Application Note
How to Handle High Voltage Common Mode Applications using Multiplexers

TEXAS INSTRUMENTS

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ABSTRACT

High common mode voltages can often be a top concern when designing in a particularly noisy or harsh environment as they can cause irreparable damage to a signal chain or significantly impact a system's accuracy. However, sometimes high common mode voltages are present by design and the overall system needs to be able to accommodate these high voltages for everything to cohesively work together. Whether intentional or not, the components along the signal chain need to be able to withstand and operate effectively in these conditions and TI's multiplexer portfolio offers many options to handle a myriad of situations where this can be a possibility while also offering the performance needed for any application. In this report, several high common mode voltage applications will be explored which will include analog I/O modules for programmable logic controllers, industrial protocols such as CAN or RS485, and battery cell monitoring.

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1 Differential, Single-Ended, and Common Mode Signals

Differential signals are standard for many different communications protocols including LVDS, CAN, USB, RS485/422, HDMI, and so on and incorporates two complementary signals (differential pair) that are used to transmit data.
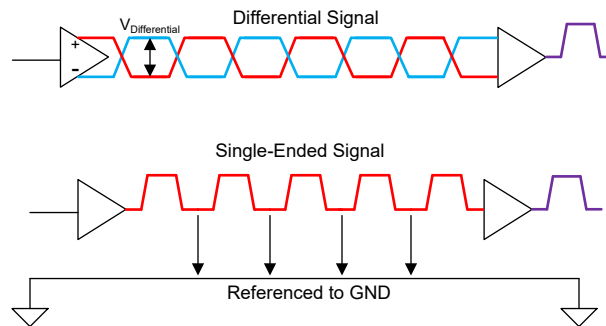
Figure 1-1. Differential vs. Single-Ended Signals

While single ended communication protocols such as I2C or SPI are often more ubiquitous due to their simplicity and are referenced to a single, stationary potential, differential signaling offers numerous advantages over single ended communication schemes and several are as follows:

- **EMI (electromagnetic interference) and Common Mode Noise Resistance**

  EMI and Common Mode Noise can be introduced from a variety of sources that can be coupled to the data transmission signals and can distort what the receiver is reading. In protocols with differential signaling, this effect is mitigated significantly as the noise is emitted onto both signals meaning that each inverted and non-inverted signal will constructively cancel each other out once they reach the receiver:
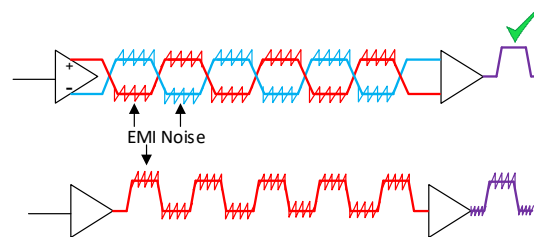
Figure 1-2. EMI Resistance in Differential Signals

- **Ground Shift Immunity**

  In addition, many differential signal protocols do not share any common ground or return current path, so ground reference shifts and ground noise acquired along the path are of no concern when utilizing such differential signaling protocols. However, for protocols that do call for common termination (such as the CAN interface as an example), there needs to be more care taken to reduce ground offsets as much as possible.

- **Reduced Power Requirements and Higher Frequency Operation**

  Differential signaling often calls for voltage signals to be in the hundreds of millivolts or just up to 1 V or 2 V and can greatly simplify power consumption needs of an application. In turn, this also allows these differential signals to operate at higher frequencies due to the much lower radiated emissions these signals have from the smaller voltages used (in addition to the resistance from external EMI imposed by using a differential pair).

Common mode signals can be simply defined as the voltage that is common between the input terminals of a device and are often an unwanted element in most systems. For instance, take the visual representation as shown in Figure 1-3.
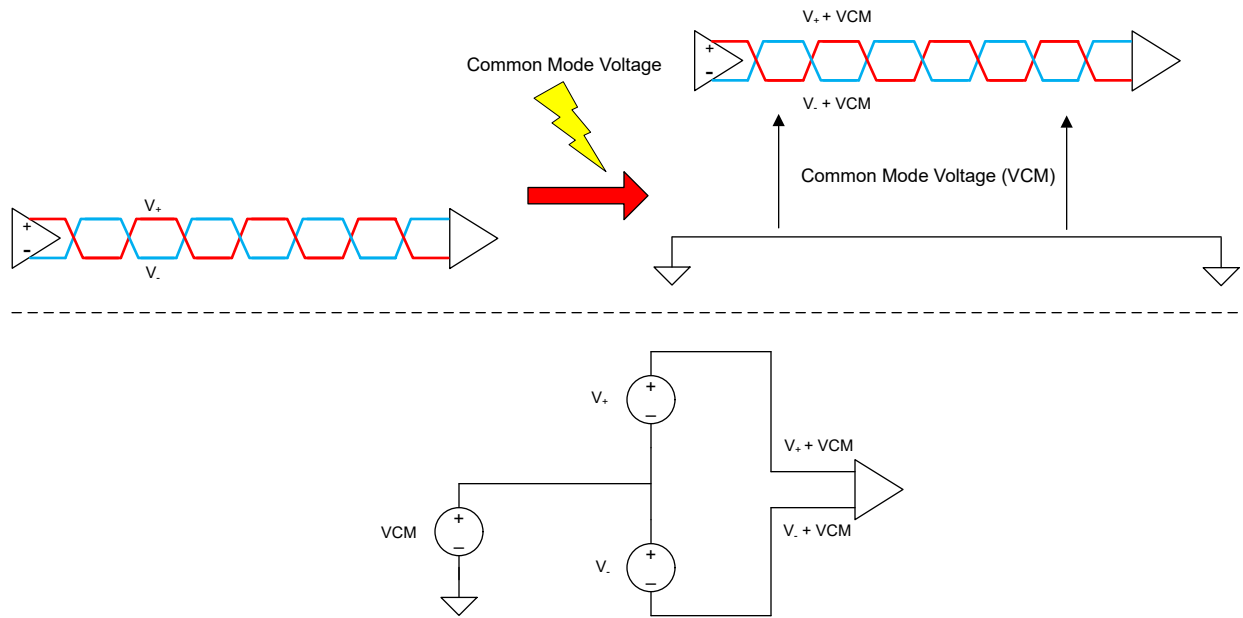
Figure 1-3. Common Mode Voltage

It is evident that when a common mode voltage is introduced to a system, this will shift the reference point of the affected components to be outside of the anticipated operating range by a given VCM (as shown above from both a graphical and equivalent circuit perspective). While common mode signals can be attributed to EMI, ground shifts, miswirings, coupling, or even lightning strikes, they can be influential enough to the system at large that it can significantly affect measurement accuracy or even permanently damage devices by causing them to exceed absolute maximum operating ratings. Hence, it is essential that the design is defined by the environment the system will be used in and components selected that can tolerate such conditions.

2 Characteristics of Interest for Selecting a Multiplexer for High Voltage Common Mode Applications

For multiplexer applications that may be exposed to high common mode voltages, there are several multiplexer parameters that need to be considered for these situations.

2.1 Operating Supply Range

The most evident parameter that one must consider is the operating supply range of the multiplexer. During nominal operation, the expected signals propagating through the multiplexer can usually be fairly low. However, if there exists common mode voltages that can potentially be upwards of ±36 V in some cases, then a higher voltage capable multiplexer would be needed to be able to survive and operate in these instances. While it may seem that this would necessitate a higher supply voltage, which certainly can be the remedy, there is a way to still utilize a lower supply rail while being able to survive an event where a high common mode voltage is present. Below illustrates how external diodes and current limiting resistors (typically in the 1k to 10k range) can be implemented to suppress damage to the multiplexer while allowing time for the fault to subside and resume nominal operation:
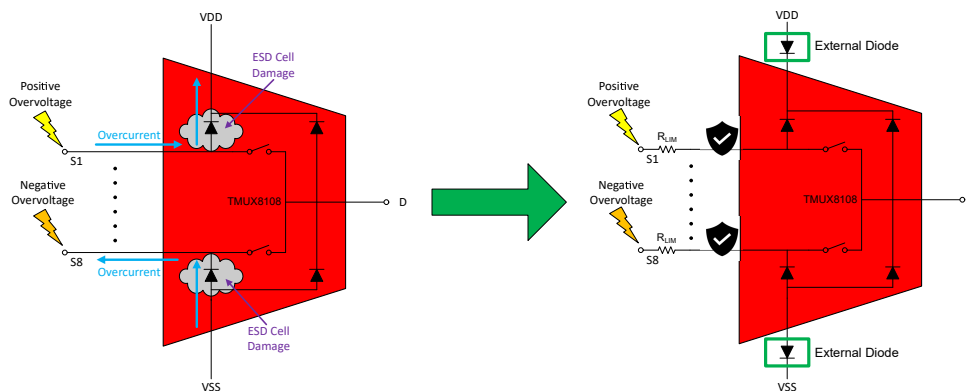

Figure 2-1. External Diode and Resistor Mux Protection

Lastly, if there still needs to be operation during a high common mode voltage event and there is no access to high supplies in the system, beyond the supply multiplexers can be used instead which offer low voltage supply rails, but can pass and tolerate voltages on the multiplexer inputs beyond those supply rails.

2.2 Crosstalk and Bandwidth

In many applications that are susceptible to common mode interference, higher speed communications are typically implemented and the multiplexer must be able to pass these signals unattenuated. The bandwidth specification found in all TI multiplexer data sheets can give an indication of the frequency of signals that can be handled by the multiplexer so they can be passed without issue. A good rule of thumb is to select a multiplexer that can handle a bandwidth of at least 1.5x-3x the application requirement to allow for margin in the design for layout and loading constraints.

At higher frequencies, there is also concern about channel to channel crosstalk. Crosstalk is defined as the magnitude of the signal of an ON-channel that appears on an adjacent channel. This can cause errors in any measurements or can introduce noise on adjacent lines that can negatively impact communications if the multiplexer does not have very good crosstalk performance.

2.3 Leakage Current

All multiplexers will have some form of leakage current that can be injected into the application, some more and some less. What can be problematic during an event that imparts a high common mode voltage onto the inputs of a device is that the leakage current will certainly increase and if not accounted for in the system, can potentially affect the accuracy of the application.

2.4 Fault Protection

TI's multiplexer portfolio includes many different configurations of fault protected multiplexers that can be utilized to prevent any damage from high common mode events. Most of these types of devices include ± 60V fault protection, fault reporting, and programmable fault detection which can prove to be invaluable for such situations where there are possibilities of these high common mode voltages existing. Lastly, given these features inherent in TI's fault protected multiplexers, this eliminates the need for external components such as current limiting resistors and diodes to provide protection to the signal chain.

3 Multiplexers in High Voltage Common Mode Applications
3.1 PLC Multi-Channel Analog I/O Modules

Programmable logic controllers (PLCs) incorporate analog input or output modules that are implemented in fairly harsh factory automation environments and will routinely be exposed to high common mode voltages. A typical analog I/O module can incorporate a multiplexer being used in conjunction with an ADC. Usually, this type of use case has a single ADC that can use a multiplexer to switch between several different inputs as shown in Figure 3-1.
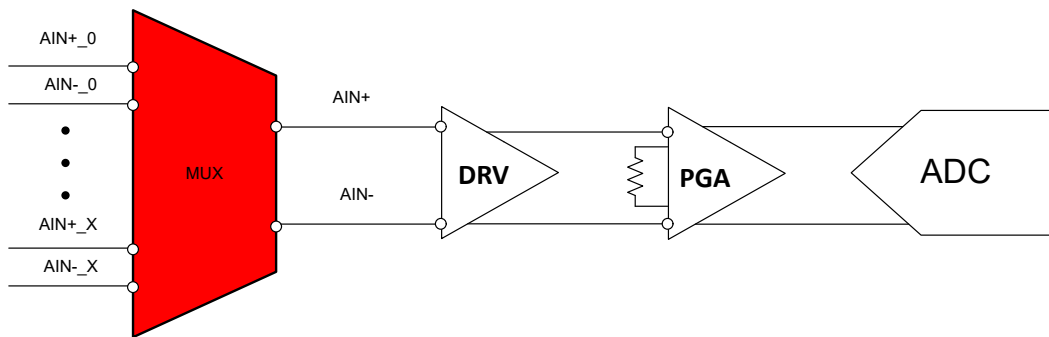

Figure 3-1. PLC with Multiplexer Application

As seen above, the multiplexer can add much needed functionality to this application by expanding the amount of inputs the ADC can sample, however, the multiplexer also needs to be able to handle a potential common mode fault that can be introduced from the surrounding environment such as shown in Figure 3-2.
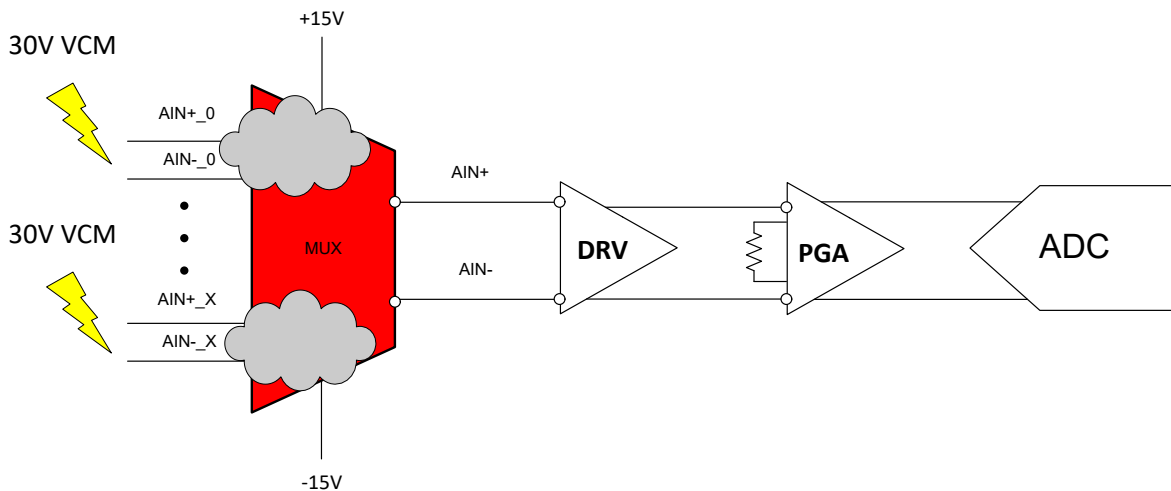

Figure 3-2. PLC with Common Mode Fault Event

The high common mode fault can shift the operating point of the application and the multiplexer must either have the supply capability to handle this shift, fault protection, or external components added to survive this event as illustrated in Figure 3-3.

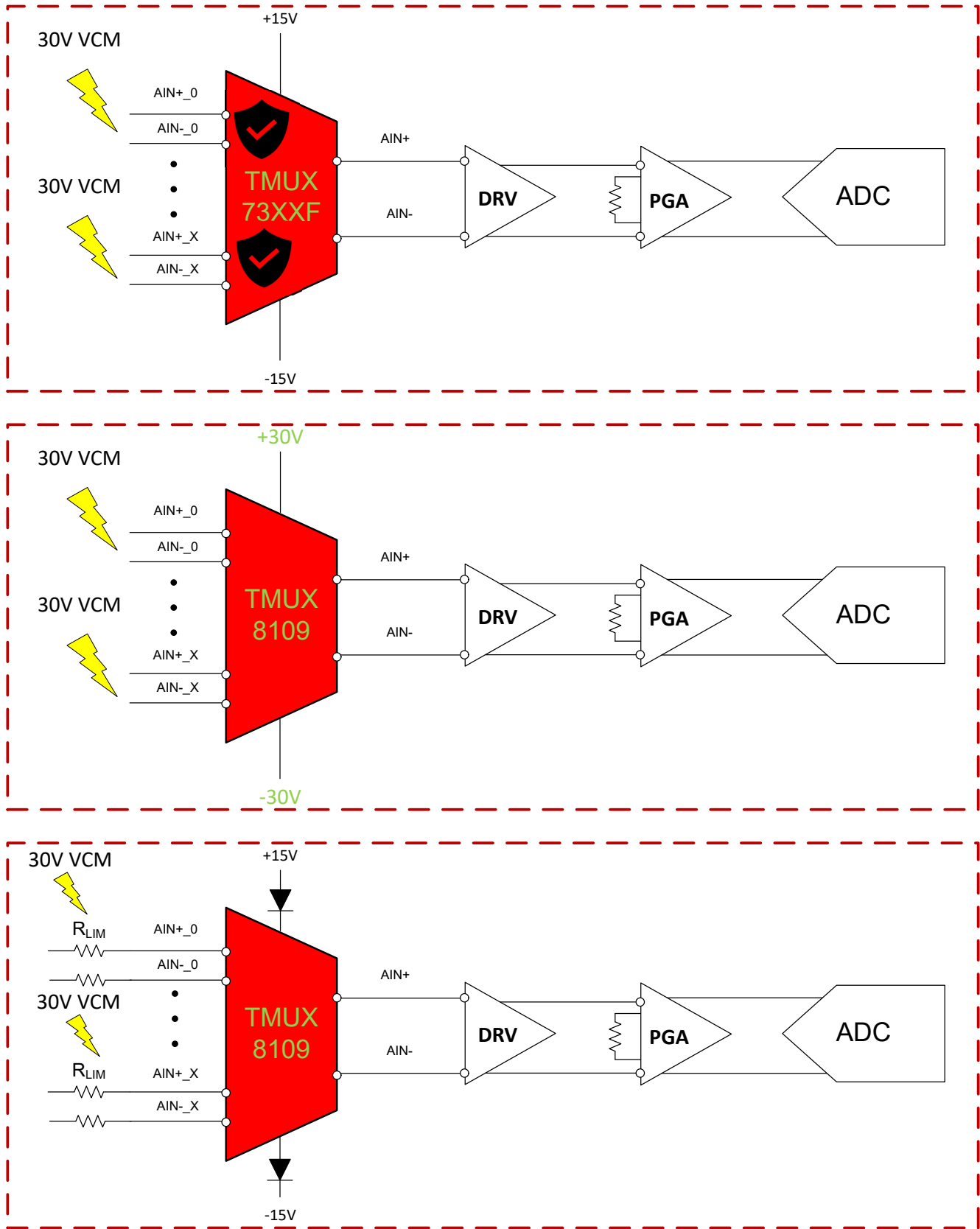**Figure 3-3. PLC Analog I/O Common Mode Fault with Fault Protected or High Voltage Multiplexer**

3.2 CAN Bus Multiplexing Applications with High Voltage Common Mode

The CAN (Controller Area Network) bus is one of the most common types of protocols that is implemented in applications that need robust communications such as in industrial and automotive end equipment. The robustness for this protocol can be attributed to the built-in fault tolerances and reporting that many CAN transceivers have today that enable them to sustain themselves in unforgiving environments. In many instances, the CAN bus is physically wired and run right next to power lines of the application and can be susceptible to a high common mode voltage by a short to battery event or the wiring can be run over long distances causing ground faults. Hence, many CAN transceivers have 2 or 3 times the typical battery voltage (12V battery for automotive, so anywhere between 24V and 36V) as fault tolerance and others even up to 60V or 70V as well to combat these types high common mode voltage scenarios. There are several different ways that a multiplexer can be paired with a CAN application and the multiplexer must constitute the same level of robustness that the paired transceiver can provide to be in a high common mode voltage environment.

The first application here would be termination resistor switching for CAN. Termination resistors in a CAN application are a critical element to the overall CAN system and a multiplexer can elegantly be used to get the desired termination resistance based on which peripheral node is determined to be the termination node. In this instance, there are 3 modular nodes and any one can be switched in or out of the signal chain, needing multiplexers to be able to switch in the appropriate termination resistance based on how many elements are present as shown in Figure 3-4.
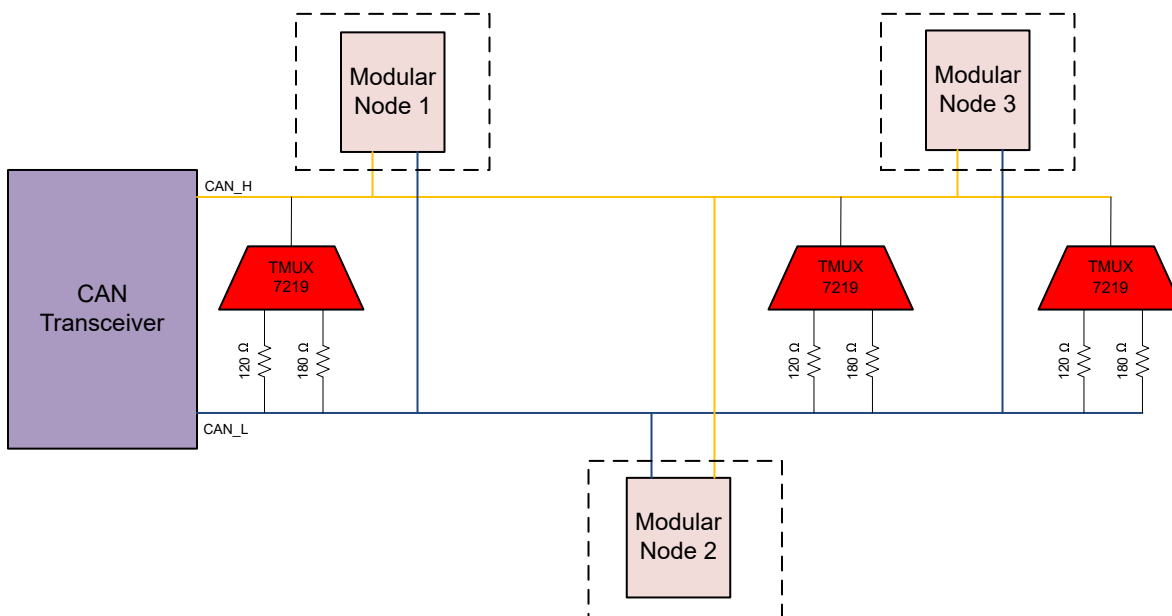

Figure 3-4. Multiplexing Termination Resistors for Modular CAN Node Application

Next, there are also applications that call for certain switching between protocols to communicate with downstream devices. In the example below, a multiplexer can be used to switch between the CAN bus or RS485 to use them in parallel, but the multiplexer allows the system to pick which protocol needs to be sent downstream to communicate while the other protocol is used locally as shown in Figure 3-5.
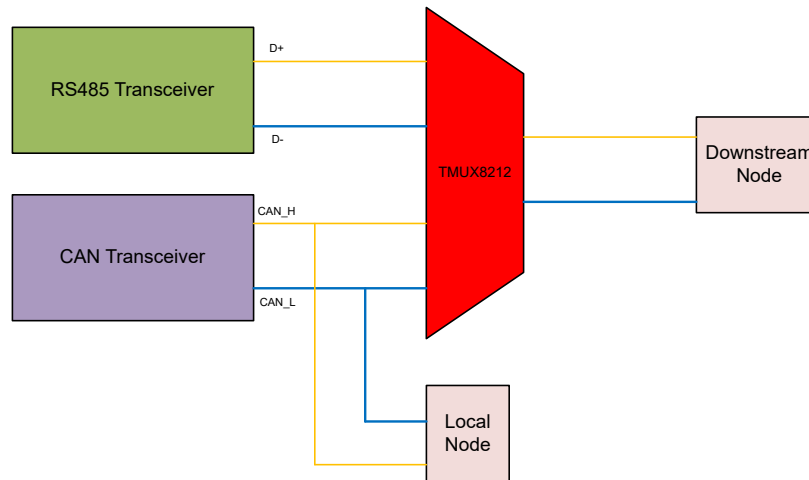
Figure 3-5. Multiplexing CAN and RS485 Protocols

One final type of application that multiplexers can be paired up with the CAN interface is simply using the multiplexer to switch between the nodes in a system and a single transceiver. If parallelism is not required, this is a great solution to being able to expand the functionality of a single CAN transceiver to communicate with several different nodes of a system without the need for individual transceivers for each one as shown in Figure 3-6.
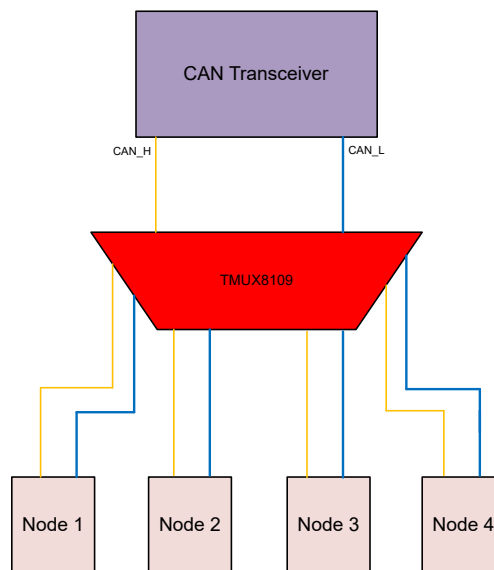

Figure 3-6. Multiplexing CAN Nodes

While the previous applications are all different instances of using a multiplexer with a CAN interface, they all must abide by being able to tolerate the same types of high common mode fault conditions that the CAN receivers are subject to. In such applications, fault protected multiplexers are a perfect companion to the CAN transceivers as they have very similar fault protection capabilities and provide fault monitoring as well. In addition, sometimes the CAN transceiver requires operation even during a fault condition. For this scenario, high voltage capable multiplexers are the ideal solution here as they can still pass signals during an event with minimal impact on the signal integrity of the CAN bus.

3.3 High Voltage Battery Cell Monitoring

As alluded to earlier, not all high common mode voltages are unintentional. In this battery cell monitoring application, a high common mode voltage is necessary to measure the battery current in systems that can call for up to 36 V in some automotive sectors. The typical setup uses a current sense amplifier that measures the voltage drop across a small, known resistance and the difference can be used to calculate the current loading of the system as shown in Figure 3-7.
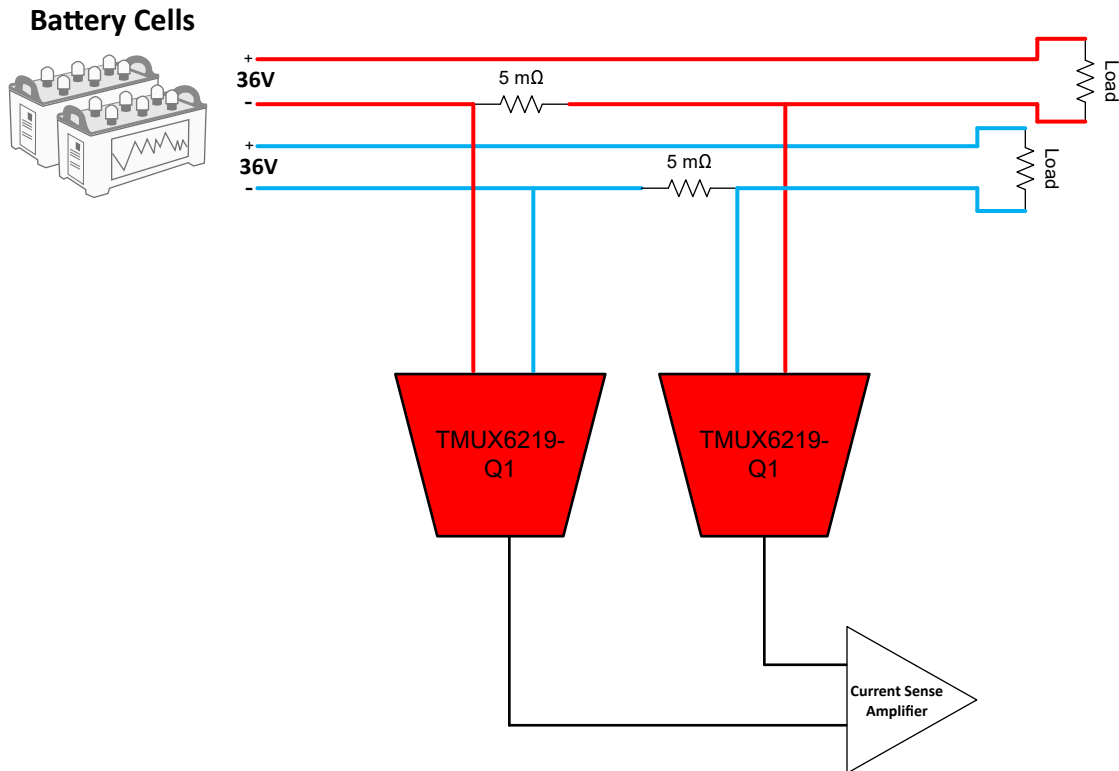
Figure 3-7. High Common Mode Voltage Battery Cell Monitoring with Multiplexer

In this instance, one can see that the common mode voltage would be just under 36 V depending on the load current and is intentional to the design to operate with this high common mode voltage present. So, the multiplexer has to have nominal operation with a high common mode voltage for this application to work properly and a high voltage multiplexer would be the choice for this type of use case.

4 Recommended Multiplexers for High Voltage Common Mode Applications

Table 4-1. Recommended Multiplexers for High Voltage Common Mode Applications

Device	Configuration	Operating Voltage Range	Leakage Current	Features
TMUX6219/ TMUX6219-Q1	2:1×1	36 V, ± 18 V	40 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity, Automotive Rated
TMUX7219/ TMUX7219-Q1	2:1×1	44 V, ± 22 V	40 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity, Automotive Rated
TMUX6208/09	8:1×1/4:1×2	36 V, ± 18 V	40 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX7208/09	8:1×1/4:1×2	44 V, ± 22 V	40 pA	1.8V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX6234	2:1×4	36 V, ± 18 V	20 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX7234	2:1×4	44 V, ± 22 V	20 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX6236	2:1×2	36 V, ± 18 V	50 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX7236	2:1×2	44 V, ± 22 V	50 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX7308F/09F	8:1×1/4:1×2	44 V, ± 22 V	100 pA	Fault Protected, 1.8V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX7348F/49F	8:1×1/4:1×2	44 V, ± 22 V	100 pA	Fault Protected, Programmable Detection, 1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX8108/09	8:1×1/4:1×2	100 V, ± 50 V	40 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity
TMUX8212	1:1×4	100 V, ± 50 V	40 pA	1.8 V Logic, Fail-Safe Logic, Latch-up Immunity, Low RON
TMUX6136	2:1×2	17 V, ± 17 V	10 pA	Extremely Low Leakage
MUX36D08	8:1×2	36 V, ± 18 V	10 pA	Extremely Low Leakage, High Channel Count

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