ANALOG DEVICES

AN-770 APPLICATION NOTE

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*i*Coupler® Isolation in CAN Bus Applications

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INTRODUCTION

The Controller Area Network (CAN) bus, a robust protocol designed for industrial applications, was originally developed for use in cars. It specifies a maximum cable length of 40 meters and up to 30 nodes. The flexibility and advantages of this specification have resulted in increased use in a wide range of applications.

Because the CAN bus system is typically used to connect multiple systems and is often run over very long distances, isolation between the bus and each system connection is critical. Isolation provides protection from overvoltage transients between the CAN bus cable network and the systems connected to it. Isolation also eliminates ground loops in the network, reduces signal distortion and errors, and provides protection from voltage/ground mismatches.

The intention of this application note is to give the user a brief overview of the CAN bus protocol, focusing on the system physical layer, as well as an understanding of why isolation is so important to the system. This application note also details how to implement isolation in a CAN bus system using Analog Devices' *i*Coupler products.

CAN BUS OVERVIEW

The CAN Bus Protocol

The CAN bus protocol standard is defined by the International Standardization Organization (ISO) as a serial communications 2-wire bus, with data rates up to 1 Mbps. It uses two layers: a differential signal physical layer, specified as ISO 11898, which provides excellent noise immunity, and a data link layer, which defines how the signals interact and communicate.

The Data Frame

The CAN bus protocol uses asynchronous data transmission design. The transmitted data is sent in a data frame, which is controlled by start and stop bits at the beginning and end of each transmission.

The data frame is composed of an arbitration field, a control field, a data field, a cyclic redundancy check field, and an acknowledge field. The frame begins with a start-of-frame *dominant* bit, and completes with an end-of-frame field (bit), as shown in Figure 1.

SOF	ARBITRATION	CONTROL	DATA	CRC	ACK	EOF

Figure 1. CAN Bus Data Transmission Frame

CAN Bus Arbitration

The CAN bus protocol also specifies nondestructive bit arbitration, which ensures that no data is lost. It is one of the protocol's most important features.

The CAN bus protocol defines the digital logic states on the bus with a logic high as the recessive state and a logic low as the dominant state. It is designed to allow every node to listen and transmit at the same time.

All nodes transmit a single dominant start of message (SOM) bit at the beginning of each message. Other nodes will see bus activity and will not attempt to start a transmission until the message packet is complete.

After the SOM bit, the arbitration field is transmitted. The arbitration field is 11 or 29 bits long, depending on which variation of the CAN bus protocol is used.

The highest priority message has an arbitration field of the highest number of dominant bits; it will transmit a dominant bit first, while the other nodes are transmitting recessive bits.

Also known as the identifier, the arbitration field prioritizes the messages on the bus. By the time the arbitration field has been sent, all nodes except the highest priority node will have stopped transmitting.

If multiple nodes start transmitting at the same time, the node transmitting the highest number of dominant bits always takes control of the bus. All nodes monitor the bus and stop transmitting when a higher priority transmission is recognized.

The other nodes attempt to transmit again after the message is completed. In this second attempt, the next highest value arbitration field will take control of the bus, and the arbitration process is repeated.

The nondestructive bus arbitration ensures that the highest priority message always gets through.

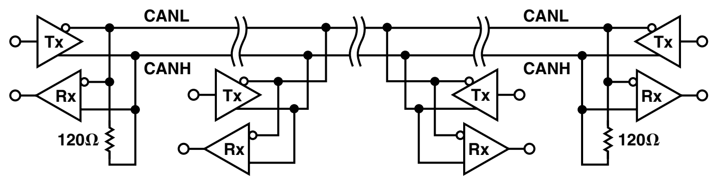

Figure 2. CAN Bus Network

CAN Bus Types

The first CAN bus standard introduced uses ISO 11519 and is designed for data rates up to 125 kbps. This is often referred to as low speed CAN. The second CAN bus standard introduced uses ISO 11898 and is designed for signaling rates between 125 kbps and 1 Mbps. This version is referred to as CAN 2.0A. Both of these standards define an 11-bit arbitration field.

The most recent CAN bus standard is Version 2.0B. This standard is identical to 2.0A, except that it specifies a 29-bit arbitration field.

CAN Bus Physical Layer

The physical layer is a balanced, or differential, 2-wire serial interface (Figure 2). Most CAN systems are designed to use a supply voltage of 5 V, although some 3 V systems have been designed.

Non-return-to-zero (NRZ) encoding is used for data communication on the differential 2-wire bus. Using NRZ encoding ensures compact messages with a minimum number of transitions and high noise immunity.

The CAN bus specification defines several data rates from 10 kbps to 1 Mbps. However, all system modules must support 20 kbps.

The ISO 11898 standard specification defines a maximum bus length of 40 meters, a maximum stub length of 0.3 meters, and a maximum of 30 nodes. However, the robust design of the CAN bus physical layer allows the use of much longer cable lengths. With careful design, a bus cable length of 1,000 meters is possible. As bus length increases, a corresponding decrease in maximum data rate will be experienced.

System maximum speed depends on the bus cable length. Maximum cable length for 1 Mbps is 40 meters. The worst-case transmission time of an 8-byte frame with an 11-bit identifier is 134 bit times or 134 microseconds at the maximum baud rate of 1 Mbps.

Operation

CAN bus transceivers use a unique open drain design (Figure 3).

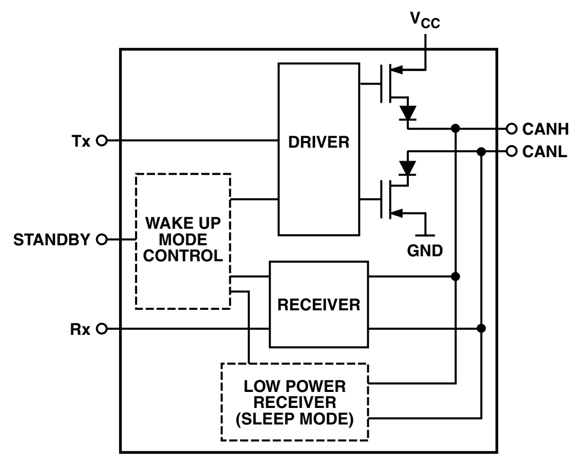

Figure 3. Typical CAN Transceiver, Including Low Power Standby Mode Circuit

The driver uses a pair of open drain devices to create a differential signal consisting of CANH (high) and CANL (low) on the bus. Combined, these signals produce the dominant signal level on the bus. The dominant signal level represents a logic low. If no transmitter is driving, pull-up resistors are used to set the bus voltage level to $V_{CC}/2$. The $V_{CC}/2$ level is the recessive signal bus level and represents a logic high (Figure 4).

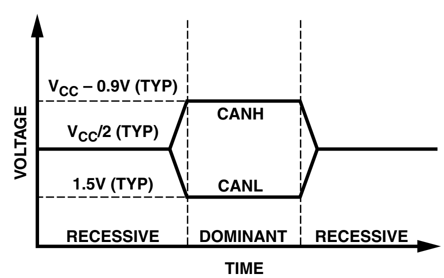

Figure 4. CAN Bus Signals

During dominant state the active driver configures the CANH line to a high level and the CANL line to a low voltage level. These differential signal levels are typically V_{CC} – 0.9 V for CANH and 1.5 V above ground for CANL.

External pull-up resistors can be used to configure the bus for the recessive state. Many CAN bus transceivers have the driver input and receiver output pins passively pulled high internally.

The nonbus side of the CAN bus transceivers connect to a CAN controller or a processor. The signals on this side of the transceiver are standard 0 V to 5 V or 0 V to 3 V logic levels.

Many transceivers also include a standby control input on the processor side that allows the controller to place the transceiver into a low power use standby mode, reducing system power used. A low power receiver remains active during standby mode, monitoring the bus for state changes. The receiver signals the controller to activate the local CAN node when bus activity is detected.

Termination

Termination resistors are required at each end of the cable. The standard termination is 120 Ω between the differential cables, with termination at each cable end. This layout results in the nominal 60 Ω bus load, as required by ISO 11898.

Fault Tolerance

The CAN bus standard recommends, but does not require, transceivers to survive several fault scenarios. These fault types include bus wires shorted together, shorted to the power supply, or shorted to the ground. Typical transceiver protection for these conditions is between –4 V and +16 V. However, fault tolerance for all transceivers cannot be assumed. It is recommended that close attention be given to data sheet specifications.

SYSTEM ISOLATION OVERVIEW

Unwanted currents and voltages on a cable bus connecting two systems have the potential to cause severe problems. High voltages and currents can destroy components connected to the bus. These unwanted voltages and currents come primarily from two sources: ground loops and electrical line surges. These voltages can far exceed the CAN bus recommended fault protection levels.

Ground loops occur when a bus or system uses multiple ground paths. It cannot be assumed that two system grounds connected to the bus and separated by several meters or more will be at the same potential. Because these grounds are unlikely to be at the same potential, current will flow between these points. This unintended current flow can damage or destroy components.

Electrical surges can be caused by many sources. These surges are the result of currents coupled onto cable lines through induction. Long cable lines and systems in industrial environments are especially susceptible to electrical surges.

The operation of equipment switching large currents, such as electric motors, causes rapid changes in the ground potential. These changes can generate a current flow through any nearby lines to equalize the ground potential.

Other induction surge sources include electrostatic discharge (ESD) and lightning strikes. These induced surges can result in hundreds or even thousands of volts of potential on the line, and manifest themselves as transient current and voltage surges.

Thus, the cable end node may receive a switching signal superimposed on a high voltage level with respect to its local ground. These uncontrolled voltages and currents can corrupt the signal, and can be catastrophic to the local transceiver device and system, causing damage or destruction of the components connected to the bus, and resulting in system failure. Because CAN bus systems run over cables of 40 meters or more, and typically interconnect multiple systems, they are susceptible to these events.

To protect against this potentially destructive energy, all devices on the bus, and on the systems connected to the bus, must each be referenced to only one ground. That is, the systems connected to the CAN bus, and each CAN bus transceiver, have a separate and isolated ground. Referencing the CAN bus system to only one ground eliminates ground loops, thereby preventing ground loops and electrical surges from destroying circuits.

Isolation also allows the CAN bus circuit reference voltage levels to rise and fall with any surges that appear on the cable line. Allowing the circuit voltage reference to move with surges, rather than being clamped to a fixed ground, prevents devices from being damaged or destroyed.

To accomplish system isolation, both the CAN bus signal lines and power supplies must be isolated. Power isolation is obtained through the use of an isolated dc-to-dc power supply. Signal isolation can be implemented using optocouplers or with Analog Devices' innovative *i*Couplers.

ISOLATION IMPLEMENTATION

The implementation of isolation is not overly complex, however, the designer must consider several important factors when implementing the isolation circuitry.

The CAN bus requires resistor connections to achieve the recessive state, which is typically $V_{CC}/2$, and the combination of CANH and CANL to achieve the dominant state. Digital isolators do not support this signal standard. Therefore, it is not possible to insert a digital isolator between the CAN bus transceivers and the cable.

CAN bus signal path isolation is accomplished by designing isolators into the digital signal path between the transceivers and the local CAN bus controller. The system side of the CAN bus transceivers use digital logic level signals of 0 V to 5 V or 0 V to 3 V, and typically connect to a CAN controller or processor. *i*Coupler isolators contain input and output circuits that are isolated from each other. Placing an *i*Coupler in this location electrically isolates the CAN bus cable signals from each system connected to it.

To complete the isolation of the CAN bus circuits from the local system, a dc-to-dc isolated power converter is required, regardless of whether *i*Couplers or optocouplers are used. The isolated power supply is used to supply power to the local CAN bus transceiver and CAN bus side of the isolator. The isolated power supply is typically supplied from the local system.

The combination of digital isolators and an isolated dc-to-dc power supply creates an effective protection against surge damage, and eliminates ground loops. Figure 5 illustrates system isolation design in a typical CAN bus system configuration using *i*Coupler integration.

ISOLATION DEVICE SELECTION

System performance requirements will have the most impact on the selection of an isolation device. Other considerations include space constraints and cost.

Data Rate Requirements

System data rate requirements are likely to be the single most important parameter for device selection.

The CAN bus specification defines two maximum data rate speeds: 125 kbps and 1 Mbps. Fortunately, all *i*Coupler products operate up to data rates of 1 Mbps. The *i*Coupler products portfolio also includes devices that operate up to data rates of 10 Mbps, 25 Mbps, and 100 Mbps.

Device cost typically rises in proportion to data rate performance. Therefore, a designer should take care not to specify a device with more performance than is required. However, low performance device selection can make future system performance upgrades more costly and involved, because all devices not compatible with upgraded system data speeds will require replacement.

ADI's *i*Couplers have a significantly shorter propagation delay than optocouplers. Shorter propagation delays allow a faster signal response time between a processor and the bus. This is especially critical during the arbitration period, when each node must decide which message receives priority and controls the bus. Therefore, the propagation delay time will define the maximum allowable line length of the bus at the required data rate.

Space Requirements

Maximum dimension requirements are a concern for virtually all applications, and some implementations can be severely space-limited. Fortunately, there are now solutions for these situations.

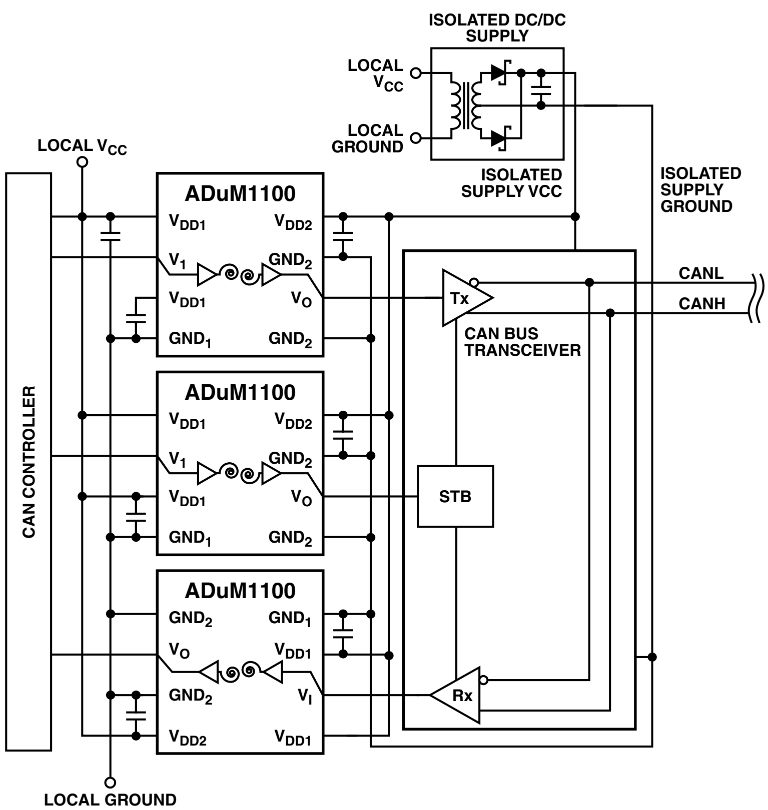

Figure 5. CAN Bus Isolation Using Three ADuM1100s

Solutions for systems where space is an issue include the ADuM1301. The ADuM1301 is a 3-channel isolation device in a 16-lead SOIC package, taking the place of three optocouplers and associated circuitry (Figure 6).

Cost Requirements

Cost constraints and concerns are a reality in virtually all system design work, and therefore must be considered. Cost considerations can have an effect on the design choices for a system. As noted previously, isolator device cost rises in proportion with data rate performance. Specifying a device with only the system performance required can reduce costs.

Other cost issues include a consideration of the number of devices used. The *i*Coupler device cost increases with channel count. However, the cost per channel decreases as the device channel count increases.

Additional cost benefits of integrating as many channels into one device as possible include reduction in board space and assembly costs. A lower device count results in smaller boards. Also, lower device count typically results in a less complex board layout. The combination of smaller boards and less complex layout reduces board costs. In addition, circuit board assembly costs typically decrease proportionally as the number of devices required for the board assembly process decreases. Therefore, designing with fewer devices results in lower manufacturing costs.

ADI *i*COUPLER PRODUCTS

ADI's *i*Coupler device technology has created products that possess distinct advantages for the system designer in comparison to other available isolation options. The *i*Coupler products provide superior performance, lower power consumption, higher reliability, and lower component count, with cost characteristics that are comparable with optocouplers.

ADI *i*Coupler Technology Overview

ADI's unique *i*Coupler technology provides isolation based on chip scale transformers rather than on the LEDs and photodiodes used in optocouplers. By fabricating the transformers directly on-chip using wafer-level processing, *i*Coupler channels can be integrated with each other and with other semiconductor functions at low cost (Figure 7).

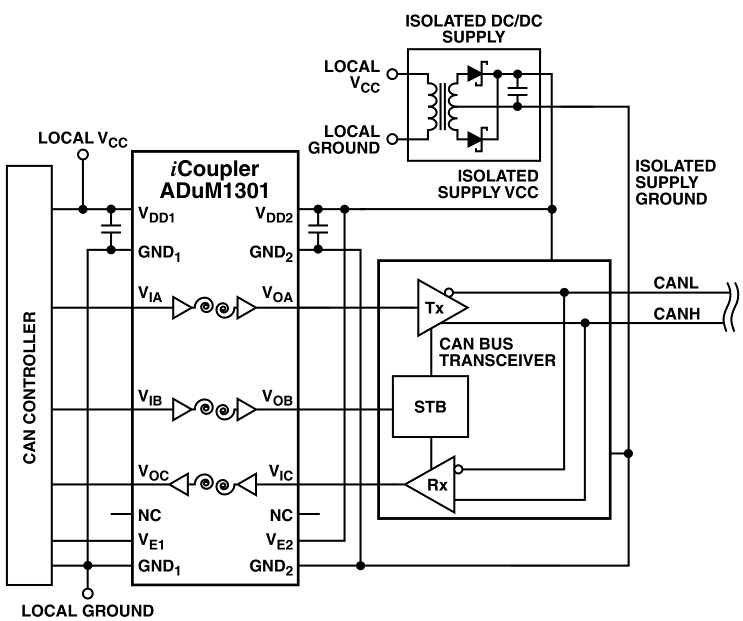

Figure 6. CAN Bus Node Network with Isolation Using ADuM1301

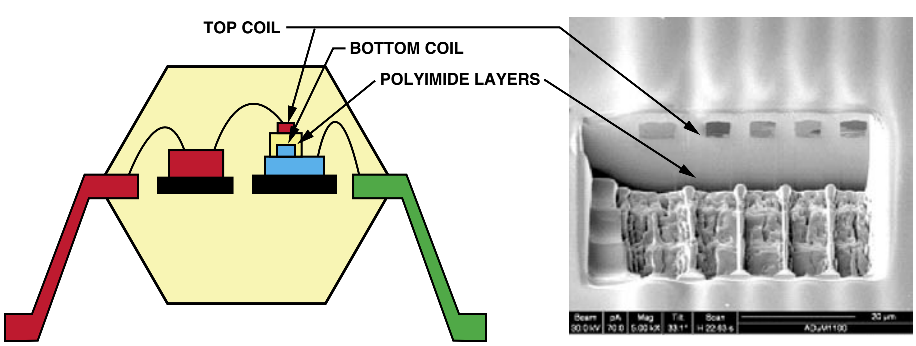

Figure 7. Cross-Sectional View of iCoupler Configuration

The technology used in *i*Coupler design eliminates the inefficient electro-optical conversions that take place in optocouplers. This is because *i*Couplers eliminate the LEDs used in optocouplers. Also, because channels are fabricated entirely with wafer-level processing, multiple *i*Coupler channels can be easily integrated within a single package. *i*Coupler technology provides increased performance, reduced power consumption, smaller size, increased reliability, and lower cost.

Another distinct advantage of *i*Couplers over optocouplers is the elimination of external components. In addition to bypass capacitors, optocouplers require external discrete devices to bias the output transistors and drive the LEDs. Conversely, *i*Coupler devices require no external components other than decoupling capacitors. The *i*Coupler solution results in less circuit complexity and lower cost.

The *i*Coupler products also incorporate unique refresh and watchdog circuits.

In the absence of logic transitions at the input for more than 2 μs, a periodic set of refresh pulses indicative of the correct input state is generated to ensure dc correctness at the output. If the *i*Coupler output side circuit receives no pulses for more than about 5 μs, the input side circuit is assumed to be unpowered or nonfunctional, in which case the isolator output is forced to a default state by the watchdog timer.

ADI *i*Coupler Selection

The *i*Coupler family contains a broad portfolio of products, allowing the system designer to select a product ideally suited for the design. In addition, features and options allow the design of a system using fewer devices.

The *i*Coupler portfolio includes 1-channel through 4-channel options. Among the choices are devices designed for bidirectional communication that enhance flowthrough board design. *i*Coupler devices are also available for a range of data rate performances.

Table I shows a comparison of product options, including the number of channels, and data rate performance.

Table I. *i*Coupler and Isolated RS-485 Transceiver Products

Product	Model	Number of Channels	Channel Configuration*	UL Insulation Rating (kV)	Max Data Rate, 5 V (Mbps)	Max Prop. Delay 5 V (ns)	Max Operating Temp. (°C)	Package
ADuM1100	ADuM1100AR	1	1/0	2.5	25	18	105	8-Lead Narrow Body SOIC
	ADuM1100BR	1	1/0	2.5	100	18	105	8-Lead Narrow Body SOIC
	ADuM1100UR	1	1/0	2.5	100	18	125	8-Lead Narrow Body SOIC
ADuM120x	ADuM1200AR	2	2/0	2.5	1	150	105	8-Lead Narrow Body SOIC
	ADuM1200BR	2	2/0	2.5	10	50	105	8-Lead Narrow Body SOIC
	ADuM1200CR	2	2/0	2.5	25	45	105	8-Lead Narrow Body SOIC
	ADuM1201AR	2	1/1	2.5	1	150	105	8-Lead Narrow Body SOIC
	ADuM1201BR	2	1/1	2.5	10	50	105	8-Lead Narrow Body SOIC
	ADuM1201CR	2	1/1	2.5	25	45	105	8-Lead Narrow Body SOIC
ADuM130x	ADuM1300ARW	3	3/0	2.5	1	100	105	16-Lead Wide Body SOIC
	ADuM1300BRW	3	3/0	2.5	10	50	105	16-Lead Wide Body SOIC
	ADuM1300CRW	3	3/0	2.5	90	32	105	16-Lead Wide Body SOIC
	ADuM1301ARW	3	2/1	2.5	1	100	105	16-Lead Wide Body SOIC
	ADuM1301BRW	3	2/1	2.5	10	50	105	16-Lead Wide Body SOIC
	ADuM1301CRW	3	2/1	2.5	90	32	105	16-Lead Wide Body SOIC
ADuM140x	ADuM1400ARW	4	4/0	2.5	1	100	105	16-Lead Wide Body SOIC
	ADuM1400BRW	4	4/0	2.5	10	50	105	16-Lead Wide Body SOIC
	ADuM1400CRW	4	4/0	2.5	90	32	105	16-Lead Wide Body SOIC
	ADuM1401ARW	4	3/1	2.5	1	100	105	16-Lead Wide Body SOIC
	ADuM1401BRW	4	3/1	2.5	10	50	105	16-Lead Wide Body SOIC
	ADuM1401CRW	4	3/1	2.5	90	32	105	16-Lead Wide Body SOIC
	ADuM1402ARW	4	2/2	2.5	1	100	105	16-Lead Wide Body SOIC
	ADuM1402BRW	4	2/2	2.5	10	50	105	16-Lead Wide Body SOIC
	ADuM1402CRW	4	2/2	2.5	90	32	105	16-Lead Wide Body SOIC

*Channel configuration refers to the directionality of the isolation channels. For example, 2/1 means two channels communicate in one direction while the third channel communicates in the reverse direction.

Bypass Capacitors

The *i*Coupler products need no external components other than bypass capacitors. A bypass capacitor is strongly recommended for the input and output supply pins. The bypass capacitor value should be between 0.01 μF and 0.1 μF. The total lead length between both ends of the capacitor and the power supply pins should not exceed 20 mm.

Output Enable Control

Many of the *i*Coupler products have output enable control pins (V_{EX}) to allow outputs to be placed into a high impedance state. The outputs are in an active logic state when the output enable pins are high or floating. The outputs are disabled when the output enable pin is low. It is recommended that the output enable pins be pulled to a known logic level, either high or low, in noisy applications.

SUMMARY

The flexibility and high noise immunity of the CAN bus specification make this protocol very popular for intersystem communication. However, intersystem communication cable systems are highly susceptible to interference or damage from overvoltage transients and ground loops.

Digitally isolating the CAN bus from the systems connected to the bus reduces signal distortion and errors. This also provides system and component protection from system and bus voltage and ground mismatches.

Analog Devices' *i*Coupler products cover a broad range of performance, channel counts, and configurations. The combination of performance and channel configuration allow the system designer multiple options, allowing system design optimization. The *i*Coupler products provide a cost-effective method for including critical isolation into a system design.

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