ANALOG DEVICES

AN-727
APPLICATION NOTE

One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106 • Tel: 781/329-4700 • Fax: 781/326-8703 • www.analog.com

*i*Coupler® Isolation in RS-485 Applications

by Sean Clark

INTRODUCTION

The RS-485 bus standard is one of the most widely used physical layer bus designs. The RS-485 standard is specified to drive up to 32 driver/receiver pairs. Although no maximum cable length is specified, lengths of 4000 meters are possible. The versatility of the RS-485 makes this design popular for a wide range of applications, especially intersystem connections over long distances.

Because the RS-485 system is typically used to connect multiple systems, and is often run over very long cable distances, isolation between the bus and each system connected is critical. Digital isolation provides crucial isolation and protection from overvoltage transients between the RS-485 cable network and the systems connected to it. Digital isolation also eliminates ground loops in the RS-485 network. Digitally isolating the RS-485 bus from each system 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-485 system physical layer, as well as an understanding of why isolation is so important to the system. This application note details how to implement isolation in an RS-485 system using Analog Devices *i*Coupler products.

RS-485 OVERVIEW

RS-485 is more properly known as EIA/TIA485, but is commonly referred to by the older "Recommended Standard" 485 designation. The RS-485 specification defines the physical layer only. Signal protocol is defined by the user, or standards that define the protocol, and specify RS-485 for the physical layer.

The RS-485 is found in products ranging from industrial systems to computers. Examples of protocols that specify this bus design include the SCIS2 and SCIS3 (Small Computer Systems Interface) busses, and the PROFIBUS (Process Field Bus) high performance protocol.

Usable lengths are dependent upon system data speed requirements. Examples of data rate and length combinations vary from 200 kbps at 1200 meters, to 12 Mbps at 100 meters for the PROFIBUS high performance RS-485 bus. Note that the PROFIBUS also requires special high performance RS-485 drivers.

The RS-485 uses balanced differential signaling. RS-485 drivers send the data signal across two output lines. The receiver determines the logic state by comparing these two input signals to each other, rather than to a ground reference. The receiver looks for a greater than 200 mV difference between the A and B inputs for a valid logic level. The RS-485 drivers and receivers contain differential amplifiers and their circuits steer current between the two differential signal lines.

The use of differential signaling imbues the system with a high level of noise immunity when compared to single-ended drive schemes, such as that used in the RS-232 specification.

All RS-485 drivers also include an enable function to allow the drivers to be placed in high impedance state. The enable function allows multiple drivers to share one bus and prevents bus contention problems. The driver enable feature and the software protocol define the arbitration procedure for line sharing between the drivers. The software protocol arbitrates between the drivers, keeping all but one at a time in the inactive state. This arbitration allows line sharing by up to 32 drivers.

2-WIRE AND 4-WIRE CONFIGURATIONS

RS-485 is specified to support up to 32 drivers and 32 receivers in a half-duplex, bidirectional, 2-wire, multi-drop configuration on one bus. Each node on the line contains a receiver and a driver. In this configuration, all receiver and driver pairs share the same set of two differential signal lines. (Figure 1) The 2-wire system can be installed using just one twisted pair cable. This design simplifies installation and keeps costs down. However, the design requires that all drivers share the line, limiting maximum data throughput speed.

A 4-wire RS-485 full-duplex design is also possible. (Figure 2). In the 4-wire configuration, one node is the master node that communicates to all other nodes. The slave nodes communicate only with the master node. Although more complex, this design greatly improves data throughput rates.

TERMINATION AND BIASING NETWORKS

Termination is used to match the line end nodes to the impedance value of the transmission line, reducing or eliminating reflections. However, termination also increases the line load. Also, since the termination is connected only to the end nodes on the line, this can make system modifications more difficult. Termination is needed in high data rate and long line applications. Although various termination designs can be used, the most common is a resistor connected in parallel across the differential lines (Figures 1 and 2).

Every stub line adds capacitance and can generate reflections and disruptions to the signal on the RS-485 bus. To minimize these effects, stub connections to all receivers and transmitters on the line should be as short as possible.

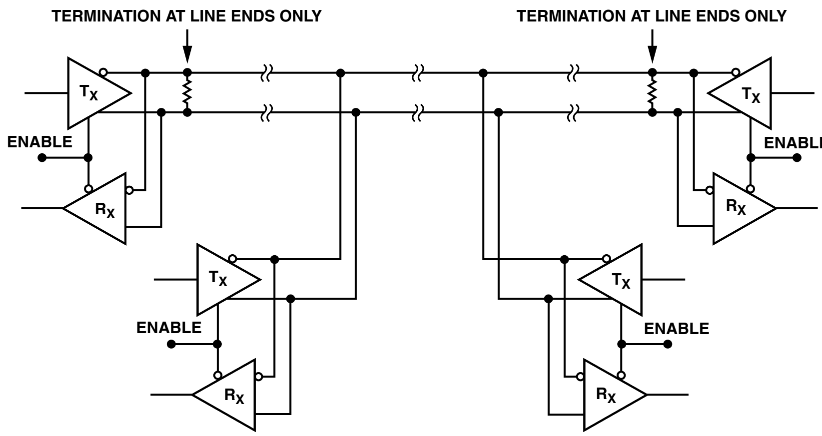

Figure 1. RS-485 2-Wire Multidrop, Half-Duplex Network

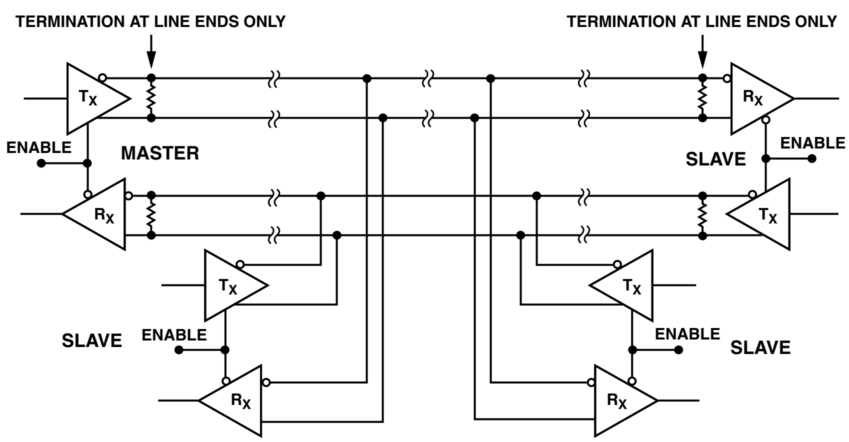

Figure 2. RS-485 4-Wire Multidrop, Full-Duplex Network

A resistor biasing network, (also known as a fail-safe, or idle line network) is necessary if the network is placed in an idle condition where all drivers are in a high impedance state (Figure 3).

The biasing resistors ensure that all receiver A inputs are 200 mV above the B inputs when no driver signal is present. This prevents receivers from going into oscillations. Oscillations can appear on receiver outputs as erroneous data. The biasing network does add loading to a system, and values are in direct relation to the specific system design parameters.

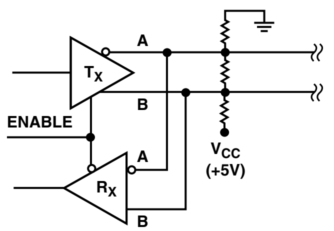

Figure 3. RS-485 Fail-Safe Biasing Network

SYSTEM ISOLATION OVERVIEW

Unwanted currents and voltages on a cable bus connecting multiple 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 hundreds or thousands of meters 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 in industrial environments are especially susceptible to this phenomena. The operation of electric motors, in particular, 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, a remote node may receive a 5 V switching signal superimposed on a high voltage level with respect to the 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. RS-485 systems that run over long distances and connect multiple systems are especially susceptible to these events.

To protect against this potentially destructive energy, all devices on the bus, and systems connected to the bus, must be referenced to only one ground. Isolating the RS-485 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 each system connected to RS-485 cable bus, and each RS-485 circuit, has a separate and isolated ground. By referencing each RS-485 circuit only to one ground, ground loops are eliminated.

Isolation also allows the RS-485 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-485 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 is typically accomplished with optocouplers, or with Analog Device’s 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.

Because digital isolators do not support the RS-485 standard, it is not possible to insert a digital isolator between the RS-485 receivers and drivers, and the RS-485 cable. Theoretically, transformers could be used to supply isolation at that location. However, the slow speeds of the bus would require large transformers, making this solution impractical.

RS-485 system signal path isolation is accomplished by designing isolators into the digital signal path between the RS-485 driver and receiver, and the local system. The isolator contains input and output circuits that are electrically isolated from one another.

To complete the isolation of the RS-485 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-485 driver, receiver, and RS-485 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 4).

ISOLATION DEVICE SELECTION

System performance requirements 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. If a system uses high data rates, such as the high speed PROFIBUS protocol, the minimum data rate speed requirement of 9.6 Mbps will narrow the device selection to the high performance products available. Conversely, if the RS-485 network runs at much lower data rate speeds, the possible device selection options are more numerous.

Device costs typically rise 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.

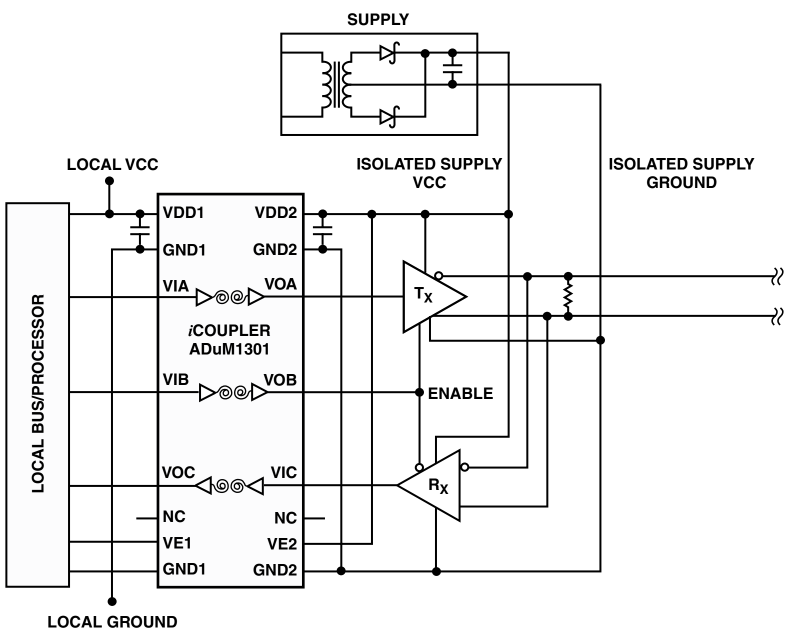

Figure 4. Isolated RS-485 Circuit: Receiver, Driver, iCoupler Signal Isolator, and Isolated DC Supply

SPACE REQUIREMENTS

Space constraints are a second area of concern that can also limit a designer's choices. Maximum dimension requirements are a concern for virtually all applications. However, some implementations can be severely space-limited. Fortunately, there are solutions for these situations.

Solutions for systems where space is an issue include the ADuM1301 and ADuM1401 *i*Couplers for isolation of a half-duplex RS-485 receiver and transmitter pair. The ADuM1301 is a three-channel isolation device in a 16-lead SOIC package, replacing three optocouplers and associated circuitry. The ADuM1401 is a four-channel isolation device in a 16-lead SOIC package, taking the place of four optocouplers and associated circuitry. The ADuM1401 is used in applications requiring separate control of the receiver and transmitter enable functions.

For even more severely space-constrained systems, the ADM2483 and ADM2486 are RS-485 transceivers with *i*Coupler isolation built in. These devices reduce part count to one device, plus decoupling.

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 above, 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 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. The unique technology results in a new option for implementing isolation that provides superior performance, lower power consumption, higher reliability, and lower component count, with cost characteristics comparable with optocouplers.

ADI *i*COUPLER TECHNOLOGY OVERVIEW

ADI's *i*Coupler technology provides isolation based on chip scale transformers, rather than LEDs and photodiodes used in optocouplers. By fabricating the transformers directly on chip using wafer-level processing, *i*Coupler channels can be integrated with other semiconductor functions at low cost (Figure 5).

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 cost benefits.

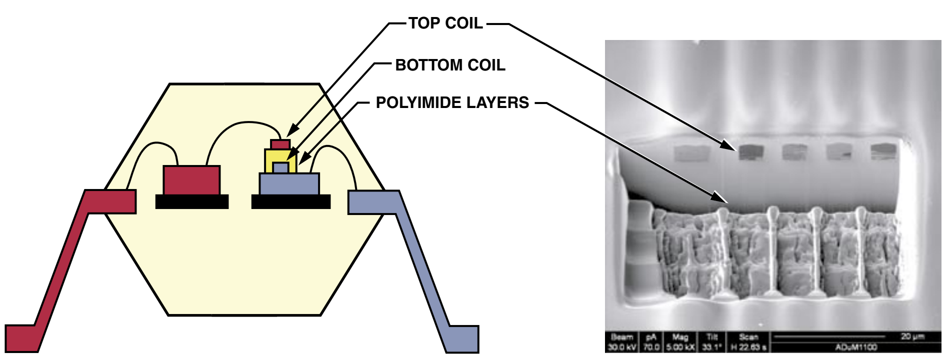

Figure 5. Cross Section of iCoupler Configuration

Another distinct advantage of *i*Couplers over optcouplers 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—whereas *i*Coupler devices require no external components other than bypass capacitors. The *i*Coupler solution results in less circuit complexity and lower cost.

*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

ADI's *i*Coupler broad portfolio of products allow the system designer to select a product ideally suited for the design. The *i*Coupler device portfolio includes options from one channel up to four channels. These options include devices designed for bidirectional communication, which aids in flowthrough 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 a system to be designed with fewer devices, thus creating a better match for the system data performance requirements (Table 1).

Also available are ADI's RS-485 transceivers with *i*Coupler isolation built in. These devices reduce part count and board space requirements even further by combining the transceiver and isolation in one device. The devices are available in two performance levels, the ADM2483, with 250 kbps data rate, and the PROFIBUS-compatible ADM2486, with 20 Mbps data rate. (Table 1 and Figures 9 and 10).

As noted, ADI 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. Figures 6, 7, and 8 illustrate some of the configuration options for *i*Coupler integration. Figures 9 and 10 show the RS-485 transceivers with *i*Coupler isolation. Table 1 has also been included to allow a comparison of product options including the number of channels and data speed performance.

BYPASS CAPACITORS

*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 *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.

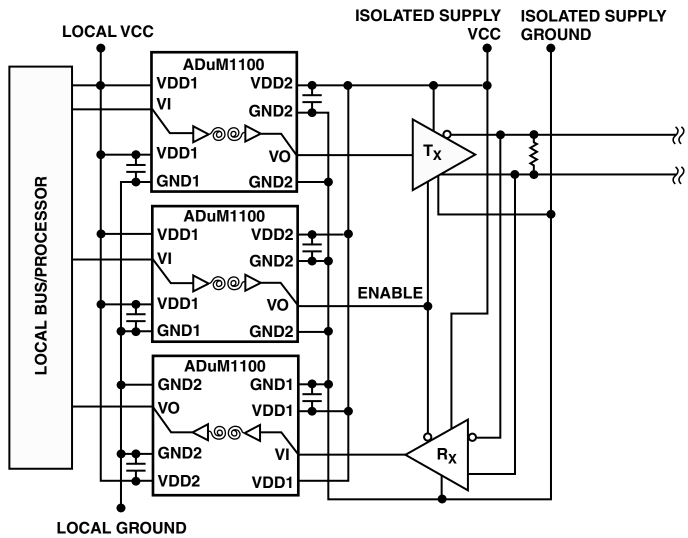

Figure 6. Half-Duplex Single-Channel System Isolation Using Three ADuM1100s. GND2 Pins Are Connected Internally. VDD1 Pins Are Connected Internally. Either or Both Can Be Used For External Connection.

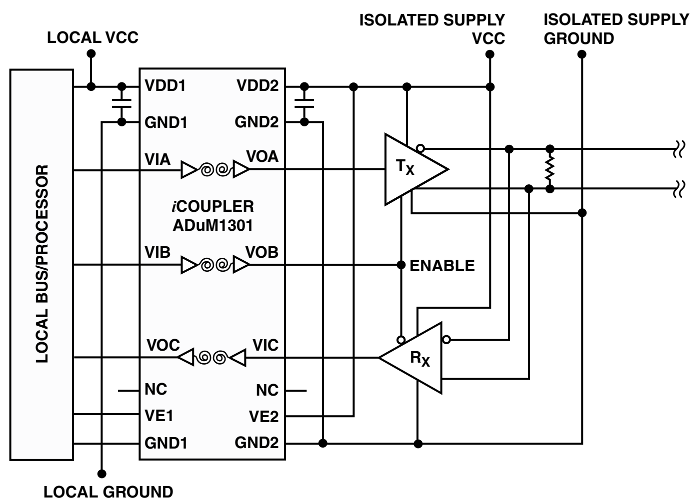

Figure 7. Half-Duplex Single-Channel System Isolation Using One ADuM1301. GND1 Pins Are Connected Internally. GND2 Pins Are Connected Internally. Either or Both Can Be Used For External Connection.

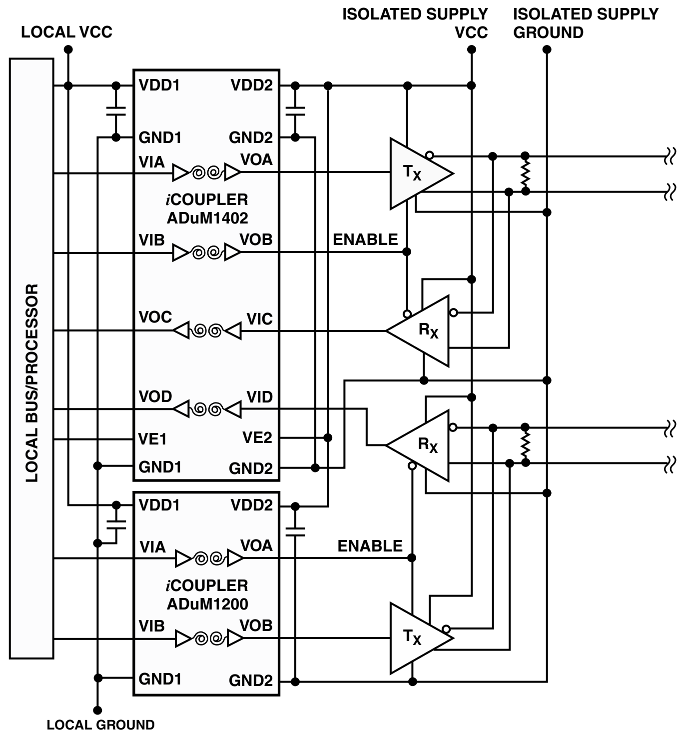

Figure 8. Full-Duplex Dual-Channel System Using One ADuM1200 and One ADuM1402

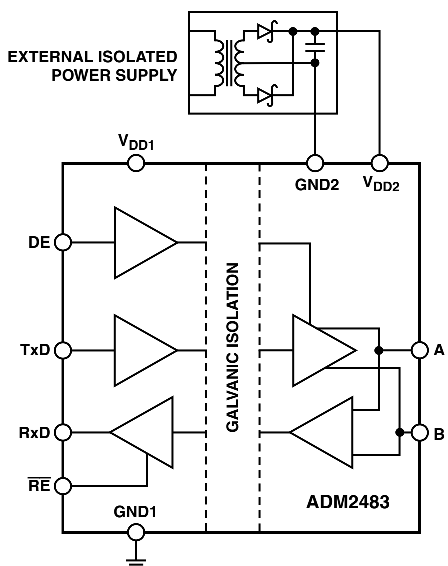

Figure 9. ADM2483 Isolated RS-485 Transceiver

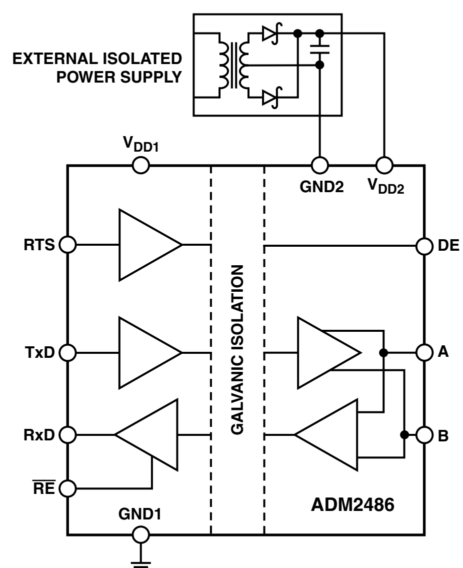

Figure 10. ADM2486 Isolated RS-485 Transceiver

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
ADM248x	ADM2483	3	R_X / T_X Enable	2.5	0.25	1000	85	16-Lead, Wide Body SOIC
	ADM2486	3	R_X / T_X Enable	2.5	20	55	85	16-Lead, Wide Body SOIC

AN04871–0–6/04(0)