AN-960
APPLICATION NOTE

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RS-485/RS-422 Circuit Implementation Guide
by Hein Marais

INTRODUCTION

Industrial and instrumentation applications (I&I) require transmission of data between multiple systems often over very long distances. The RS-485 bus standard is one of the most widely used physical layer bus designs in I&I applications. The key features of RS-485 that make it ideal for use in I&I communications applications are

- Long distance links—up to 4000 feet.

- Bidirectional communications possible over a single pair of twisted cables.

- Differential transmission increases noise immunity and decreases noise emissions.

- Multiple drivers and receivers can be connected on the same bus.

- Wide common-mode range allows for differences in ground potential between the driver and receiver.

- TIA/EIA-485-A allow for data rates of up to 10 Mbps. Devices meeting the TIA/EIA-485-A specifications do not have to operate over the entire range and are not limited to 10 Mbps.

The purpose of this application note is to discuss the implementation of RS-485/RS-422 in an industrial environment. Applications for RS-485/RS-422 include process control networks; industrial automation; remote terminals; building automation, such as heating, ventilation, air conditioning (HVAC), security systems; motor control; and motion control.

TIA/EIA-485-A, the telecommunication industry's most widely used transmission line standard, describes the physical layer of the RS-485 interface and is normally used with a higher-level protocol, such as Profibus, Interbus, Modbus, or BACnet. This allows for robust data transmission over relatively long distances. The RS-422 physical layer is described in TIA/EIA-422-B. The TIA/EIA-485-A standards are similar to those described in TIA/EIA-422-B, and the values used to specify the drivers and receivers in TIA/EIA-485-A standards are specified so that it can meet both standards.

WHY USE DIFFERENTIAL DATA TRANSMISSION?

The main reason why RS-485 can communicate over long distances is the use of differential or balanced lines. A communication channel requires a dedicated pair of signal lines to exchange information. The voltage on one line equals the inverse of the voltage on the other line.

TIA/EIA-485-A designates the two lines in this differential pair as A and B. Line A is more positive than Line B ($V_{OA} > V_{OB}$) on the driver output if a logic high is received on the input of the transmitter (DI = 1). If a logic low is received on the input of the transmitter (DI = 0), the transmitter causes Line B to be more positive than Line A ($V_{OB} > V_{OA}$). See Figure 1.
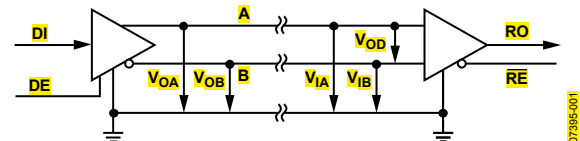

Figure 1. Differential Transmitter and Receiver

If Line A is more positive than line B ($V_{IA} − V_{IB} > 200$ mV) on the input of the receiver, the receiver output is a logic high (RO = 1). If Line B is more positive than Line A ($V_{IB} − V_{IA} > 200$ mV) on the input of the receiver, the receiver output is a logic low (RO = 0).

Figure 1 shows that a differential signaling interface circuit consists of a driver with differential outputs and a receiver with differential inputs. This circuit has increased noise performance because the noise coupling into the system is equal on both signals. One signal emits the opposite of the other signal and electromagnetic fields cancel each other. This reduces the electromagnetic interference (EMI) of the system.

TABLE OF CONTENTS

RS-485 OR RS-422?

RS-422 is specified as a simplex multidrop standard, which means that only one driver and up to ten receivers can be connected to the same bus. If more than one driver needs to be connected on the same bus, then RS-485 is recommended. RS-485 is specified as a multipoint standard, which means up to 32 transceivers can be connected on the same bus.

Figure 2 shows a typical RS-422 interface circuit. Although an RS-485 circuit may appear similar, the main difference is in the bus architecture. Figure 3 shows a typical RS-485 application circuit.

RS-422

The RS-422 standard specifies data rates up to 10 Mbps and line lengths of up to 4000 feet. A single driver can drive a transmission line with up to 10 receivers. The common-mode voltage (V_{CM}) is defined as the mean voltage of A and B terminals with respect to signal ground ($V_{CM} = (V_{IA} + V_{IB})/2$). The RS-422 receivers can withstand a common-mode voltage (V_{CM}) of ±7 V. When all ten receivers are placed on the bus, a maximum load condition occurs. The input impedance of the RS-422 receiver must be larger than or equal to 4 kΩ.

RS-485 AND THE UNIT LOAD CONCEPT

The input impedance of the RS-485 receiver is specified as larger than or equal to 12 kΩ. This impedance is defined as having one unit load (UL). The RS-485 specification specifies the capability to sustain up to 32 ULs.

Some RS-485 receivers are specified as having ¼ UL or ⅛ UL. A receiver specified to have ¼ UL means that the receiver only loads the bus by ¼ of the standard UL and, therefore, 4 times as many of these receivers can be connected to the bus (4 × 32 = 128 nodes).

Similarly, if an RS-485 receiver is specified to have ⅛ UL, the receiver only loads the bus by ⅛ of the standard UL and, therefore, 8 times as many of these receivers can be connected to the bus (8 × 32 = 256 nodes). See Table 1 for UL and receiver input impedance details.

Many of the RS-485 transceivers characteristics are the same as for RS-422. The common-mode voltage range for RS-485 is expanded to −7 V to +12 V. The RS-485 transceivers must withstand this common-mode voltage range while tristated (disconnected from the bus).

An RS-485 system must have a driver that can be disconnected from the transmission line when a particular node is not transmitting. The DE (RTS) pin on the RS-485 transceiver enables the driver when a logic high is set to DE (DE = 1). Setting the DE pin to low (DE = 0) puts the driver in a tristate condition. This effectively disconnects the driver from the bus and allows other nodes to transmit over the same twisted pair cable.

RS-485 transceivers also have an $\overline{RE}$ pin that enables/disables the receiver. The DE and $\overline{RE}$ pins combined allow some RS-485 transceivers to be put into a low power shutdown mode. This is important for battery-powered applications.

Table 1. UL Receiver Input Impedance

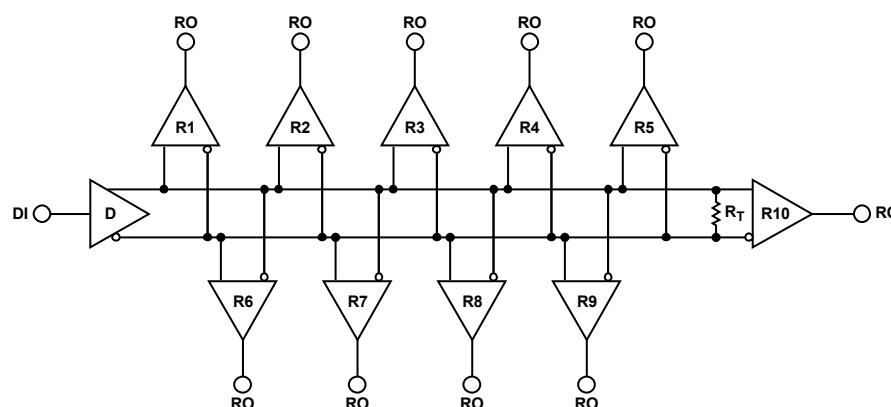| Unit Load	No. of Nodes	Min. Receiver Input Impedance
1	32	12 kΩ
½	64	24 kΩ
¼	128	48 kΩ
⅛	256	96 kΩ

Figure 2. Typical RS-422 Interface Circuit

HALF-DUPLEX RS-485

Half-duplex RS-485 links have multiple drivers and receivers on the same signal path. This is the reason why RS-485 transceivers must have driver/receiver enable pins enabling only one driver to send data at a time. See Figure 3 for a half-duplex bus configuration. This configuration is also known as a 2-wire RS-485 network connected in a multipoint configuration and allows for data transmission in both directions, but only in one direction at a time.
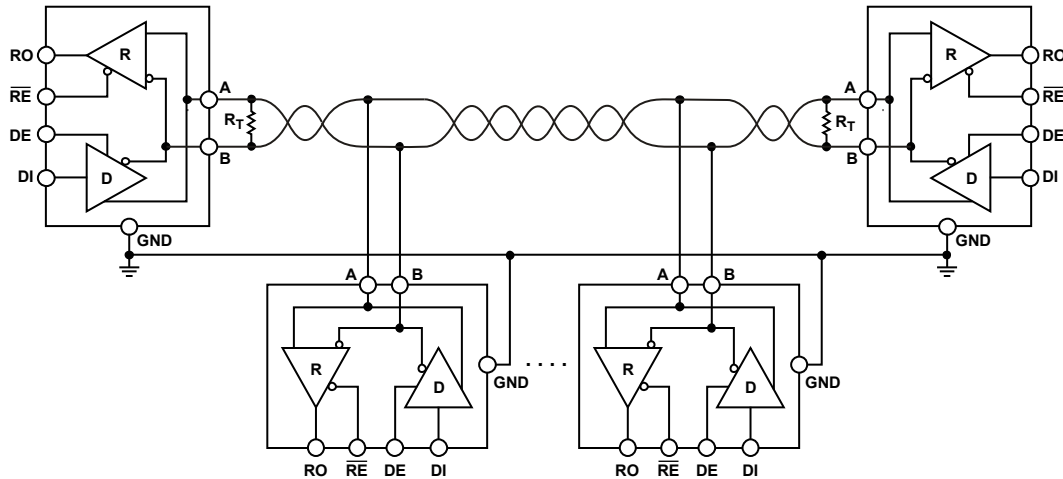
FULL-DUPLEX RS-485

Figure 4 shows an example of an RS-485 bus connected in a full-duplex bus configuration. This configuration is also known as a 4-wire RS-485 network connected in a multipoint master/slave configuration. Full-duplex RS-485 allows for simultaneous communication in both directions between master and slave nodes.
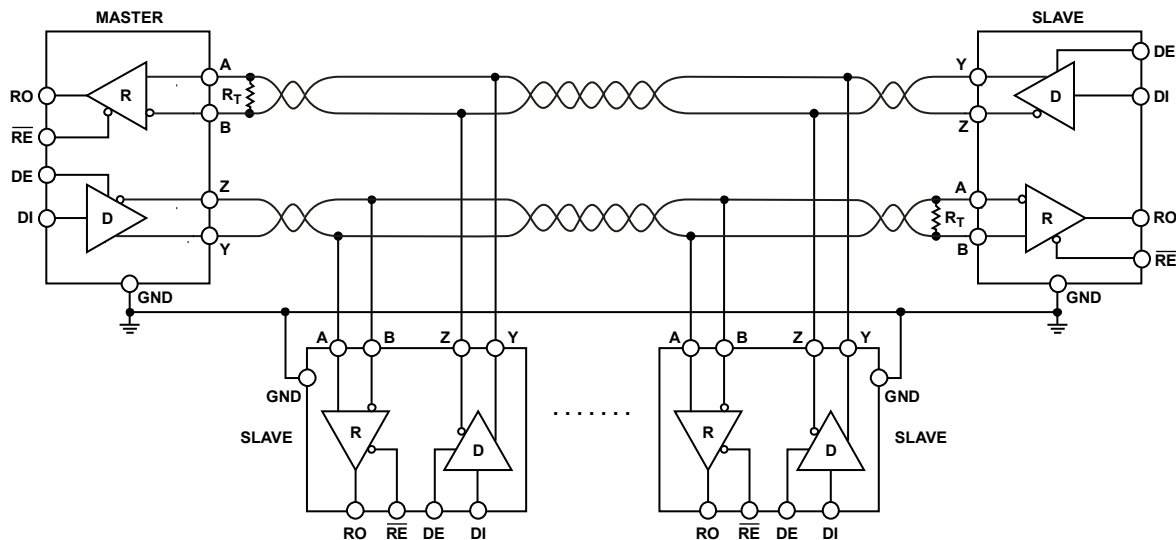

Figure 3. Half-Duplex RS-485 Bus Configuration

Figure 4. Full Duplex RS-485 Bus Configuration

TERMINATION

In a transmission line, there are two wires, one to carry the currents from the driver to the receiver and another to provide the return path back to the driver. RS-485 links are a little more complicated because of the fact that they have two signal wires that share a termination as well as a ground return path. However, the basic principles of transmission lines are the same.

For reliable RS-485 and RS-422 communications, it is essential that the reflections in the transmission line be kept as small as possible. This can only be done by proper cable termination.

Reflections happen very quickly during and just after signal transitions. On a long line, the reflections are more likely to continue long enough to cause the receiver to misread logic levels. On short lines, the reflections occur much sooner and have no effect on the received logic levels.

In RS-422 applications there is only one driver on the bus and if termination is to be used it must be placed at the end of the cable near the last receiver. RS-485 applications require termination at the master node and the slave node furthest from the master. Table 2 shows a comparison of different termination techniques.

No Termination

The time required for a signal to propagate down the line to a receiver determines if a line is considered a transmission line. Physically long wires have longer propagation times, whereas physically short wires have shorter propagation times. When the propagation time is short relative to the data bit duration, the effect on the signal quality is minimized. A cable is not seen as a transmission line if the signal rise time is more than four times the propagation delay of the cable.

Parallel Termination

When two or more drivers share a pair of wires, each end of the link has a termination resistor equal to the characteristic impedance of the cable. There should be no more than two terminating resistors in the network regardless of how many nodes are connected.

In a half-duplex configuration, both ends of the cable must be terminated (see Figure 3). In a full duplex configuration only the master receiver and most remote slave receiver need to be terminated.

AC Termination

AC termination is used to reduce the power consumption of idle links as well as to reduce ringing voltages. The negative effect though is a reduction in cable length and bit rate. A resistor and capacitor can be placed in series across the bus (between A and B) as shown in Figure 5. The Capacitor C_T is selected by using the following formula:

$$C_T(pF) > \frac{2(One\text{-}Way\ Cable\ Delay\ (ps))}{Characteristic\ Impedance\ (\Omega)}$$
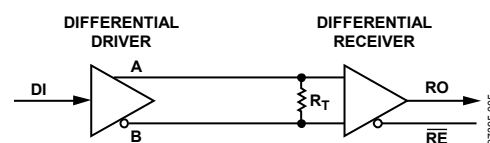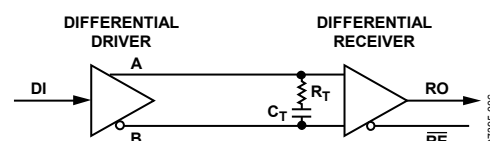
Figure 5. Parallel Termination

Figure 6. AC Termination

Table 2. Termination Advantages and Disadvantages

Termination	Advantages	Disadvantages
None	Simple, low power	Suitable only for short links with slow drivers
Parallel	Simple	High power
AC	Low power	Suitable only for low bit rates and short links

Stub Length

Stub length should be much less than ¼ of a wavelength of the frequency equal to the inverse of the bit period.

DATA RATE AND CABLE LENGTH

When high data rates are used, the application is limited to a shorter cable. It is possible to use longer cables when low data rates are used. The dc resistance of the cable limits the length of the cable for low data rate applications by increasing the noise margin as the voltage drop in the cable increases. The ac effects of the cable limit the quality of the signal and limit the cable length to short distances when high data rates are used.

Examples of data rate and cable length combinations vary from 90 kbps at 4000 feet to 10 Mbps at 15 feet for RS-422.

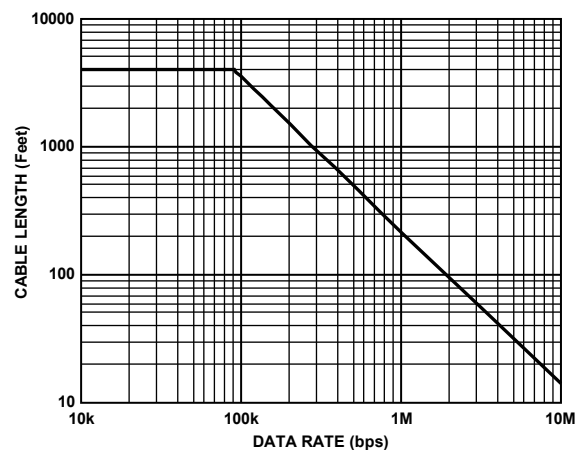Figure 7 can be used as a conservative guide for cable length vs. data rate.
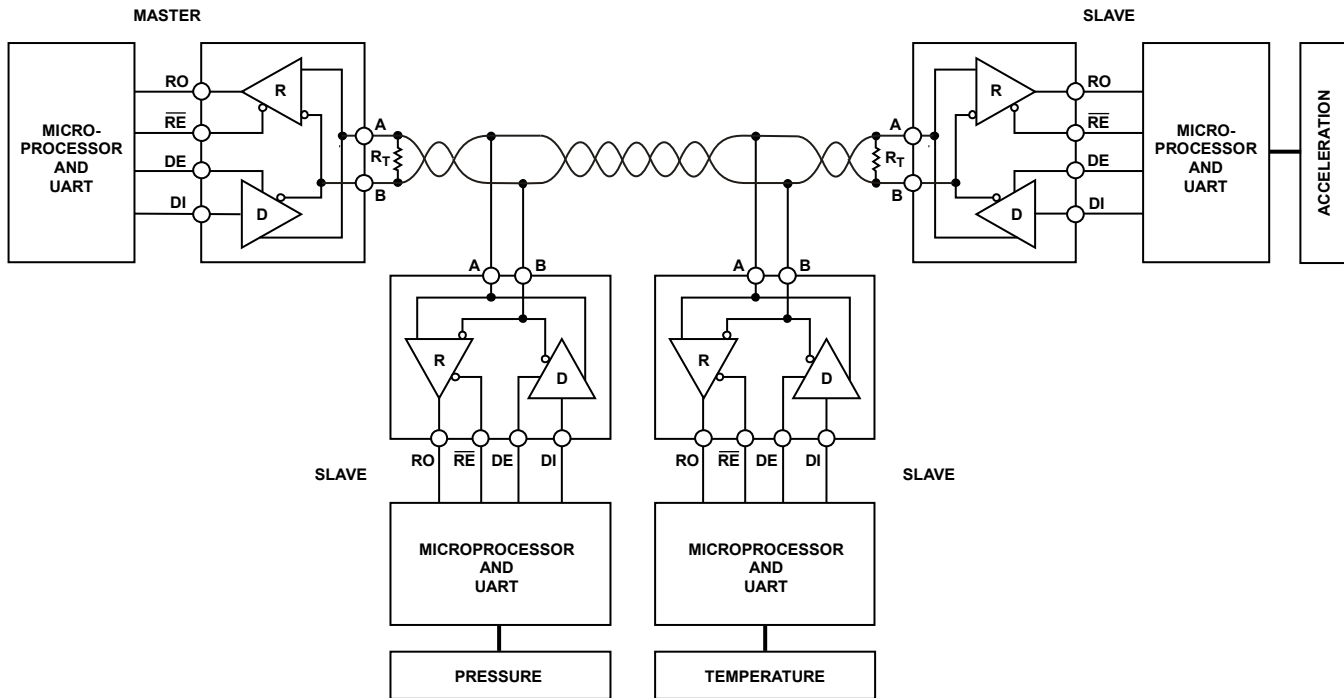
Figure 7. Cable Length vs. Data Rate

Figure 8. Master/Slave RS-485 Network with No Fail-Safe Biasing of the Network

FAIL-SAFE BIASING

Figure 8 shows a configuration of a master/slave RS-485 network with no fail-safe biasing. Asynchronous data transmission is typically used in these applications. A start bit indicates the start of a bit sequence and is detected when a transition occurs from high to low. Eight data bits and a parity bit follow the start bit. A stop bit that can be one or two bits long follows this bit sequence. Another start bit starts the next bit sequence. When the last character is sent the line should stay high until the next start bit. This causes problems in multipoint applications when the transceivers connected on the bus are in receive mode simultaneously. This is known as a bus idle condition and in this case, the differential voltage on the bus ($V_{OA} - V_{OB}$) is 0 V. Under this condition, the receiver output (RO) is undefined by the RS-485 standard and, thus, the receiver output can produce random data. This data is connected to the UART and can cause erroneous system operation.

Differential Input Threshold Voltage of a Receiver

The differential input threshold voltage (V_{TH}) of a receiver is the voltage on the receiver input at which a transition (low to high or high to low) of the receiver output is guaranteed. A typical RS-485 transceiver has a differential input threshold voltage of ±200 mV. What this means is that when the differential input is larger than or equal to 200 mV ($V_{IA} - V_{IB} \geq 200$ mV), the receiver output is guaranteed to be high (RO = 1). When the differential input is less than or equal to −200 mV ($V_{IA} - V_{IB} \leq -200$ mV), the receiver output is guaranteed to be low (RO = 0). See Table 3 for a truth table for the receiver.

Table 3. Differential Receiver Truth Table

$\overline{RE}$	A − B (Inputs)	RO
0	≥+200 mV	1
0	≤−200 mV	0
0	−200 mV ≤ (A − B) ≤ +200 mV	X
1	X	High-Z

Open Fail-Safe

During the bus idle condition, there is no device driving the bus. The receiver output is undefined. This can cause random data to be received on the UART, which in turn can cause false start bits, false interrupts, and framing errors.

This problem can be solved by placing a combination of pull-up and pull-down resistors at one position on the bus. Figure 9 shows the biasing resistor circuit. An example of calculating R1 and R2 is shown below (assume $R_T = 120$ Ω):

$$R_1 = R_2 = R$$
$$V_{IA} - V_{IB} \geq 200 \text{ mV}$$
$$V_{IA} - V_{IB} = R_T \frac{V_{CC}}{2R + R_T} = 200 \text{ mV}$$
if $V_{CC} = 5$ V, then R = 1440 Ω
if $V_{CC} = 3$ V, then R = 960 Ω

If lower values for R are used ($V_{IA} - V_{IB} > 200$ mV), a greater noise margin can be achieved in the system. See Figure 10 for a graphical representation of the bus states and differential input voltage.
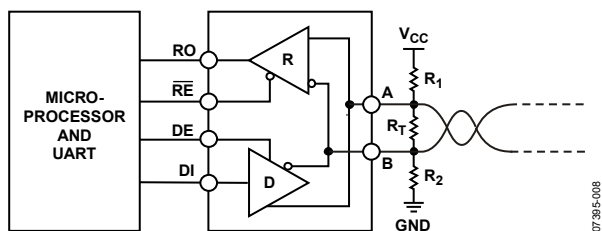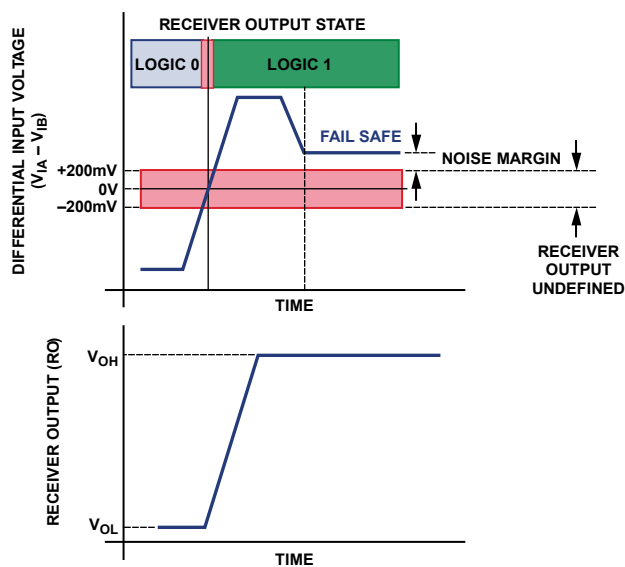
Figure 9. Fail-Safe Biasing Circuit

Figure 10. Differential Input Voltage and the Receiver Output State

True Fail-Safe Receivers

New generation RS-485 transceivers have an improved feature that includes true fail-safe receiver inputs. This eliminates the need for pull-up/pull-down resistors as shown in the previous example. If a transceiver is specified to have a true fail-safe feature this means that, the differential input threshold voltage (V_{TH}) has been adjusted from ±200 mV to −200 mV to −30 mV (see Figure 11).

During the bus idle condition, $V_{IA} - V_{IB} = 0$ and therefore is larger than −30 mV, resulting in the receiver output being high (RO = 1). This means that if all transceivers connected to the bus have true fail-safe features, the receiver output is always defined. See Figure 12 for a graph of the bus states and differential input voltage.
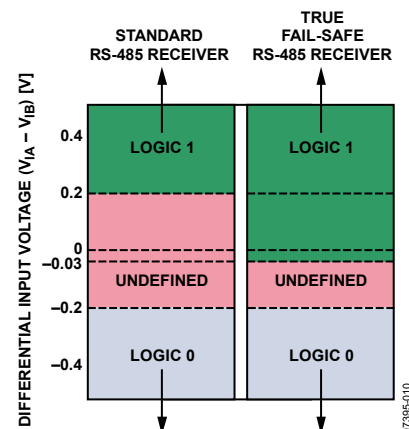

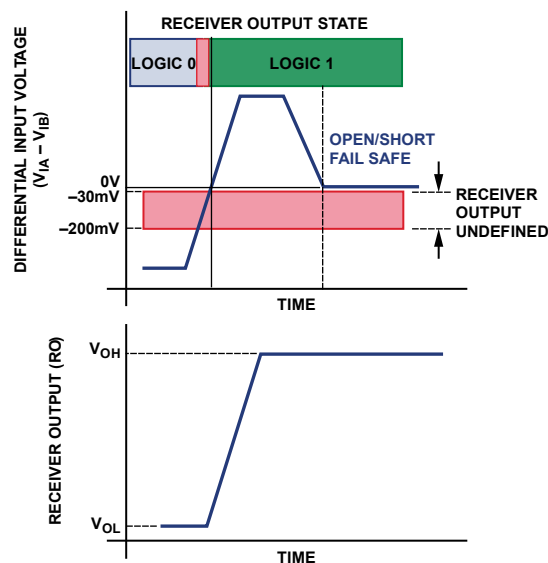*Figure 11. Input Threshold Voltage*

Figure 12. Differential Input Voltage and Receiver Output State

ISOLATION

In RS-485 applications, there are often long links, which can cause the ground potential at different nodes on the bus to be slightly different. This causes ground currents to flow through the path of least resistance through either the common earth ground or the ground wire. If the same electrical system is used to connect the power supplies of all nodes to the same earth ground, the ground connection may have reduced noise. Note, however, that motors, switches, and other electrically noisy equipment can still induce ground noise into the system.

When different nodes are situated in different buildings, different power systems are required. This is likely to increase the impedance of the earth ground and the ground currents from other sources are more likely to find their way into the link's ground wire. Isolating the link reduces or even eliminates these problems. Galvanic isolation is a perfect solution if there is no guarantee that the potential at the earth grounds at different nodes in the system are within the common-mode range of the transceiver. Galvanic isolation allows information flow, but prevents current flow (see Figure 13).
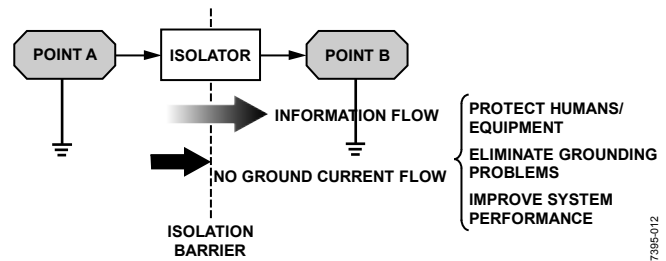

Figure 13. Galvanic Isolation Allows Information Flow While Preventing Ground Current Flow

The signal lines, as well as the power supply, must be isolated. Power isolation is achieved by an isolated dc-dc supply, such as Analog Devices, Inc. *iso*Power™, and signal isolation is achieved via Analog Devices *i*Coupler® technology. See Figure 14 for an example of how to achieve signal and power isolation using the ADM2485.
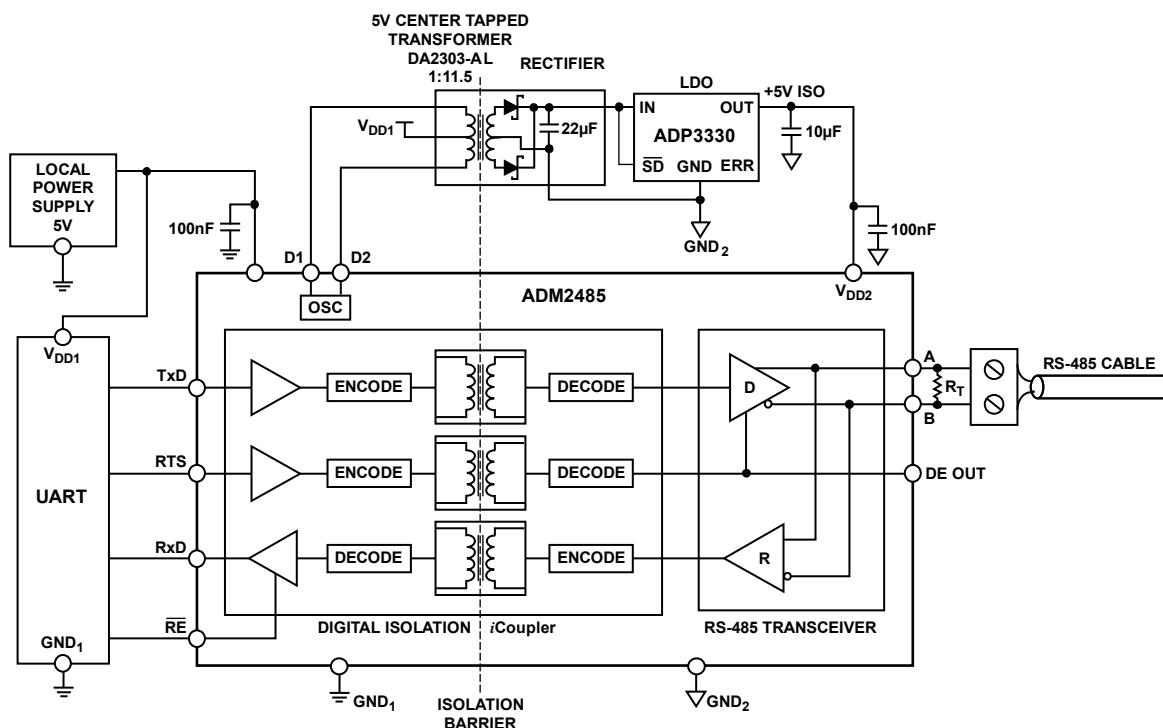

Figure 14. Signal and Power Isolation using the ADM2485

TRANSIENT OVERVOLTAGE STRESS PROTECTION

In I&I applications, lightning strikes, power source fluctuations, inductive switching, and electrostatic discharge can cause damage to RS-485 transceivers by generating large transient voltages. The following ESD protection, EFT protection, and surge protection specifications are relevant to RS-485 applications:

• IEC 61000-4-2 ESD protection

• IEC 61000-4-4 EFT protection

• IEC 61000-4-5 surge protection

Analog Devices offers a broad range of RS-485 devices with enhanced ESD protection. An E appended to the part number, such as ADM3072E, indicates enhanced ESD protection. For a full range of the Analog Devices RS-485 portfolio, refer to http://www.analog.com/RS485.

The level of protection can be further enhanced when using external clamping devices, such as TVS diodes. TVS diodes are normally used to protect silicon devices, like RS-485 transceivers, from transients. The protection is accomplished by clamping the voltage spike to a limit, by the low impedance avalanche breakdown of a PN junction. TVS diodes are ideally open-circuit devices. A TVS diode can be modeled as a large resistance in parallel with some capacitance while working below its breakdown voltage. When a transient is generated and the surge voltage is larger than the breakdown voltage of the TVS, the resistance of the TVS decreases to keep the clamping voltage constant. The TVS clamps the pulse to a level that does not damage the device that it is protecting. The transients are clamped instantaneously (< 1 ns) and the damaging current is diverted away from the protected device (see Figure 15).

The function of a TVS in RS-485 applications is to clamp the voltage on the bus to the common-mode voltage range of the RS-485 transceiver (−7 V to +12 V). Some TVS devices have been specifically designed for RS-485 applications. For higher power transients, protection can be increased by adding Resistors R_S (between 10 Ω and 20 Ω) between the protected device and the input pin as shown in Figure 15 and Figure 16.
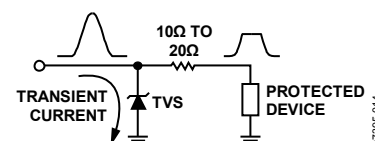
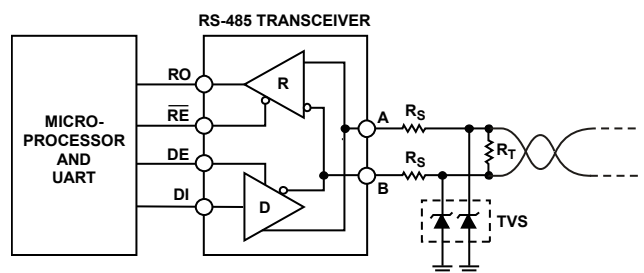

Figure 15. Transient Voltage Supressor

Figure 16. TVS Application Circuit

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