Addressing high-voltage design challenges with reliable and affordable isolation technologies

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The high voltages present in factory automation, motor drives, grid infrastructure and electric vehicles (EVs) can be several hundred or even thousands of volts. Galvanic isolation helps resolve the challenge of designing a safe human interface in the presence of such high voltages.

At a glance

This paper provides an overview of galvanic isolation, explains common isolation methods for high-voltage systems, and shows how Texas Instruments (TI) isolation integrated circuits (ICs) can help designers meet isolation needs reliably while reducing solution size and cost.

1

What is galvanic isolation?

Galvanic isolation introduces electrical partitions that prevent current from flowing between two or more parts of a system. Isolating signals and power protects personnel and equipment and adheres to industry and international standards.

2

High-voltage galvanic isolation concerns and methods

Learn the primary considerations when constructing an isolation barrier, such as voltage ratings, spacing dimensions, common-mode transient immunity (CMTI) and electromagnetic interference (EMI).

3

Achieve isolation needs reliably while reducing solution size and cost

Advancements in capacitive and magnetic isolation, package development, and process technology from TI can deliver power and high-speed signals safely and reliably across the isolation barrier in industrial and automotive systems such as electric vehicles (EVs), grid infrastructure, factory automation and motor drives.

The first priority in any high-voltage power system is to protect maintenance personnel and end-equipment users. Galvanic isolation satisfies this priority by isolating the high voltage from other low-voltage human interface sections.

The second priority is to establish reliable and safe operation between high- and low-voltage circuits, such as voltage and current sensing, power-supply control, digital communication and signal processing. Reliable isolation techniques, materials and ICs allow designers to satisfy this priority.

What is galvanic isolation?

Galvanic isolation partitions an electrical system to prevent the flow of DC and undesirable AC between two parts, while still allowing signal and power transfer. Figure 1 illustrates two galvanically isolated circuits.

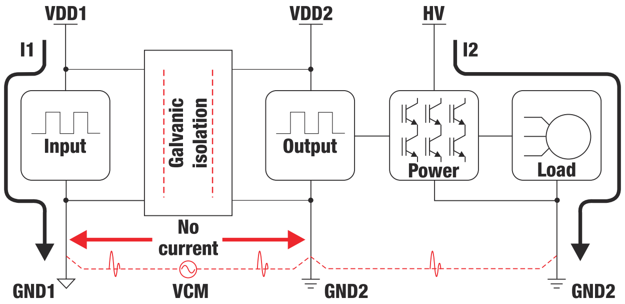

Figure 1. *Low- to high-voltage galvanic signal isolation.*

When GND1 is broken from GND2, I1 is galvanically isolated from I2. Since there is no commonality between GND1 and GND2, there is no common DC GND current shared through the isolation barrier. In addition to isolating shared GND connections and signal communication without conduction, it is also possible to use galvanic isolation for voltage-level shifting, since GND2 is transferable to a different floating potential relative to GND1.

High-voltage systems require additional isolation because more bidirectional signal information is communicated across the barrier. **Figure 2** illustrates an example in which power, high-speed gate-driver signals and digital communication signals must all cross the isolation barrier. Many analog and digital circuits have specific bias voltage requirements where both digital signals and power cross the isolation barrier. An isolated high-resolution analog-to-digital converter (ADC) may require 3.3 V in the same system, whereas an isolated gate driver may require +15 V and –5 V. These requirements necessitate not just the transfer of signals across the isolation barrier but power as well.

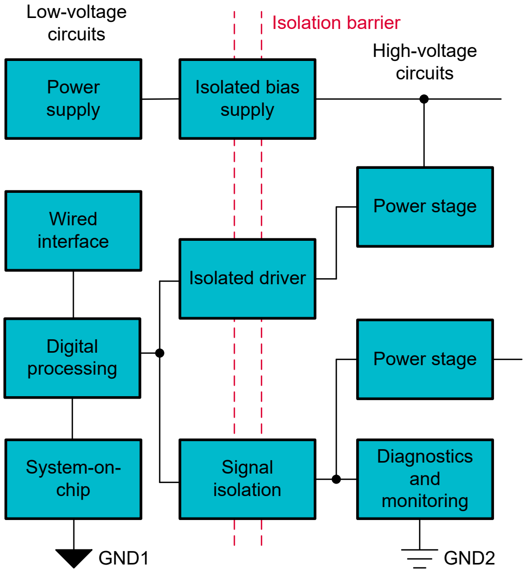

Figure 2. *Types of signals transferring across an isolation barrier.*

Learn more about galvanic isolation in the **What is Galvanic Isolation?** video.

High-voltage galvanic isolation concerns

There is much to consider when constructing a reliable isolation barrier in a system, including the isolation rating, creepage and clearance distance, CMTI, and EMI.

Functional, basic and reinforced isolation refer to the insulation rating level assigned to an electrical system, as listed in **Table 1**.

Insulator rating	Description
Functional	Insulation necessary for the correct operation of the equipment
Basic	Insulation that provides basic protection against electric shock
Supplementary	Independent insulation applied – in addition to basic insulation – to protect against electric shock in the event of a failure of the basic insulation
Double	Insulation comprising both basic and supplementary insulation
Reinforced	A single insulation system that provides a degree of protection against electric shock equivalent to double insulation

Table 1. *Insulation ratings.*

Functional isolation refers to the minimum amount of isolation assigned to a system so that it will function properly, without necessarily protecting against electrical shock. One example of functional isolation is proper printed circuit board (PCB) conductor spacing for a given voltage rating.

Basic isolation provides “sufficient” protection against electrical shock, with a safety rating at parity with the highest system-level voltage.

Reinforced isolation is the highest commercial rating applied to high-voltage systems. One way to meet reinforced isolation requirements is to introduce further distance across the isolation barrier such that it can withstand higher-voltage testing standards and a longer rated lifetime. For example, in International Electrotechnical Commission (IEC) 60747-17 and IEC 607475-5, the mandatory partial discharge test voltage (V_{PD}) is held to a higher standard for reinforced isolation compared to basic isolation. Learn more about reinforced isolation in the **What is Reinforced Isolation?** video.

Certifying a high-voltage system for reinforced isolation begins by selecting isolators compliant with safety and certification testing protocols, as defined by various committees. Underwriters Laboratories (UL) is a global safety certification lab in the United States, but different countries regulate compliance to their local or regional system standards. Thus, isolators intended for global use must comply with various international safety standards.

Table 2 summarizes IEC standard requirements for digital (capacitive and magnetic) isolators and optocouplers.

Test	IEC 60747-17 capacitive and magnetic isolators		IEC 60747-5-5 optocouplers
	Basic isolation	Reinforced isolation	Reinforced isolation only
V_{IORM} – maximum repetitive peak isolation voltage	AC voltage (bipolar)	AC voltage (bipolar)	AC voltage (bipolar)
V_{IOWM} – maximum working isolation voltage	AC voltage based on time-dependent dielectric breakdown (TDDB)	AC voltage based on TDDB	Based on partial discharge test
V_{PD} – partial discharge test voltage	$V_{TEST} = 1.5 \times V_{IOWM}$	$V_{TEST} = 1.875 \times V_{IOWM}$	$V_{TEST} = 1.875 \times V_{IOWM}$
V_{IOSM} – maximum surge isolation voltage	$V_{TEST} = 1.3 \times V_{IMP}$	$V_{TEST} = 1.6 \times V_{IMP}$10 kV_{PK} (minimum)	10 kV_{PK} (minimum)
Minimum rated lifetime	20 years × 1.2	20 years × 1.5	Not defined
Failure rate over lifetime	1,000 ppm	1 ppm	Not defined
Allowable isolation materials	Silicon dioxide (SiO_2) and thin-film polymer	SiO_2 and thin-film polymer	Not defined

Table 2. IEC standards for capacitive and magnetic isolators and optocouplers.

Isolators have several important parameters. The creepage and clearance distance, for example, is the shortest distance between two conductive leads across the isolation barrier. As shown in Figure 3, creepage distance is the shortest distance measured between adjacent conductors across the surface of an IC package, whereas clearance distance is measured through the air.

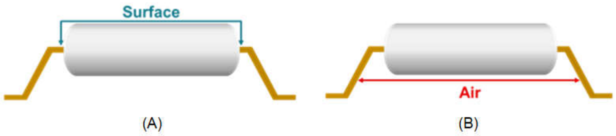

Figure 3. Creepage across the surface and clearance through the air across an isolator package.

Package technology plays an important role in achieving higher measures of creepage and clearance distance by providing different options for engineers. High-quality mold compounds, wide-body packages and higher reinforced isolation ratings must complement each other, because higher isolation ratings need wider packages and better mold compounds so that packages don't cause breakdown and arcing.

Another parameter is CMTI, which indicates an isolator's ability to operate reliably in the presence of high-speed transients and is measured in kilovolts per microsecond or volts per nanosecond. The proliferation of wide band-gap semiconductors has resulted in higher transient voltage (dV/dt) edge rates, making the measure of CMTI critical for gauging an isolator's resiliency. High-performance isolators have CMTI ratings easily reaching 100 V/ns, and many are tested in excess of 200 V/ns. A low CMTI isolator operating in a high dV/dt environment can expect to have signal integrity problems such as pulse jitter, distortion, erratic operation or missing pulse information.

Isolation trade-offs are similar at the IC and system level. Smaller IC package sizes, higher integration, thermal management and compliance with certification standards often compete against the need to reduce EMI and achieve higher efficiency. Selecting isolated components designed to meet all of these needs at the IC level helps facilitate a seamless transition to fully reinforced compliance at the system level.

Methods of isolation

ICs are the basic building blocks used to achieve isolation in modern high-voltage systems because they can block DC and low-frequency AC currents while allowing power, analog signals or high-speed digital signals to transfer across the barrier. Figure 4 shows three popular semiconductor technologies: optical (optocoupler), electric field signal transfer (capacitive) and magnetic field coupling (transformer). TI isolation ICs use both advanced capacitive isolation technology and proprietary integrated planar transformers. TI leverages its position in package development, isolation and process technology to achieve some of the highest levels of integration, performance and reliability.

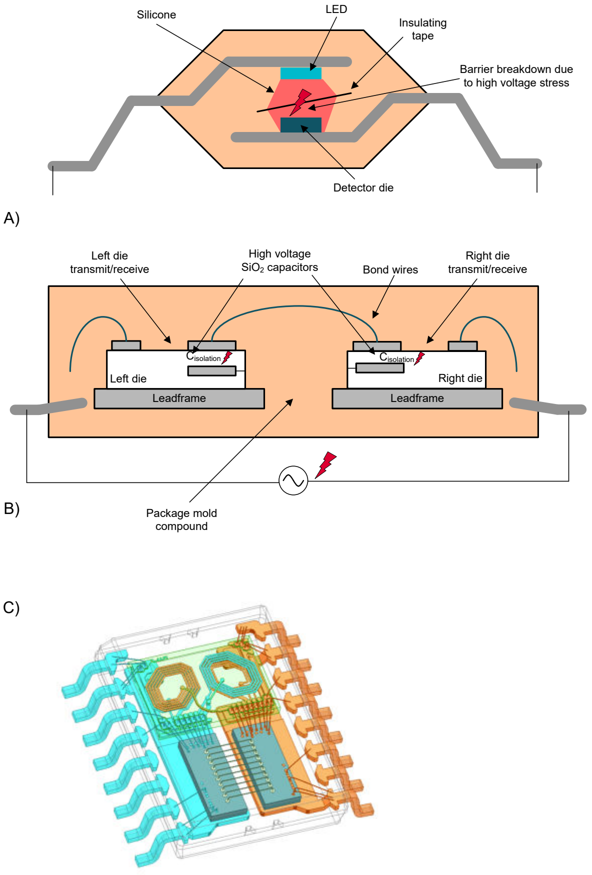

Figure 4. Semiconductor isolation technologies: optocoupler (a); capacitive (b); transformer (c).

Each technology relies on one or more semiconductor insulating materials, such as those listed in Table 3, to achieve the required level of isolation performance. Higher dielectric strength materials are more effective for isolating similar voltages over a given distance.

Insulator materials	Dielectric strength
Air	Approximately 1 V_{RMS}/µm
Epoxies	Approximately 20 V_{RMS}/µm
Silica-filled mold compounds	Approximately 100 V_{RMS}/µm
Polyimide	Approximately 300 V_{RMS}/µm
SiO_2	Approximately 500 V_{RMS}/µm

Table 3. Semiconductor insulator materials.

Optical isolation

Optocouplers are ICs used in analog and digital signal isolation applications. They operate on the principle of emission from an LED light source transmitted to a phototransistor through a dielectric insulating material of air, epoxy or mold compound. You can see in Table 3 that these materials have the lowest dielectric strength, and therefore require more physical separation to achieve higher levels of isolation. TI's portfolio does not currently include optically isolated products, but does include Opto-emulators that are pin-to-pin solutions emulating the behavior of optocouplers, while using TI's SiO2 isolation technology.

Although light-emitting photons are the fastest known vehicles for electromagnetic energy transfer, LED switching speeds, forward bias requirements and drive circuitry limit their signal rate to less than a few megabits per second. Furthermore, optical transmission efficiency does not transfer enough power for effective use as a power supply, so typically optocouplers are used only for transmitting data.

Combining functions such as LED drive circuitry and amplifiers inside an optocoupler package helps achieve higher data rates, but at a higher cost. The input-to-output current transfer ratio is a measure of an optocoupler's gain and will vary and degrade over time. Designers sometimes compensate for this aging effect by overspecifying the required bias current. Thus, optocouplers tend to have higher power consumption compared to capacitive or magnetic isolators.

Capacitive isolation

Capacitive isolation technology is based on AC signal transfer across a dielectric using schemes such as on-off keying, phase-shift keying, edge-based transfer or other types of higher-order modulation, as the capacitor inherently blocks DC signals. Figure 5 illustrates a very basic modulator/demodulator pair using differential signaling through a series capacitive isolation barrier. These capacitors can send data and a very limited amount of power. Figure 5 shows two capacitors used to construct the isolation barrier, but depending on the product requirements and the desired isolation rating, one capacitor may easily suffice.

A series capacitive isolator is a multichip module comprising a transmitter (the left die) and a receiver (the right die). As shown in Figure 6, each die has a dedicated capacitor to provide high-voltage isolation and electrical shock protection while meeting reinforced isolation equivalent to two levels of basic isolation.

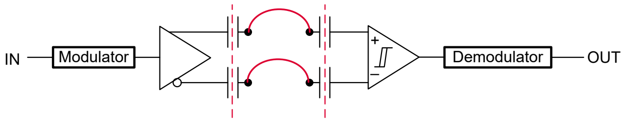

Figure 5. *Modulation is used to carry information across the capacitively formed isolation barrier.*

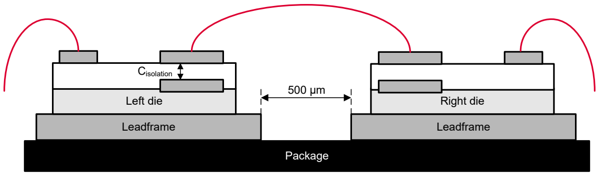

Figure 6. *Capacitive isolator example.*

It is possible to place multiple capacitive channels into a single IC package where either side can be the transmitter or receiver, thus enabling bidirectional signal communication. Capacitive isolators have low propagation delay, can transfer data exceeding 150 Mbps, and consume less bias current compared to optocouplers – but still require separate bias supply voltages for each side of the isolation boundary.

TI's capacitive isolators are constructed using a SiO_2 dielectric (see Figure 7), which has the highest dielectric strength of the materials listed in Table 3. In addition to having the highest dielectric strength among other insulators, SiO_2 is also an inorganic material and therefore very stable over moisture and temperature. TI's proprietary methodology for multilayered capacitor and multilayer passivation improves isolator quality and reliability by reducing the dependence of high-voltage performance on any single layer. This technology supports working voltages (V_{IOWM}) of 2 kV_{RMS}, withstands isolation voltages (V_{ISO}) of 7.5 kV_{RMS} and has a surge voltage capability of 12.8 kV_{PK}.

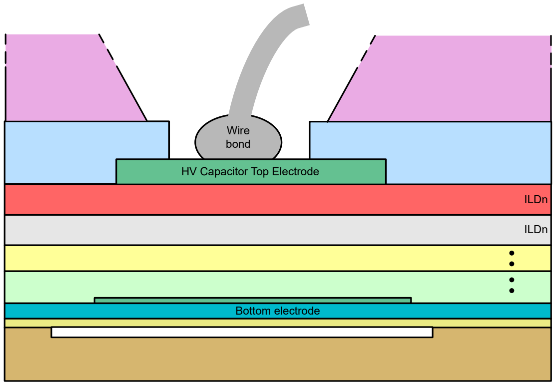

Figure 7. *Example cross-section of TI's high-voltage isolation SiO_2 capacitor.*

Isolators must have long lifetimes – well beyond those of nonisolated components – to protect circuitry from faults. TI tests rigorously to the IEC standards listed in Table 2.

Magnetic isolation

While capacitive isolators are popular for low-voltage analog signaling, digital signal transmission or applications requiring limited power transfer (<100 µW), integrated IC magnetic isolation has advantages in applications that require high-frequency DC/DC power conversion. One particular advantage of IC transformer-coupled isolation is the ability to transfer power in excess of hundreds of milliwatts, eliminating the need for a secondary-side bias supply in most applications. It is also possible to use magnetic isolation to send high-frequency signals. In systems that need to send both power and data, you can use the same transformer winding coils for power and the signal needs, as shown in **Figure 8**.

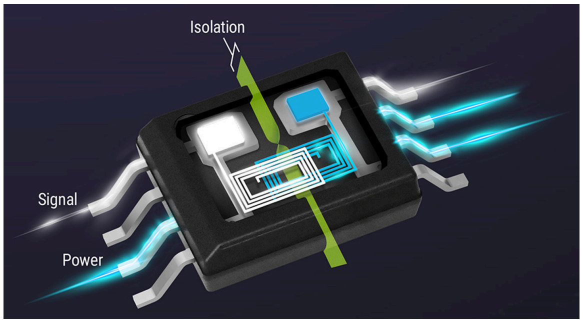

Figure 8. *Using magnetic isolation to send both power and signals reliably across an isolation barrier.*

TI uses a proprietary multichip module approach for magnetic isolation, co-packaging a high-performance planar transformer with an isolated power stage and dedicated controller die. TI can build these transformers with either a high-performance ferrite core to improve coupling and transformer efficiency, or an air core to save cost and complexity when the application requires only modest power transfer.

Figure 9 is one example of a dual-die multichip module that uses specialized control mechanisms, clocking schemes and a high-Q integrated planar transformer to provide low radiated emissions and high efficiency while also providing exceptional thermal performance. The transformer topology may consist of optional top and bottom ferrite plates, with TI's proprietary thin-film polymer laminate array as the insulation barrier. The transformer configuration shown in **Figure 9** is an example of transformer windings contained within the polymer laminate, sandwiched between two parallel ferrite plates.

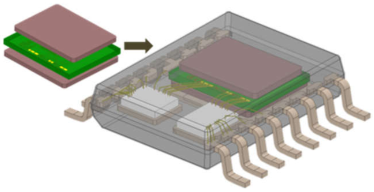

Figure 9. *Magnetic coupling ferrite-plated high-performance transformer.*

In many applications, the amount of power needed across the isolation barrier is modest (sub-100 mW). For these applications, TI has developed a technology for creating high-performance air-core transformers. TI's air-core transformers are similar to the technology shown in **Figure 9**, but without the ferrite plates.

All of TI's transformers (both air core and ferrite plated) employ shielding techniques to provide better radiated EMI performance. Employing EMI mitigation techniques at the package level reduces the need for additional board-level filtering to meet the limits of conducted and radiated emissions standards.

A single isolation solution may not fit every application, making it necessary to understand the different parameters and specifications while balancing design trade-offs.

Learn about essential isolation parameters, certifications, and how to design and troubleshoot with each type of device by watching the **TI Precision Labs – Isolation** training series.

Achieve isolation needs reliably while reducing solution size and cost

Different applications require different isolation approaches. Let's look at a few examples of how TI ICs can help solve a high-voltage isolation need with very high reliability while also reducing solution size and cost.

EV applications

EV battery stack voltage levels continue increasing from 400 V to 800 V – even as high as 1 kV – enabling automakers to achieve reduced weight, increased torque, high efficiency and faster charging.

Isolated semiconductors enable low-voltage digital and analog circuits to safely operate with high-voltage batteries while achieving the required level of galvanic isolation. Isolated voltage sensors, current sensors, ADCs and CAN transceivers are a few examples of signal-chain ICs requiring low-voltage DC bias on both sides of the isolation boundary. The **UCC12051-Q1** is a low-voltage isolated DC/DC power module leveraging

TI's integrated magnetic laminate, planar transformer technology to provide up to 500 mW of 5-V to 5-V (or 3.3-V) bias while achieving 5-kV$_{RMS}$ isolation.

Battery management systems (BMSs) and **traction inverters** are two of the most critical EV subsystems where the 800-V domain needs to be isolated from the chassis.

BMSs use a **pre-charge circuit** when connecting high-voltage battery terminals to subsystems. The 5-kV$_{RMS}$ **TPSI3050-Q1** isolated switch driver replaces mechanical pre-charge contactors to form a smaller, more reliable solid-state solution. To prevent passenger exposure to high voltages, the BMS frequently monitors the insulation between each terminal of the battery (HV+ and HV–) to the metal chassis. Solid-state relays (such as the **TPSI2140-Q1**) work with a battery-pack monitor (such as the **BQ79631-Q1**) to detect insulation faults in 800-V BMSs faster and with higher accuracy than solid-state photorelays. The TPSI2140-Q1 enables the use of <1-MΩ resistors and withstands over 300% more avalanche current than traditional photorelays to help enable safer human-system interaction.

The block diagram shown in **Figure 10** is an example of a traction inverter highlighting the use of isolated gate drivers to drive high-voltage insulated-gate bipolar transistor (IGBT) or silicon carbide (SiC) modules in a three-phase, DC/AC inverter configuration. These modules often co-package as many as six IGBT or SiC switches, requiring up to six isolation transformers, powering six independent gate-driver ICs. To minimize PCB area by reducing the number of external transformers, the **UCC14240-Q1** is a dual-output, mid-voltage, isolated DC/DC power module that can enable higher performance in traction inverter, gate-driver bias applications.

Isolated DC/DC modules such as the UCC14240-Q1 and **UCC12051-Q1** are not limited to a particular bias function, and therefore lend themselves to a variety of power architectures. With some sacrifice in scalability, it is possible to realize even higher degrees of integration by combining signal chain and power into a single IC package. Examples include power plus a digital isolator (the **ISOW7841A-Q1**), power plus an ADC (the **AMC3336-Q1**) and power plus an amplifier (the **AMC1350-Q1**).

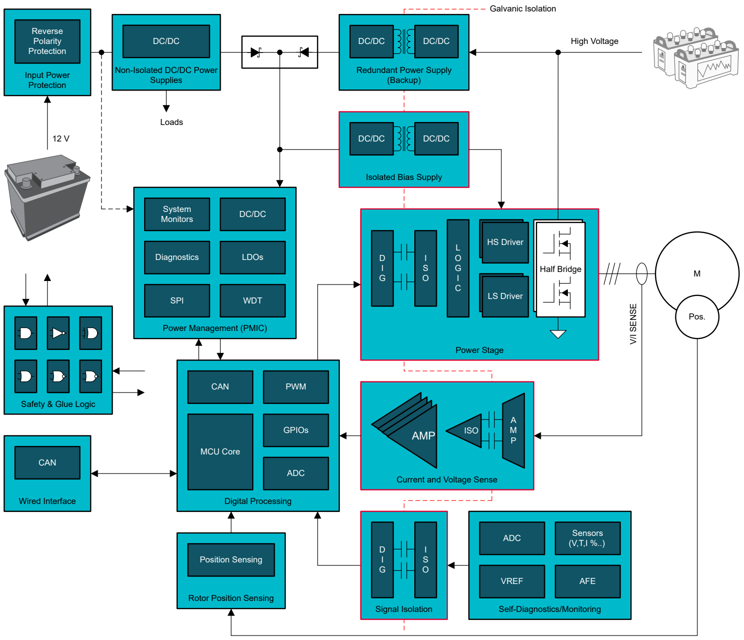

__Figure 10.__ A typical traction inverter block diagram.

Grid infrastructure applications

Solar energy equipment and EV chargers can use voltages from 200 V to 1,500 V or more. Insulating materials help prevent these high-voltage terminals from inadvertently connecting to protective ground. If these insulating materials begin to deteriorate and the risk of exposure increases, then the potential for high-current faults, explosions, damage to equipment and property, or fatal accidents can occur.

Figure 11 shows the **AFE for Insulation Monitoring in High-Voltage EV Charging and Solar Energy Reference Design**, designed for insulation resistance monitoring in grid infrastructure applications using the TPSI2140-Q1 isolated switch and **AMC3330** precision isolated amplifier. Because there are no moving parts, this solid-state relay solution can perform frequent measurements for decades without any performance degradation. These devices are designed for high-temperature operation up to 125°C, while alternative technologies such as photorelays are typically designed for operating temperatures up to 105°C. Both power and signals are transferable across isolation within these devices, so there is no need for secondary-side bias supplies. Since these devices are available in low-profile small outline IC packages, their solution size can be as much as 50% smaller than photorelay- or mechanical relay-based solutions. The ability to maintain accuracy over temperature makes it possible to detect and monitor insulation wear, and issue corresponding warnings or faults.

Solar string inverter and DC fast chargers contain high-voltage DC/AC and AC/DC power conversions. The photovoltaic panel output can go as high as 1,500 V and the DC fast charger output can go as high as 1,000 V, depending on the EV battery pack. For safety reasons, both systems require galvanic isolation.

To implement the voltage and current control loops in power-conversion systems, the microcontroller needs isolated, fast and accurate voltage and current readings. The **AMC3302** isolated amplifier and **AMC3306M05** isolated ADC both have a ±50-mV input range that enables small shunt resistors to keep power losses small and measurement resolutions high.

The **Bidirectional Dual Active Bridge Reference Design for Level 3 Electric Vehicle Charging Stations** (see **Figure 12**) uses a 10-kW bidirectional DC/DC converter. Peak power losses amount to less than 0.01% of the total power converted. An isolated power supply eliminates the need for a low-voltage supply on the hot side. The reference design uses the **AMC1311** isolated amplifier for voltage sensing, while the **UCC21530** isolated gate driver and **ISO7721** isolated digital interface isolate low-voltage control signals from the high-voltage DC link or DC output.

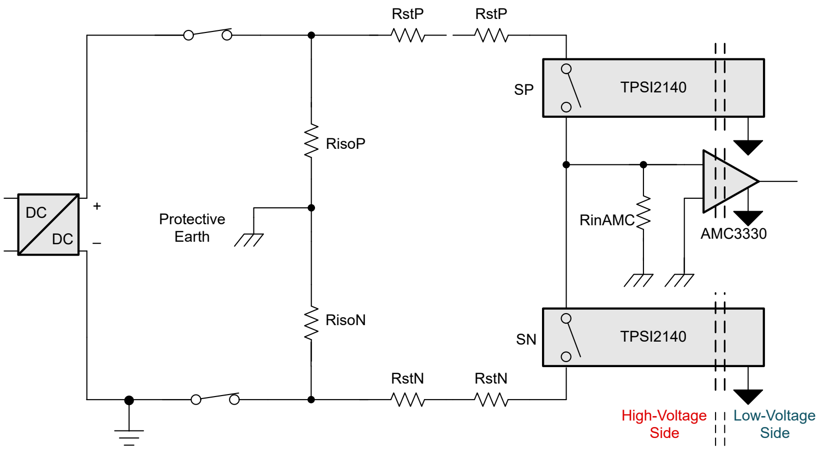

Figure 11. *AFE for Insulation Monitoring in High-Voltage EV Charging and Solar Energy Reference Design block diagram.*

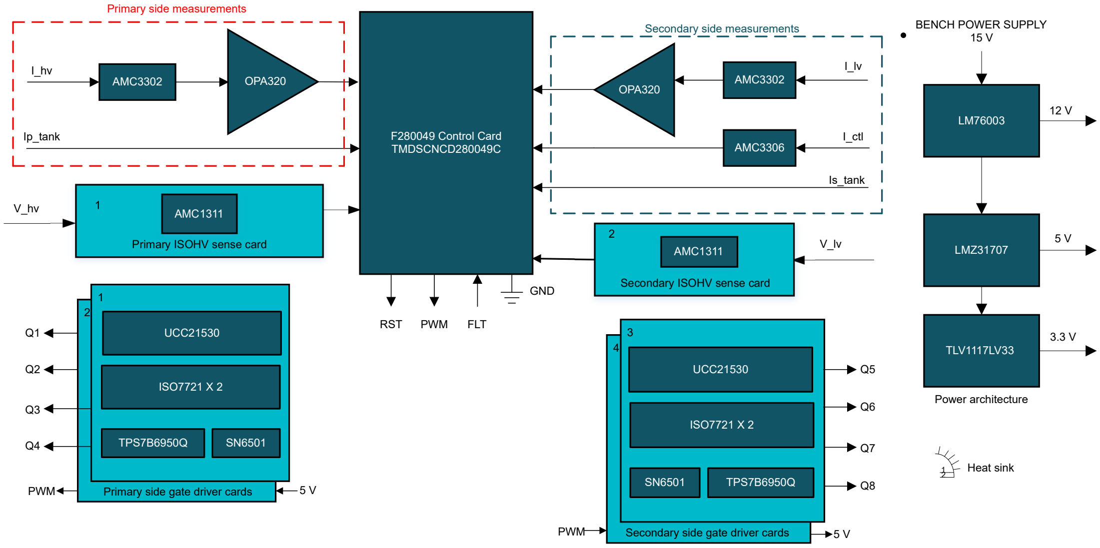

Figure 12. Bidirectional Dual Active Bridge Reference Design block diagram.

Factory automation applications

Programmable logic controllers (PLCs) process data from sensors or transmitters by transmitting through an isolator to a microcontroller (MCU). Since the field-side voltages are typically 24 V, basic isolation usually suffices for breaking the ground loops. Working voltages of 100 V_{RMS} to 500 V_{RMS} and isolation voltages of 2.5 kV_{RMS} are good enough for most low-voltage PLC applications. Packages with small creepage and clearance distances are preferable in these space-constrained applications.

The dual-channel 24-V to 60-V **ISO1212** digital input receiver is designed to help simplify and improve PLC digital input designs by combining accurate current limiting, protection circuitry and isolation in one package to help reduce component count and improve performance. It also increases reliability by integrating a long-lifetime SiO_2 isolation barrier and reducing system board temperatures.

The **Sub 1-W, 16-Channel, Isolated Digital Input Module Reference Design** is designed to withstand electrostatic discharge, electrical fast transient and surge events according to IEC 6100-4-2, while using less than 1-W input power combined. Each channel can withstand input voltages as high as ±60 V.

In the PLC digital input module shown in **Figure 13**, the serializer and field side of the isolator need power from a 5-V or 3.3-V supply. An isolated power supply or digital isolator with an integrated power supply providing the required bias from the MCU side eliminates the need for a separate power supply on the field side. PLC analog input modules process signals through an analog input front end, through a digital isolator such as the **ISO7741**, and then into the MCU.

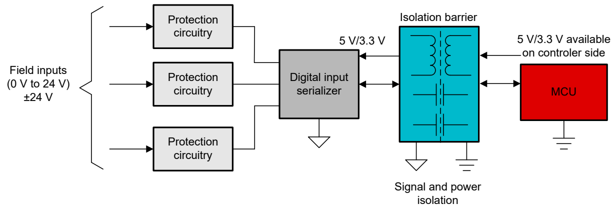

Figure 13. PLC digital input module with isolated data and power.

Another challenge in factory automation involves the isolation of field transmitters. Since the entire system is powered from 4 mA to 20 mA, the zero-scale value sets the system's maximum budget, usually less than 3.3 mA.

Historical isolation solutions can consume anywhere from 500 µA up to 1 mA per channel, forcing designers to either minimize the number of communication lines brought across the isolation barrier or slow data transfer speeds. The **ISO7041** family integrates two to four ultra-low-power digital isolator channels in small packages while providing power consumption as low as 3.5 µA per channel, data rates up to 4 Mbps, a temperature range from –55°C to 125°C, and the stability and reliability advantages of TI's SiO_2 insulation dielectric. The **Isolated Power and Data Interface for Low-Power Applications Reference Design** shows the ISO7041 in a 4-mA to 20-mA transmitter application.

Motor-drive applications

As shown in **Figure 14**, a motor drive takes power from AC mains, rectifies it to a DC voltage, and inverts the DC back to AC with variable magnitude and frequency based on motor load demand.

A motor drive typically has an isolation barrier between power and control circuits through isolated semiconductor components. An isolated amplifier or modulator measures and isolates current and voltage feedback signals from the power circuits. An isolated gate driver provides isolation between the MCU generating the pulse-width modulation (PWM) control signals and power transistors such as IGBTs. An isolated comparator checks for any overcurrent, overvoltage or overtemperature conditions and provides a fault signal to the MCU. Optional interface isolation with digital isolators can help meet any additional system safety requirements.

It's important for a galvanically isolated motor drive to minimize noise interference between power and control circuits and ensure safety for human operators. Modern motor-drive systems must also meet IEC 61800-5-1 safety standards.

Increasing measurement accuracy for current and voltage feedback loops helps minimize torque ripple and provides smooth speed and torque current profiles to the motor. Isolated amplifiers such as the **AMC1300** and **AMC1311B** and isolated modulators such as the **AMC1306M25** and **AMC1336** support accurate current and voltage measurements with high CMTI that improves system reliability with reduced noise coupling.

With low propagation delay, high CMTI, and reduced rise and fall times, isolated gate drivers enable higher PWM frequencies and minimal switching losses, making it easier for designers to adopt SiC and gallium nitride (GaN) transistors in their motor-drive systems. For accurate and fast fault detection in fault-tolerant systems, the **AMC23C12** family of reinforced isolated comparators provides a cost-effective solution with <3% accuracy, <400-ns latency, and up to 50% space and bill-of-materials (BOM) reductions.

Digital isolators such as the **ISO6760L** with integrated interlock and low EMI ensure the transmission of digital signals with high signal integrity between the power and control circuit or (optionally) between the MCU and interface. The **Isolated Delta-Sigma Modulator Based AC/DC Voltage and Current Measurement Module Reference Design** provides a cost-optimized and highly reliable solution to achieve sub-1% accuracy for isolated current and voltage measurements.

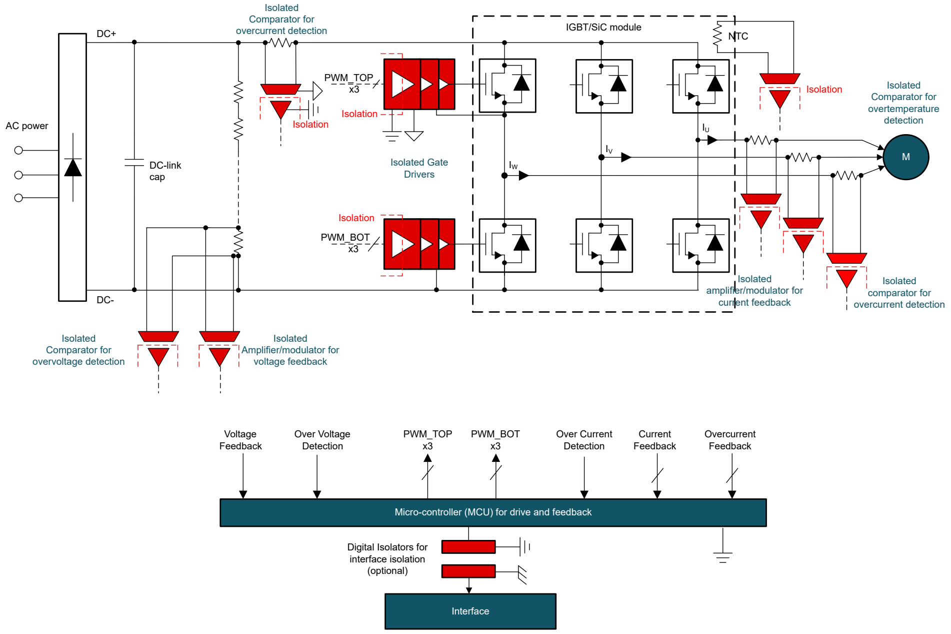

Figure 14. *Motor-drive block diagram.*

Conclusion

In industrial and automotive applications, isolation enables communication between different voltage domains by protecting low-voltage circuitry from high-voltage faults and maintaining signal integrity by breaking ground loops. Of the different dielectric materials available for isolation, the SiO_2 dielectric used in TI's capacitive isolators offers some of the highest lifetimes in the industry, along with stability over moisture and temperature. TI's integrated transformer technology enables high-density isolated DC/DC power conversion while lowering EMI.

The TI portfolio of signal and power isolators helps engineers ensure compliance with the most stringent isolation system requirements.

See **www.ti.com/isolationtechnology** to learn how to increase safety with high working voltages and reliability, or explore TI's extensive isolation portfolio:

- **Digital isolators**
- **Isolated ADCs**
- **Isolated amplifiers**
- **Isolated comparators**
- **Isolated gate drivers**
- **Isolated interface ICs**
- **Power for signal isolators**
- **Solid-state relays**

Additional resources

- Read the white paper, ***Enabling High Voltage Signal Isolation Quality and Reliability***, for more information about the reliability of TI's high-voltage isolation capacitors.
- Check out the application brief, ***How to Simplify Isolated 24-V PLC Digital Input Module Designs***.

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