Isolation Technologies for Reliable Industrial Measurements

Overview

Voltage, current, temperature, pressure, strain, and flow measurements are an integral part of industrial and process control applications. Often these applications involve environments with hazardous voltages, transient signals, common-mode voltages, and fluctuating ground potentials capable of damaging measurement systems and ruining measurement accuracy. To overcome these challenges, measurement systems designed for industrial applications make use of electrical isolation. This white paper focuses on isolation for analog measurements, provides answers to common isolation questions, and includes information on different isolation implementation technologies.

Understanding Isolation

Isolation electrically separates the sensor signals, which can be exposed to hazardous voltages [1], from the measurement system's low-voltage backplane. Isolation offers many benefits including:

- Protection for expensive equipment, the user, and data from transient voltages
- Improved noise immunity
- Ground loop removal
- Increased common-mode voltage rejection

Isolated measurement systems provide separate ground planes for the analog front end and the system backplane to separate the sensor measurements from the rest of the system. The ground connection of the isolated front end is a floating pin that can operate at a different potential than the earth ground. Figure 1 represents an analog voltage measurement device. Any common-mode voltage that exists between the sensor ground and the measurement system ground is rejected. This prevents ground loops from forming and removes any noise on the sensor lines.

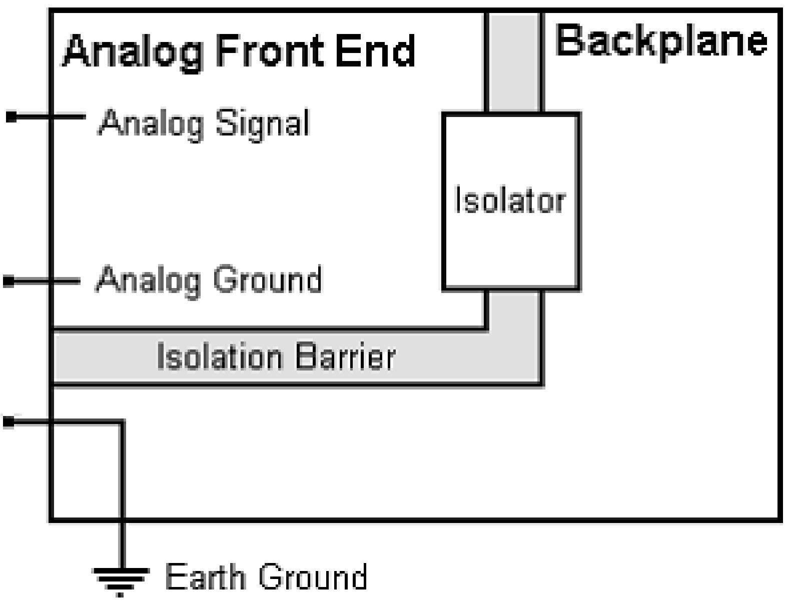

Figure 1. Bank Isolated Analog Input Circuitry

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Hazardous Voltages are greater than 30 Vrms, 42.4 Vpk or 60 VDC

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Need for Isolation

Consider isolation for measurement systems that involve any of the following:

- Vicinity to hazardous voltages
- Industrial environments with possibility of transient voltages
- Environments with common mode voltage or fluctuating ground potentials
- Electrically noisy environments such as those with industrial motors
- Transient sensitive applications where it is imperative to prevent voltage spikes from being transmitted through the measurement system

Industrial measurement, process control, and automotive test are examples of applications where common-mode voltages, high voltage transients, and electrical noise are common. Measurement equipment with isolation can offer reliable measurements in these harsh environments. For medical equipment in direct contact with patients, isolation is useful in preventing power line transients from being transmitted through the equipment.

Based on your voltage and data rate requirements, you have several options for making isolated measurements. You can use plug-in boards for laptops, desktop PCs, industrial PCs, PXI, Panel PCs, and CompactPCI with the option of built-in isolation or external signal conditioning. Isolated measurements can also be made using programmable automation controllers (PACs) and measurement systems for USB.

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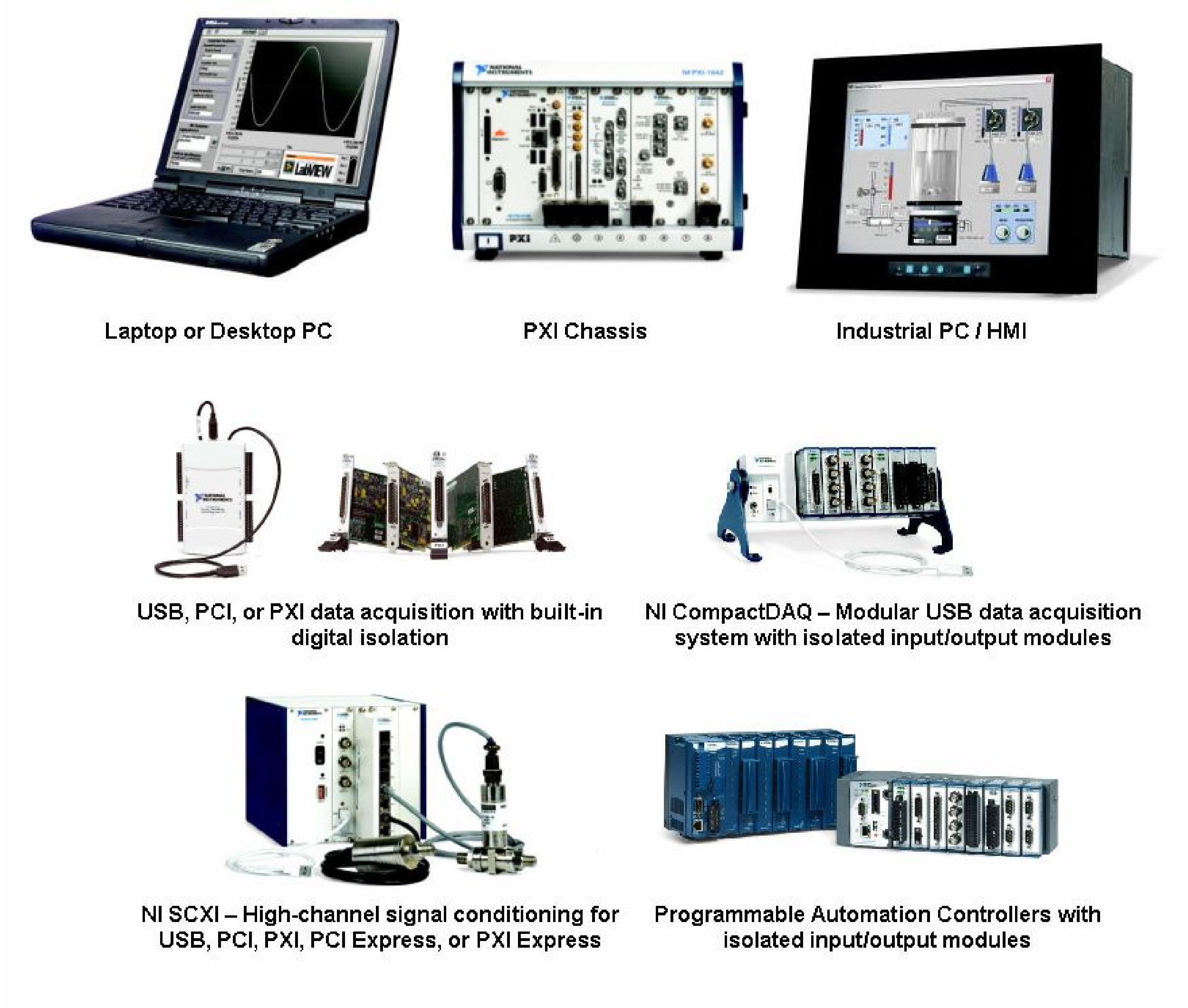

Figure 2. Isolated Data Acquisition Systems

Methods of Implementing Isolation

Isolation requires signals to be transmitted across an isolation barrier without any direct electrical contact. Light emitting diodes (LEDs), capacitors, and inductors are three commonly available components that allow electrical signal transmission without any direct contact. The principles on which these devices are based form the core of the three most common technologies for isolation – optical, capacitive, and inductive coupling.

Optical Coupling

LEDs produce light when a voltage is applied across them. Optical isolation uses an LED along with a photo-detector device to transmit signals across an isolation barrier using light as the method of data translation. A photo-detector receives the light transmitted by the LED and converts it back to the original signal.

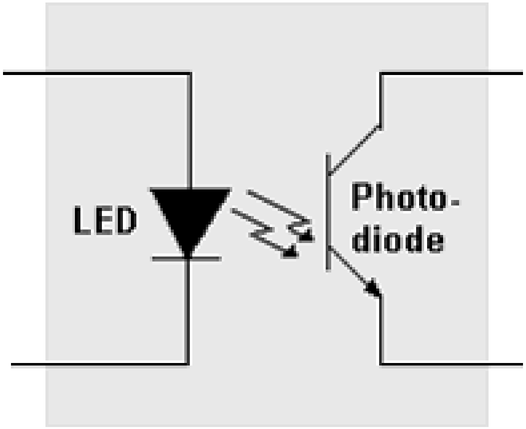

Figure 3. Optical Coupling

Optical isolation is one of the most commonly used methods for isolation. One benefit of using optical isolation is its immunity to electrical and magnetic noise. Some of the disadvantages include transmission speed, which is restricted by the LED switching speed, high-power dissipation, and LED wear.

Capacitive Coupling

Capacitive isolation is based on an electric field that changes based on the level of charge on a capacitor plate. This charge is detected across an isolation barrier and is proportional to the level of the measured signal.

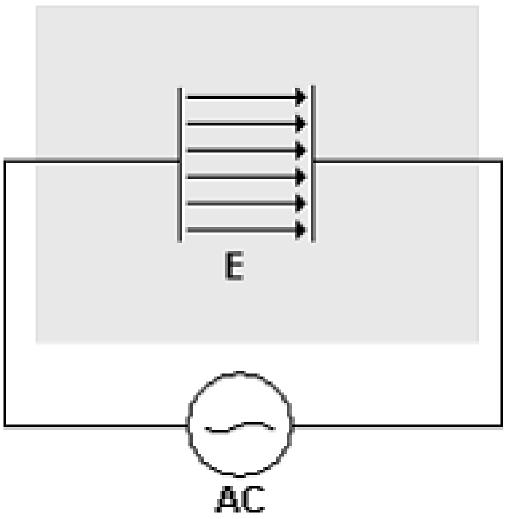

Figure 4. Capacitive Isolation

One advantage of capacitive isolation is its immunity to magnetic noise. Compared to optical isolation, capacitive isolation can support faster data transmission rates because there are no LEDs that need to be switched. Since capacitive coupling involves the use of electric fields for data transmission, it can be susceptible to interference from external electric fields.

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Inductive Coupling

In the early 1800s, Hans Oersted, a Danish physicist, discovered that current through a coil of wire produces a magnetic field. It was later discovered that current can be induced in a second coil by placing it in close vicinity of the changing magnetic field from the first coil. The voltage and current induced in the second coil depend on the rate of current change through the first. This principle is called mutual induction and forms the basis of inductive isolation.

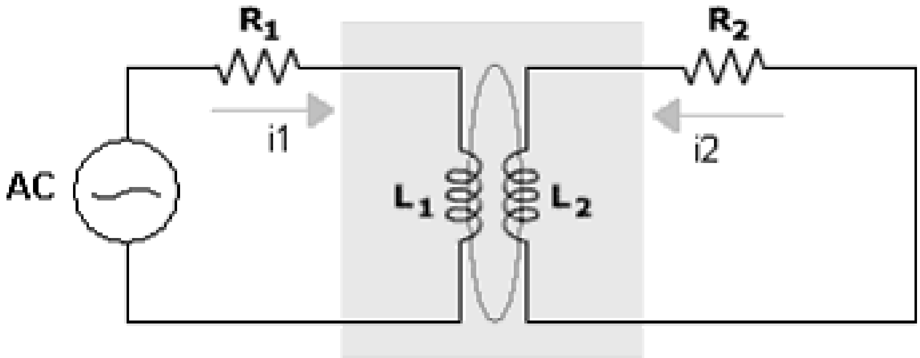

Figure 5. Inductive Coupling

Inductive isolation uses a pair of coils separated by a layer of insulation. Insulation prevents any physical signal transmission. Signals can be transmitted by varying current flowing through one of the coils, which causes a similar current to be induced in the second coil across the insulation barrier. Inductive isolation can provide high-speed transmission similar to capacitive techniques. Because inductive coupling involves the use of magnetic fields for data transmission, it can be susceptible to interference from external magnetic fields.

Analog Isolation and Digital Isolation

Several commercial off-the-shelf (COTS) components are available today, many of which incorporate one of the above technologies to provide isolation. For analog input/output channels, isolation can be implemented either in the analog section of the board, before the analog-to-digital converter (ADC) has digitized the signal (analog isolation) or after the ADC has digitized the signal (digital isolation). Different circuitry needs to be designed around one of these techniques based on the location in the circuit where isolation is being implementing. You can choose analog or digital isolation based on your data acquisition system performance, cost, and physical requirements. Figure 6 shows the different stages of implementing isolation.

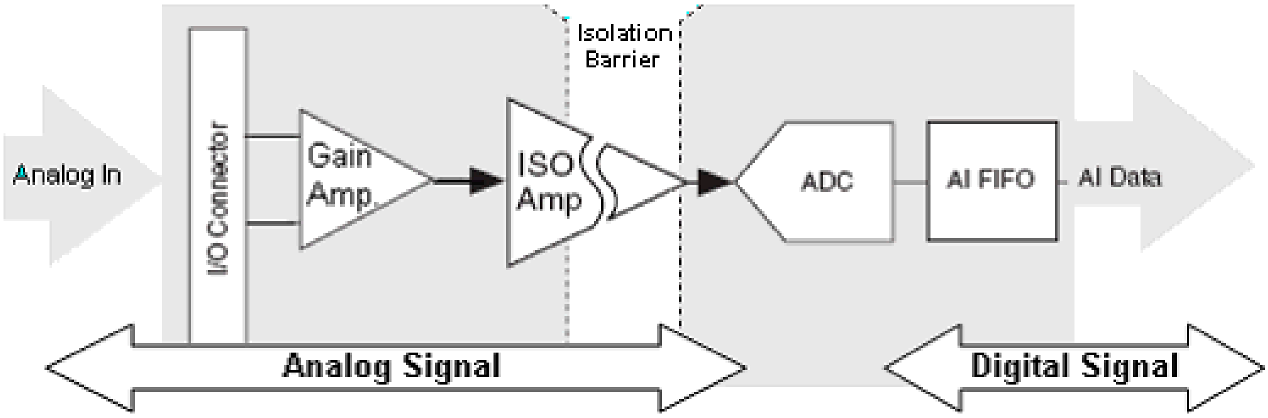

Figure 6a. Analog Isolation

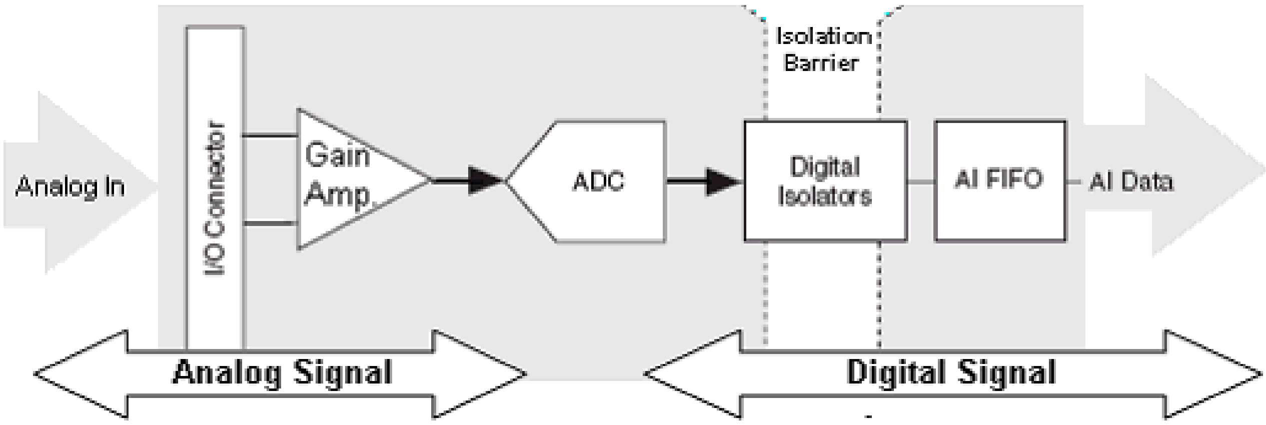

Figure 6b. Digital Isolation

The following sections cover analog and digital isolation in more detail and explore the different techniques for implementing each.

Analog Isolation

The isolation amplifier is generally used to provide isolation in the analog front end of data acquisition devices. “ISO Amp” in Figure 6a represents an isolation amplifier. The isolation amplifier in most circuits is one of the first components of the analog circuitry. The analog signal from a sensor is passed to the isolation amplifier, which provides isolation and passes the signal to the analog-to-digital conversion circuitry. Figure 7 represents the general layout of an isolation amplifier.

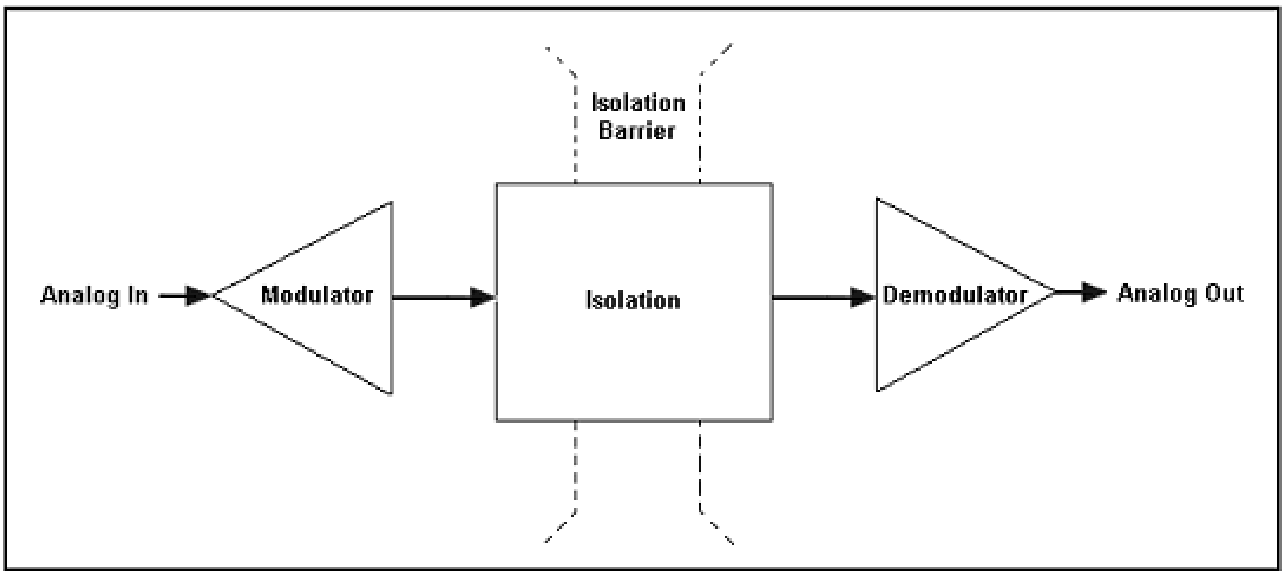

Figure 7. Isolation Amplifier

In an ideal isolation amplifier, the analog output signal is the same as the analog input signal. The section labeled “isolation” in Figure 7 uses one of the techniques discussed in the previous section (optical, capacitive, or inductive coupling) to pass the signal across the isolation barrier. The modulator circuit prepares the signal for the isolation circuitry. For optical methods, this signal needs to be digitized or translated into varying light intensities. For capacitive and inductive methods, the signal is translated into varying electric or magnetic fields. The demodulator circuit then reads the isolation circuit output and converts it back into the original analog signal.

Because analog isolation is performed before the signal is digitized, it is the best method to apply when designing external signal conditioning for use with existing non-isolated data acquisition devices. In this case, the data acquisition device performs the analog-to-digital conversion and the external circuitry provides isolation. With the data acquisition device and external signal conditioning combination, measurement system vendors can develop general-purpose data acquisition devices and sensor-specific signal conditioning. Figure 8 shows analog isolation being implemented with flexible signal conditioning that uses isolation amplifiers. Another benefit to isolation in the analog front end is protection for the ADC and other analog circuitry from voltage spikes.

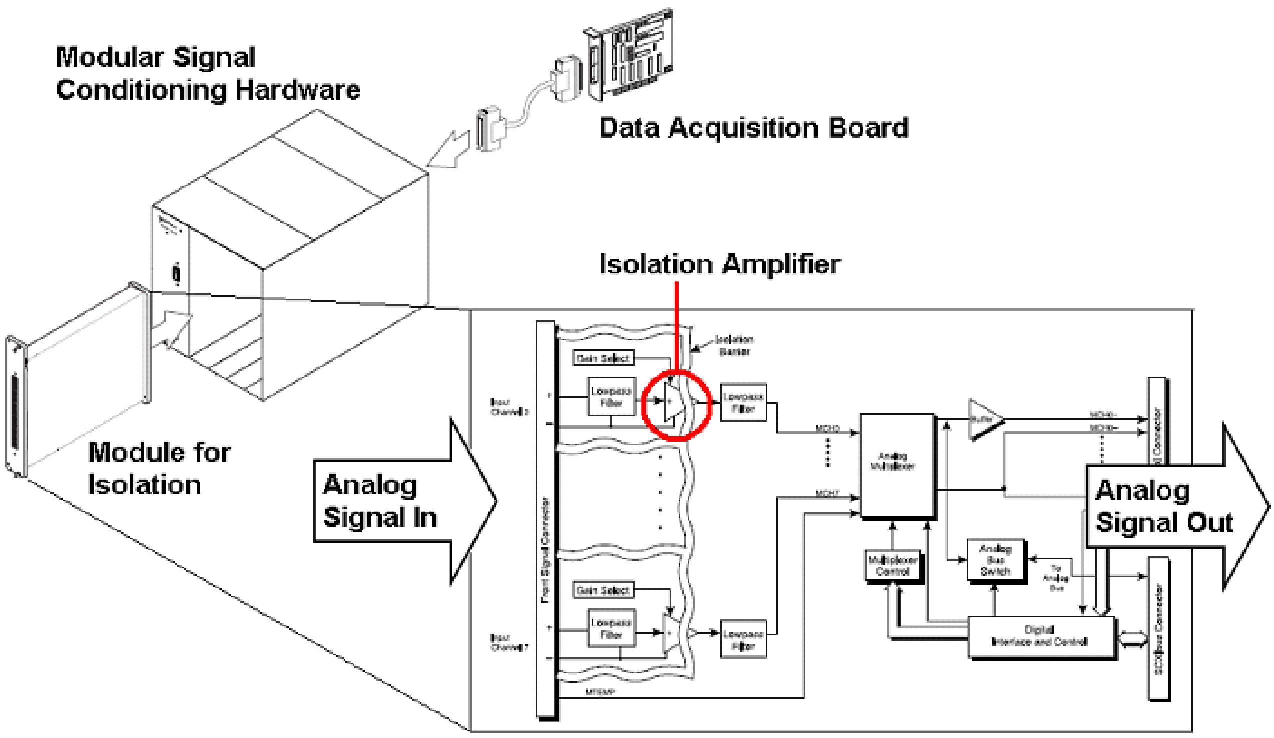

Figure 8. Use of Isolation Amplifiers in Flexible Signal Conditioning Hardware

There are several options available on the market for measurement products that use a general-purpose data acquisition device and external signal conditioning. For example, the National Instruments M Series includes several non-isolated, general-purpose multifunction data acquisition devices that provide high-performance analog I/O and digital I/O. For applications that need isolation, you can use the NI M Series devices with external signal conditioning, such as the National Instruments SCXI or SCC modules. These signal conditioning platforms deliver the isolation and specialized signal conditioning needed for direct connection to industrial sensors such as load cells, strain gages, pH sensors, and others.

Digital Isolation

Analog-to-digital converters are one of the key components of any analog input data acquisition device. For best performance the input signal to the analog-to-digital converter should be as close to the original analog signal as possible. Analog isolation can add errors such as gain, non-linearity and offset before the signal reaches the ADC. Placing the ADC closer to the signal source can lead to better performance. Analog isolation components are also costly and can suffer from long settling times. Despite better performance of digital isolation one of the reasons for using analog isolation in the past was to provide protection for the expensive analog-to-digital converters. As the ADCs prices have significantly declined, measurement equipment vendors are choosing to trade ADC protection for better performance and lower cost offered by digital isolators (see Figure 9).

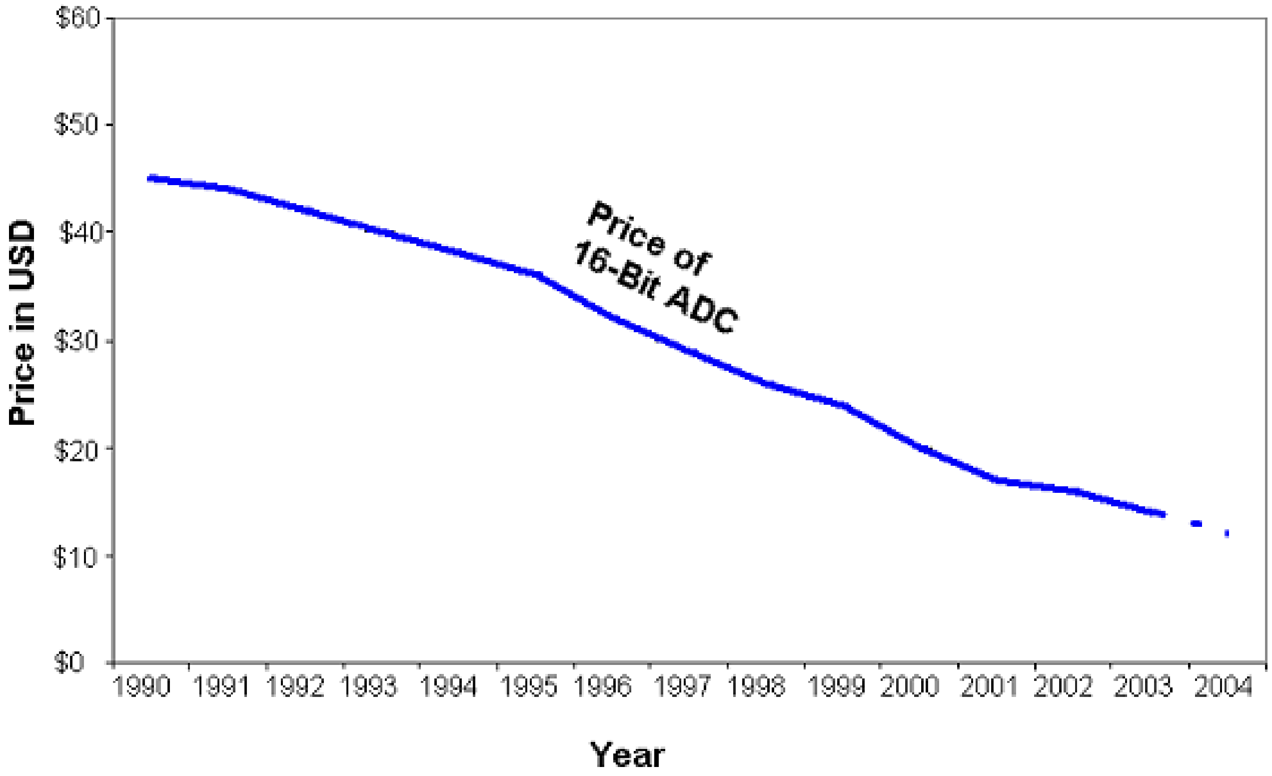

Figure 9. Declining Price of 16-Bit Analog-to-Digital Converters

Graph Source: National Instruments and a Leading ADC Supplier

Compared to isolation amplifiers, digital isolation components are lower in cost and offer higher data transfer speeds. Digital isolation techniques also give analog designers more flexibility to choose components and develop optimal analog front ends for measurement devices. Products with digital isolation use current- and voltage-limiting circuits to provide ADC protection. Digital isolation components follow the same fundamental principles of optical, capacitive, and inductive coupling that form the basis of analog isolation.

Leading digital isolation component vendors such as Avago Technologies (www.avagotech.com), Texas Instruments (www.ti.com), and Analog Devices (www.analog.com) have developed their isolation technologies around one of these basic principles. Avago Technologies offers digital isolators based on optical coupling, Texas instruments bases its isolators on capacitive coupling, and Analog Devices isolators use inductive coupling.

Optocouplers

Optocouplers, digital isolators based on the optical coupling principles, are one of the oldest and most commonly used methods for digital isolation. They can withstand high voltages and offer high immunity to electrical and magnetic noise. Optocouplers are often used on industrial digital I/O products, such as the National Instruments PXI-6514 isolated digital input/output board (see Figure 10) and National Instruments PCI-7390 industrial motion controller.

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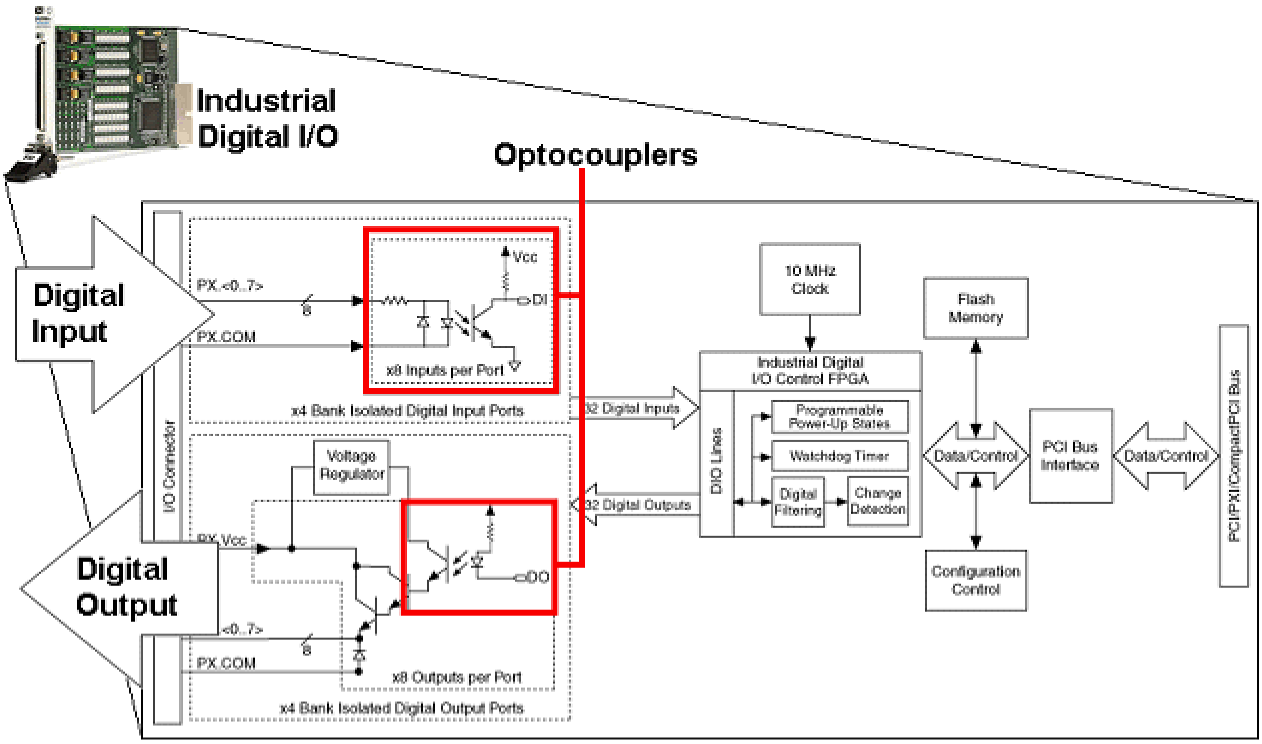


Figure 10. Industrial Digital I/O Products Use Optocouplers

For high-speed analog measurements, optocouplers, however, suffer from speed, power dissipation, and LED ware limitations associated with optical coupling. Digital isolators based on capacitive and inductive coupling can alleviate many optocoupler limitations.

Capacitive Isolation

Texas Instruments offers digital isolation components based on capacitive coupling. These isolators provide high data transfer rates and high transient immunity. Compared to capacitive and optical isolation methods inductive isolation offers lower power consumption.

Inductive Isolation

*i*Coupler® technology, introduced by Analog Devices in 2001 (www.analog.com/*i*Coupler), uses inductive coupling to offer digital isolation for high-speed and high-channel-count applications. *i*Couplers can provide 100 Mb/s data transfer rates with 2,500 V isolation withstand; for a 16-bit analog measurement system that implies sampling rates in the mega hertz range. Compared to optocouplers, *i*Couplers offer other benefits such as reduced power consumption, high operating temperature range up to 125 °C, and high transient immunity up to 25 kV/ms.

*i*Coupler technology is based on small, chip-scale transformers. An *i*Coupler has three main parts – a transmitter, transformers, and a receiver. The transmitter circuit uses edge trigger encoding and converts rising and falling edges on the digital lines to 1 ns pulses. These pulses are transmitted across the isolation barrier using the transformer and decoded on the other side by the receiver circuitry (see Figure 11). The small size of the transformers, about three-tenths of a millimeter, makes them practically impervious to external magnetic noise. *i*Couplers can also lower measurement hardware cost by integrating up to four isolated channels per integrated circuit (IC) and, compared to optocouplers, they require fewer external components.

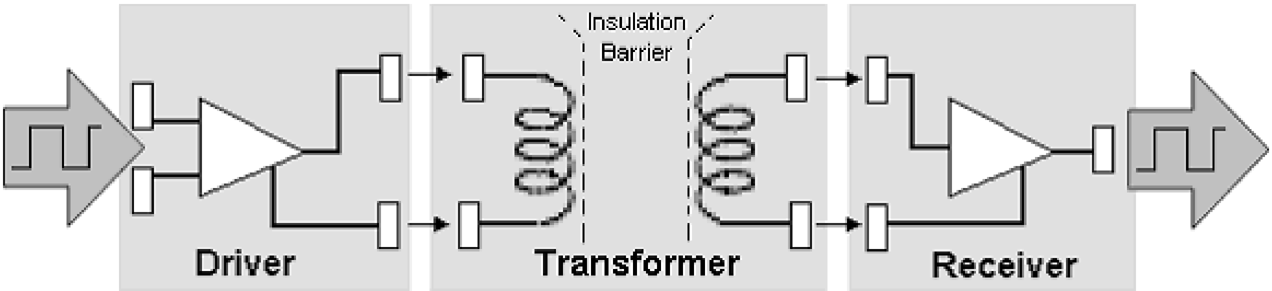


Figure 11. Induction Coupling-Based iCoupler Technology from Analog Devices

Source: Analog Devices (www.analog.com/*i*Coupler)
Measurement hardware vendors are using *i*Couplers to offer high-performance data acquisition systems at lower costs. National Instruments industrial data acquisition devices intended for high-speed measurements, such as the isolated M Series multifunction data acquisition devices, use *i*Coupler digital isolators (see Figure 12). These devices provide 60 VDC continuous isolation and 1,400 Vrms/1,900 VDC channel-to-bus isolation withstand for 5 s on multiple analog and digital channels and support sampling rates up to 250 kS/s. National Instruments C Series modules used in the NI PAC platform, NI CompactRIO, NI CompactDAQ, and other high-speed NI USB devices also use the *i*Coupler technology.

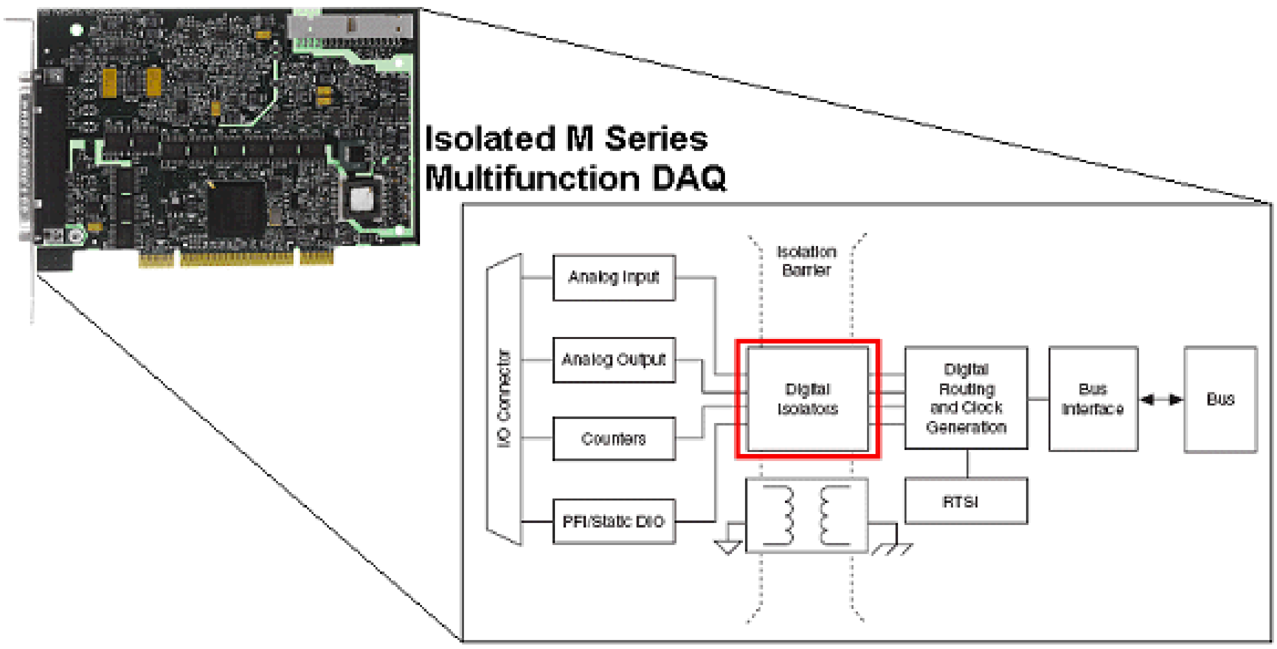


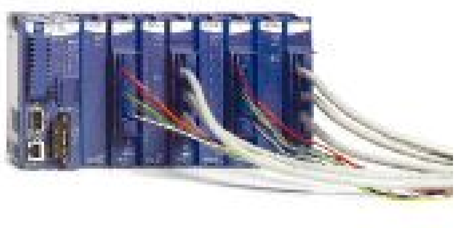
Figure 12. National Instruments Isolated M Series Multifunction DAQ Uses

Summary

Isolation Technologies for Reliable Industrial Measurements

Isolated data acquisition systems can provide reliable measurements for harsh industrial environments with hazardous voltages and transients. Your need for isolation is based on your measurement application and surrounding environments. Applications that require connectivity to different specialty sensors using a single, general-purpose data acquisition device can benefit from external signal conditioning with analog isolation. Where as applications needing lower-cost, high-performance analog inputs benefit from measurement systems with digital isolation technologies.

Isolated Products from National Instruments

	NI Isolated M Series and S Series • NI USB-6218 - Bank isolated USB multifunction DAQ • NI PCI-6230 - Bank isolated PCI/PXI multifunction DAQ • NI PCI-6154 - Ch-Ch isolated PCI simultaneous sampling DAQ
	NI CompactDAQ - USB Data Acquisition System • NI 9211 - Bank isolated thermocouple input module • NI 9206 - Bank isolated 600 VDC CAT I analog input module
	NI SCXI High-Channel External Signal Conditioning • NI SCXI-1125 - Ch-Ch isolation amplifier • NI SCXI-1121 - Bank isolated universal input sensor measurement amplifier
	NI CompactRIO - Reconfigurable Embedded Control and Acquisition System • NI 9203 - Isolated current input module • NI 9422 - Ch-ch isolated digital input module
	NI Compact FieldPoint - Distributed Programmable Automation Controller • NI cFP-TC-125 - Ch-Ch isolated thermocouple input module • NI cFP-AI-118 - Ch-Ch isolated voltage input module
	NI Motion Plug-in Motion Controller with Isolation
	NI Serial RS-232 and RS-485 Devices with Isolation

Related Links:

Safety isolation protects users and electronic instruments - EDN September 2004