**ANALOG
DEVICES**

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A. • Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com

*i*Coupler Isolation in RS-232 Applications
by Richard Anslow and Neil Yuan

INTRODUCTION

The RS-232 bus standard is a popular serial communication bus design. The Electronics Industry Association (EIA) originally specified the RS-232 in 1962 to communicate between computing equipment and modems. The RS-232 standard is still widely used as an intersystem serial communication link.

The RS-232 standard is a serial data, point to point design, with a signal line dedicated for communication in each direction. These two dedicated unidirectional lines result in full-duplex communication.

Although no maximum cable length is specified, maximum practical cable length is approximately 16 m. The simplicity and flexibility of the RS-232, coupled with its long legacy, contribute to its continued popularity for intersystem connections.

Because the RS-232 standard is typically used as an intersystem connection, isolation between the bus and each system connected is critical. Digital isolation provides crucial isolation and protection from overvoltage transients between the RS-232 cable bus and the systems connected to it. Digital isolation also eliminates ground loops on the RS-232 bus. Digitally isolating the RS-232 bus from the systems connected to the bus reduces signal distortion and errors, and provides system and component protection from system and bus voltage, and ground mismatches.

The intention of this application note is to give the user a brief overview of the RS-232 bus physical layer, as well as an understanding of why isolation is so important to the system. This application note details how to implement isolation for an RS-232 bus using the *i*Coupler® products from Analog Devices, Inc.

TABLE OF CONTENTS

REVISION HISTORY

RS-232 OVERVIEW

RS-232 is more properly known as EIA-232, but is commonly referred to by the older RS-232 designation. RS-232 uses single-ended (unbalanced), point to point signaling, with signals referenced to ground.

RS-232 specifies a maximum data rate of 20 kbps. The TIA/EIA-562 standard, a low voltage version of RS-232, is specified to operate to 64 kbps.

The RS-232 specification does not define a maximum cable length. However, RS-232 specifies a maximum line capacitance of 2500 pF and a load impedance of 3 kΩ to 7 kΩ. These specifications result in a typical maximum usable cable length of approximately 16 m.

The standard specifies driver output levels as −5 V to −15 V for a Logic 1 and +5 V to +15 V for a Logic 0. Receivers are specified to read input levels of −3 V to −15 V as a Logic 1 and levels of +3 V to +15 V as a Logic 0. Voltage levels between −3 V and +3 V are undefined. This wide voltage swing and center undefined voltage region ensure a high level of noise immunity and allow valid signal levels to be received at maximum cable lengths.

The RS-232 standard has been revised several times since its introduction. Letter designations denote the various revisions. The RS-232C is the revision commonly used by the PC industry. The fourth revision, RS-232D, added three additional test lines and defined the maximum line capacitance of 2500 pF. The fifth revision officially changed the name designation to EIA-232: some signal lines were renamed and a protective ground conductor was defined.

As of this application note, the most recent revision is TIA/EIA-232-F, introduced in 1997. No technical changes have been incorporated into TIA/EIA-232-F that create compatibility problems with equipment conforming to previous versions.

The RS-232 specification defines the physical layer only. Signal protocol is defined by the user or by standards that define the protocol and specify RS-232 for the physical layer.

The RS-232 specification defines the pinout for a 25-pin D connector with 20 signal lines. However, a 9-pin connector, eight signal configuration, as defined by EIA-574, is more commonly used.

Only one line in each direction is for data transmission in the RS-232 system. All other lines are designated for signal communications protocol. These signal lines give the designer multiple options for configuring the RS-232 protocol. The system can be designed for asynchronous operation utilizing the eight signals in the commonly used 9-pin connector. At its simplest, RS-232 can be implemented using only three lines: Tx (data), Rx (data), and GND.

The 25-pin connector specified in the RS-232 standard defines eleven signals not used in the 9-pin connector. These additional signals include a clock line for each data direction to allow the use of synchronous data protocols.

The inclusion of the protective ground line in the 25-pin connection is a particular interest in this application note. This line is designed as an equipment safety ground and is typically connected to the power ground of the serial adapter or the chassis ground. This ground must not be connected to the signal ground. Furthermore, it is not recommended that this ground be connected between the two systems, particularly in long cable line applications. Connection of these grounds together or to both systems can create ground loops.
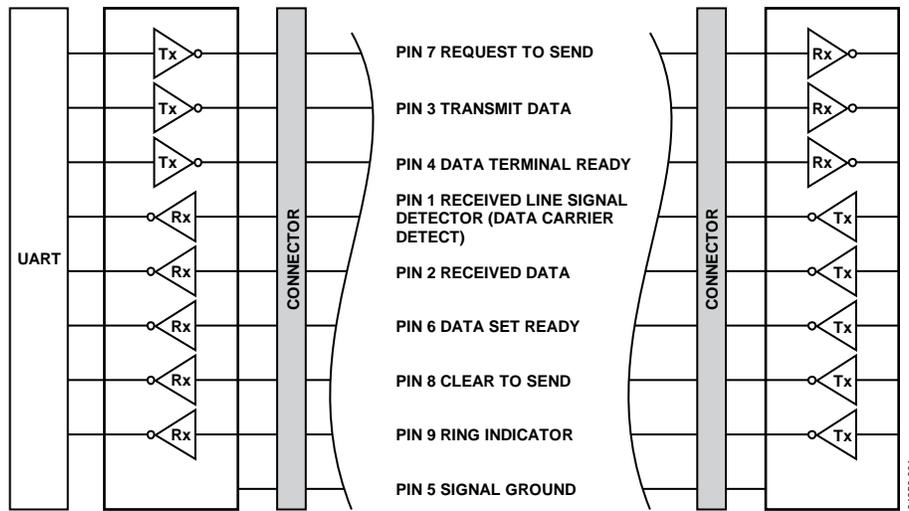
Figure 1. RS-232 Eight Signal Network Configuration

RS-232 PIN CONNECTIONS

The RS-232 standard divides equipment connected to the serial port into two categories. These categories are data communications equipment (DCE) and data terminal equipment (DTE). These designations are a legacy of the computer and modem heritage of the standard, which defined DTE as the computer or computer terminal and DCE as the modem. In practical application terms, the DCE and DTE designations define which lines are connected to each system as inputs and which lines are outputs.

Although the RS-232 specification does not define a signal protocol, a typical implementation uses asynchronous signaling, utilizing eight signal lines and a ground (see Figure 1).

As mentioned previously, systems can be configured using fewer than all six of the handshaking signal lines. Although the hardware can run with only the Tx, Rx, and ground lines to connect peripherals, some driver software continues to wait for one of the handshaking lines to go to the correct level. Depending on the signal state, this configuration may or may not work.

For reliability, the unused handshake signals must be looped back and connected to the request to send (RTS) signal. When the lines are handshake looped, the RTS output from the processor or controller immediately activates the clear to send (CTS) input. In this configuration, the transmitting system effectively controls its own handshaking. Alternatively, some of these signals, such as the data terminal ready (DTR), can be hardwired to a valid signal level effectively signaling that the system is always ready to receive data. For a more detailed explanation of connections using the RS-232 protocol, see the AN-375 Application Note.

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.

Ground loops occur when a bus or system utilizes multiple ground paths. It cannot be assumed that two system grounds connected to the bus and separated by several meters or more are at the same potential. Because these grounds are unlikely to be at the same potential, current flows between these points and 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 this phenomenon. 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 can 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 device and system, causing damage or destruction of the components connected to the bus, and resulting in system failure. Because RS-232 systems run over cables of up to 16 m and interconnect two systems, they are susceptible to these events.

To protect against this potentially destructive energy, all devices on the bus and the systems connected to the bus must be referenced to only one ground. Isolating the RS-232 system devices from each of the systems connected to the bus prevents ground loops and electrical surges from destroying circuits.

Isolation prevents ground loops because the systems connected to the RS-232 cable bus and each RS-232 circuit have a separate and isolated ground. By referencing each RS-232 circuit only to one ground, ground loops are eliminated.

Isolation also allows the RS-232 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 RS-232 signal lines and power supplies must be isolated. Power isolation is obtained through use of an isolated, dc-to-dc power supply. Signal isolation is typically accomplished with optocouplers or with the innovative *i*Coupler products. Additionally, Analog Devices can provide a fully integrated isolation solution involving signal and power transfer across the isolation barrier using microtransformers.

ISOLATION IMPLEMENTATION

The implementation of isolation is not overly complex, combining *i*Coupler products and nonisolated RS-232 products. Furthermore, system size can reduce considerably with Analog Devices isolated RS-232 products.

Several important factors must be taken into consideration when implementing isolation circuitry.

RS-232 signal path isolation is accomplished by designing isolators into the digital signal path between the RS-232 transceiver and the local system. The system side RS-232 transceivers utilize digital logic level signals of 0 V to 5 V, or 0 V to 3 V, and typically connect to a universal asynchronous receiver/transmitter (UART) or processor. The *i*Coupler isolator contains input and output circuits that are electrically isolated from one another. Placing an *i*Coupler in this location electrically isolates the RS-232 cable bus signals from each system connected to it.

To complete the isolation of the RS-232 circuits from the local system, a dc-to-dc isolated power converter is required. The isolated power supply is used to supply power to the local RS-232 transceiver and RS-232 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 2 illustrates system isolation design in typical RS-232 signal configurations using *i*Coupler integration.

The *i*Coupler signal isolator is placed between the system UART and the RS-232 transceiver. The system uses an isolated dc supply to power the RS-232 transceiver and the transceiver side of the *i*Coupler.

Some other configurations can be implemented with Analog Devices isolated RS-232 products such as the ADM3251E and ADM3252E. The products integrate with the isolated dc-to-dc converter to power the secondary side circuits. Figure 3 illustrates the RS-232 isolation with isolated RS-232 products.
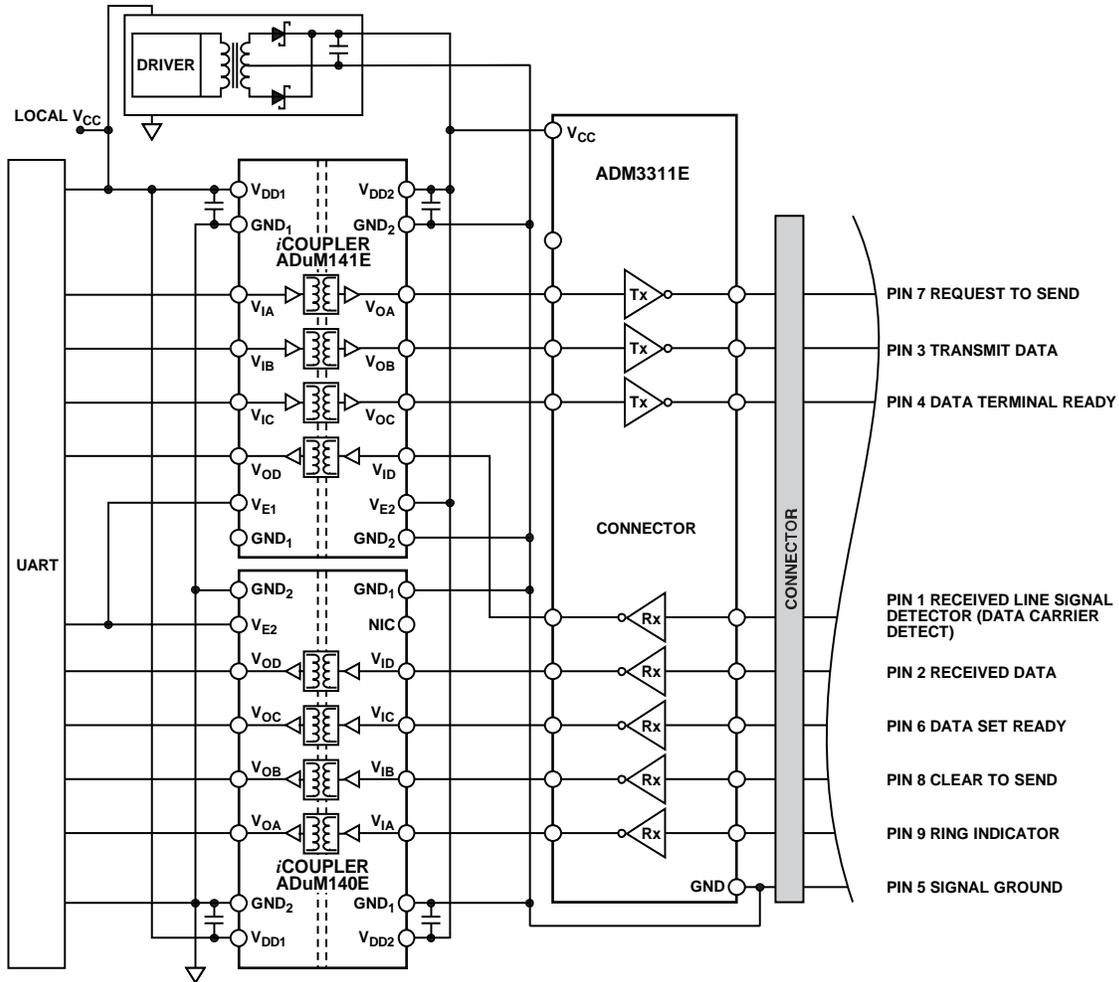
Figure 2. Isolated RS-232 Eight-Signal Circuit (DTE Side Illustrated)

Figure 3. Isolated RS-232 Signal Circuit (DTE Side Illustrated)

ISOLATION DEVICE SELECTION

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

The design shown in Figure 3 minimizes the signals used in the RS-232 bus. The isolated RS-232 transceiver is placed to connect the system UART and the RS-232 bus line.

DATA RATE REQUIREMENTS

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

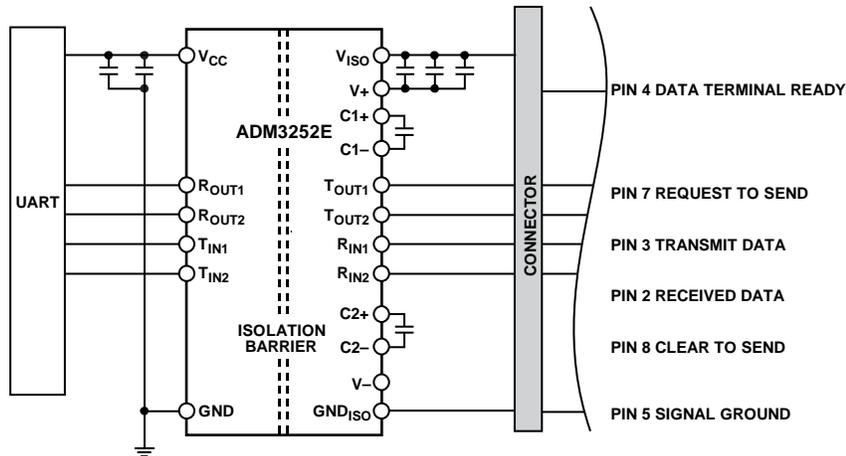Although the RS-232 specification defines data rates to 20 kbps, many newer RS-232 transceivers have the capability to run at much higher data rates. These high data rate RS-232 transceivers include low voltage RS-232 operation, and are compatible with the newer TIA/EIA-562 low voltage RS-232 standard. As noted in the RS-232 Overview section, this specification defines operation to 64 kbps. Some low voltage RS-232 transceivers have the capability to operate at even higher data speeds. Both nonisolated and isolated RS-232 products can operate at a data rate up to 460 kbps. These higher data rates extend the usability of the RS-232 specification and give system designers numerous options.

The use of high data rates in a system narrows the selection of possible isolation devices to the high performance products available. All *i*Coupler products operate up to data rates of 1 Mbps. The *i*Coupler products portfolio also includes devices that operate at data rates of up to 100 Mbps and 150 Mbps.

Device cost typically rises in proportion to data rate performance. Therefore, a designer must 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 require replacement.

SPACE REQUIREMENTS

Space constraints are a second area of concern that can also limit the choices a designer can make. Maximum dimension requirements are a concern for virtually all applications. However, some implementations can be severely space limited.

Solutions for systems where space is an issue include the combination of one ADuM141E *i*Coupler and one ADuM140E *i*Coupler for isolation of an eight signal RS-232 network (see Figure 2). The ADuM140E and ADuM141E are 4-channel isolation devices in a 16-lead small outline integrated circuit

(SOIC) package; each device takes the place of four optocouplers and associated circuitry. System space can be further reduced by applying the ADM3251E or ADM3252E. One ADM3252E is used to implement the isolation for simplified signals in the bus (see Figure 3).

COST REQUIREMENTS

Cost constraints and concerns are a reality in virtually all system design work. Cost considerations can have an effect on the design choices for a system. As noted in the Data Rate Requirements section, 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.

ANALOG DEVICES *i*COUPLER PRODUCTS

The *i*Coupler technology from Analog Devices has enabled products that possess distinct advantages for the system designer in comparison to other available isolation options.

The unique *i*Coupler technology results in a new option for implementing isolation. The *i*Coupler products provide superior performance, lower power consumption, higher reliability, and lower component count, with cost characteristics that are comparable to optocouplers.

*i*COUPLER TECHNOLOGY OVERVIEW

The *i*Coupler technology from Analog Devices provides isolation-based, on-chip scale transformers rather than 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 other semiconductor functions at low cost (see Figure 4).

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

Another distinct advantage of *i*Coupler devices 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. *i*Coupler devices require no external components other than decoupling capacitors. The *i*Coupler solution results in less circuit complexity and lower cost.
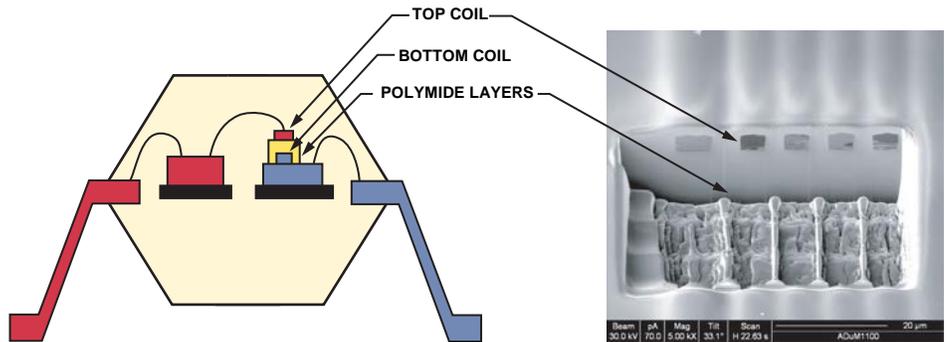
*i*COUPLER TECHNOLOGY WITH *iso*POWER

The *iso*Power® technology enables the integration of chip scale, isolated, dc-to-dc converters. These power converters are incorporated into Analog Devices isolated products, such as digital isolators and interface transceivers. *iso*Power devices provide up to 500 mW of isolated power in a 16-lead SOIC. Compared with separate dc-to-dc converters, products that utilize *iso*Power have the benefit of reducing total system cost and size.

*iso*Power devices employ isolated dc-to-dc converters that switch currents at frequencies as high as 300 MHz. These high frequency operations cause radiated emissions and conducted noise. Designers must pay attention to the printed circuit board (PCB) layout and construction, and some EMI mitigation techniques can be found in the AN-0971 Application Note.

Figure 4. Cross Section of iCoupler Configuration

*i*COUPLER PRODUCT SELECTION

The *i*Coupler family comprises a broad portfolio of products, allowing the system designer to select a product ideally suited for the design. The *i*Coupler device portfolio has 1-channel through 4-channel options and includes devices designed for bidirectional communication and enhancing flow through board design. *i*Coupler devices are also available for a range of data rate performances, allowing the designer to select the perfect product for the application.

The *i*Coupler portfolio of features and options allows the design of a system with fewer devices and a better match for the system data performance requirements (see Table 1).

As noted earlier in this section, Analog Devices offers a wide selection of *i*Coupler products. The combination of performance and channel configuration allows the system designer options for optimizing system and device match. Table 1 shows a comparison of product options, including the number of channels, as well as data speed performance.

RADIATED EMISSIONS RESULTS FOR ISOLATED RS-232 TRANCEIVERS

The EVAL-ADM3252EEBZ evaluation board for a fully isolated dual-channel RS-232 solution was tested to EN55022:2010 Class B radiated emissions standard. Measurements were carried out in a 10 m anechoic chamber from 30 MHz to 2 GHz. Table 2 shows that both horizontal and vertical scan results can pass EN55022 Class B. Table 2 shows that emissions are observed up to 1 GHz, only. There were no emissions detected in the 1 GHz to 2 GHz range.

Table 1. *i*Coupler and Isolated RS-232 Transceiver Products (N/A Means Not Applicable)

Model[1,2]	Number of Channels	Channel Configuration[3]	UL Installation Rating (kV)	Fail-Safe Output State	Maximum Data Rate, 5 V	Maximum Operating Temperature	Package
ADuM110N1BRZ	1	1/0	3.0	High	150 Mbps	125°C	8-lead SOIC_N
ADuM110N0BRZ	1	1/0	3.0	Low	150 Mbps	125°C	8-lead SOIC_N
ADuM120N1BRZ	2	2/0	3.0	High	150 Mbps	125°C	8-lead SOIC_N
ADuM120N0BRZ	2	2/0	3.0	Low	150 Mbps	125°C	8-lead SOIC_N
ADuM121N1BRZ	2	1/1	3.0	High	150 Mbps	125°C	8-lead SOIC_N
ADuM121N0BRZ	2	1/1	3.0	Low	150 Mbps	125°C	8-lead SOIC_N
ADuM121N1WBRZ	2	1/1	3.0	High	150 Mbps	125°C	8-lead SOIC_N
ADuM130E1BRZ	3	3/0	3.0	High	150 Mbps	125°C	16-lead SOIC_N
ADuM130E0BRZ	3	3/0	3.0	Low	150 Mbps	125°C	16-lead SOIC_N
ADuM130E1BRWZ	3	3/0	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM130E0BRWZ	3	3/0	3.75	Low	150 Mbps	125°C	16-lead SOIC_W
ADuM131E1BRZ	3	2/1	3.0	High	150 Mbps	125°C	16-lead SOIC_N
ADuM131E0BRZ	3	2/1	3.0	Low	150 Mbps	125°C	16-lead SOIC_N
ADuM131E1BRWZ	3	2/1	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM131E0BRWZ	3	2/1	3.75	Low	150 Mbps	125°C	16-lead SOIC_W
ADuM140E1BRZ	4	4/0	3.0	High	150 Mbps	125°C	16-lead SOIC_N
ADuM140E0BRZ	4	4/0	3.0	Low	150 Mbps	125°C	16-lead SOIC_N
ADuM140E1BRWZ	4	4/0	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM140E0BRWZ	4	4/0	3.75	Low	150 Mbps	125°C	16-lead SOIC_W
ADuM141E1BRZ	4	3/1	3.0	High	150 Mbps	125°C	16-lead SOIC_N
ADuM141E0BRZ	4	3/1	3.0	Low	150 Mbps	125°C	16-lead SOIC_N
ADum141E1BRWZ	4	3/1	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM141E0BRWZ	4	3/1	3.75	Low	150 Mbps	125°C	16-lead SOIC_W
ADuM141E1WBRWZ	4	3/1	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM142E1BRZ	4	2/2	3.0	High	150 Mbps	125°C	16-lead SOIC_N
ADuM142E0BRZ	4	2/2	3.0	Low	150 Mbps	125°C	16-lead SOIC_N
ADuM142E1BRWZ	4	2/2	3.75	High	150 Mbps	125°C	16-lead SOIC_W
ADuM142E0BRWZ	4	2/2	3.75	Low	150 Mbps	125°C	16-lead SOIC_W
ADM3251EARWZ	2	1 Tx/1 Rx	2.5	N/A	460 kbps	85°C	20-lead SOIC_W
ADM3252EABCZ	4	2 Tx/2 Rx	2.5	N/A	460 kbps	85°C	44-ball CSP_BGA

[1] D versions and E versions have different enable/disable functions. Refer to the data sheets for these products.
[2] ADuM121N1WBRZ and ADuM141E1WBRWZ are qualified for automotive applications.
[3] 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.

Table 2. Radiated Emissions, Class B Limits—Anechoic Chamber at 10 m[1]

V$_{CC}$ (V)	Frequency (MHz)	Quasi Peak Level (µV/m)	EN55022 Class B (µV/m)	Antenna Polarity	Antenna Height (m)	Pass/Fail
3.3	173.672	16.6	30	Vertical	3.3	Pass
3.3	173.500	23.3	30	Horizontal	4.0	Pass
3.0	172.588	15.5	30	Vertical	2.7	Pass
3.0	172.848	28.1	30	Horizontal	4.0	Pass
5.5	174.656	10.6	30	Vertical	1.0	Pass
5.5	190.476	10.6	30	Vertical	1.0	Pass
5.5	190.476	18.1	30	Horizontal	4.0	Pass

[1] Refer to the UG-440.

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 must be between 0.01 µF and 0.1 µF. The total lead length between both ends of the capacitor and the power supply pins must not exceed 20 mm.

OUTPUT ENABLE CONTROL

Many of the *i*Coupler products have output enable control pins 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.

CONCLUSION

The flexibility and high noise immunity of the RS-232 specification make this design 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 RS-232 bus from the systems connected to the bus reduces signal distortion and errors, and provides system and component protection from system and bus voltage and ground mismatches.

The *i*Coupler family of products from Analog Devices covers a broad range of performance, channel counts, and configurations. The combination of performance and channel configuration give 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.

ANALOG
DEVICES

www.analog.com