals from external sources still present or overvoltage faults on analog inputs.

Note that the input range of the [AD7476](#) is equal to V_{DD} , which also acts as the reference to the ADC. In this case, the input range is 0 V to 3.3 V. To drive the [AD7476](#) linearly over this range, the supply voltages of the [ADA4000-1](#) must be set slightly higher to allow sufficient headroom for the output stage (approximately 1.2 V with respect to the positive supply and 2 V with respect to the negative supply). This is achieved by setting the positive supply voltage of the [ADA4000-1](#) to +5 V, and the negative supply voltage to -3.3 V. The two external Schottky diodes connected to the [AD7476](#) input ensure that there are no problems with power supply sequencing.

For configurations other than an SPST, the [ADG4613](#) is also available; it has two switches with digital control logic similar to that of the [ADG4612](#); the logic is inverted on the other two switches. Each switch conducts equally well in both directions when on, and each switch has an input signal range that extends to the supplies. The [ADG4613](#) exhibits break-before-make switching action for use in multiplexer applications. This device can be configured as a quad SPST, a dual SPDT, or a 4:1 multiplexer to suit different applications.

Excellent layout, grounding, and decoupling techniques must be used to achieve the desired performance from the circuits discussed in this note (see [MT-031 Tutorial](#) and [MT-101 Tutorial](#)). As a minimum, use a 4-layer PCB with one ground plane layer, one power plane layer, and two signal layers.

COMMON VARIATIONS

Figure 7 shows a variation of the circuit shown in Figure 1 that operates on a single 3.3 V supply. In this application, an op amp with a rail-to-rail input and output is required to drive the [AD7476](#) over its full input range. The outputs of the [AD8655](#) op amp are specified to drive within 10 mV to 30 mV of each supply rail. This means that there are a small percentage of dead band codes at each end of the full-scale ADC range where linearity suffers.

For a 30 mV headroom requirement, this is approximately 1% of the 3.3 V input range. Further discussions of op amp rail-to-rail issues, as well as overvoltage protection, can be found in the [MT-035](#) and [MT-036](#) tutorials.

Also note that the [ADG4612](#) operates with a V_{SS} of 0 V in the circuit and still maintains good on-resistance flatness over the input signal range.

The [AD8656](#) is a dual version of the [AD8655](#). The [ADA4000-2](#) and [ADA4000-4](#) are dual and quad versions of the [ADA4000-1](#).

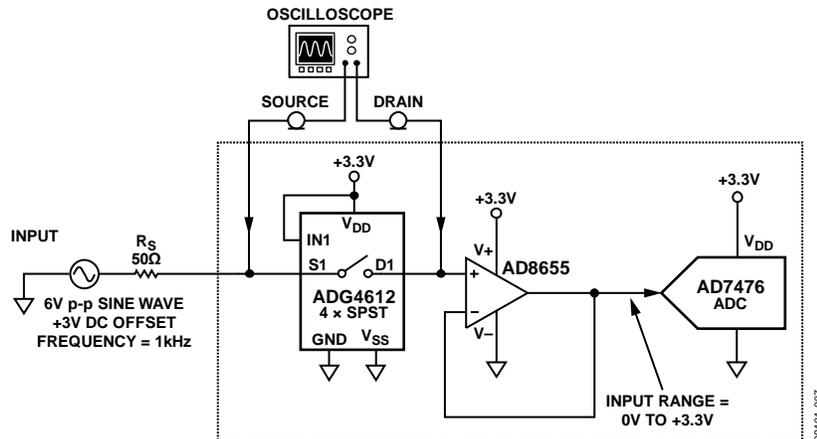


Figure 7. Single Supply Fault Protected Data Acquisition Signal Chain Circuit (Simplified Schematic: All Connections and Decoupling Not Shown)

LEARN MORE

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND,"* Analog Devices.

MT-035 Tutorial, *Op Amp Inputs, Outputs, Single-Supply, and Rail-to-Rail Issues,* Analog Devices.

MT-036 Tutorial, *Op Amp Output Phase-Reversal and Input Over-Voltage Protection,* Analog Devices.

MT-088 Tutorial, *Analog Switches and Multiplexers Basics,* Analog Devices.

MT-101 Tutorial, *Decoupling Techniques,* Analog Devices.

Data Sheets and Evaluation Boards

[ADG4612/ADG4613 Data Sheet](#)

[ADG4612 Evaluation Board \(EVAL-ADG4612EBZ\)](#)

[ADA4000-1 Data Sheet](#)

[ADA4000-2 Data Sheet](#)

[ADA4000-4 Data Sheet](#)

[AD7476 Data Sheet](#)

[AD7476 Evaluation Board](#)

REVISION HISTORY

4/13—Rev. 0 to Rev. A

Document Title Changed from CN-0165 to AN-1219 Universal

1/11—Revision 0: Initial Version