TUTORIAL

RS-485: Still the Most Robust Communication

maxim integrated™

Table of Contents

Abstract

Despite the rise in popularity of wireless networks, wired serial networks continue to provide the most robust, reliable communication, especially in harsh environments. These well-engineered networks provide effective communication in industrial and building automation applications, which require immunity from noise, electrostatic discharge and voltage faults, all resulting in increased uptime. This tutorial reviews the RS-485 protocol and discusses why it is widely used in industrial applications and the common problems it solves.

RS-485 vs. RS-422

An examination of the characteristics that make RS-485 the most popular interface protocol for use in harsh, industrial environments.

The RS-485 transceiver is the most popular interface for implementing the physical layer in harsh industrial and building automation networks for serial port communications. This serial interface standard provides single-path differential signaling over a twisted pair of wires for long-distance and high-speed transmission needed for industrial applications. The RS-485 standard provides a robust interface that can withstand harsh environments. One common problem with industrial and building applications is that large electrical transients from fast switching inductive loads, electrostatic discharge, and frequent voltage surges associated with factory automation can corrupt data transmission or physically destroy the network.

There are many types of data interface protocols commonly used today. Each was developed with a specific application in mind with a particular set of protocol specifications and structure. These interfaces include CAN, RS-232, RS-485/RS-422, I^2C, I^2S, LIN, SPI and SMBus, to name a few. Of these, RS-485 and RS-422 are still the most reliable, especially in harsh industrial, electrical environments such as factory and building automation.

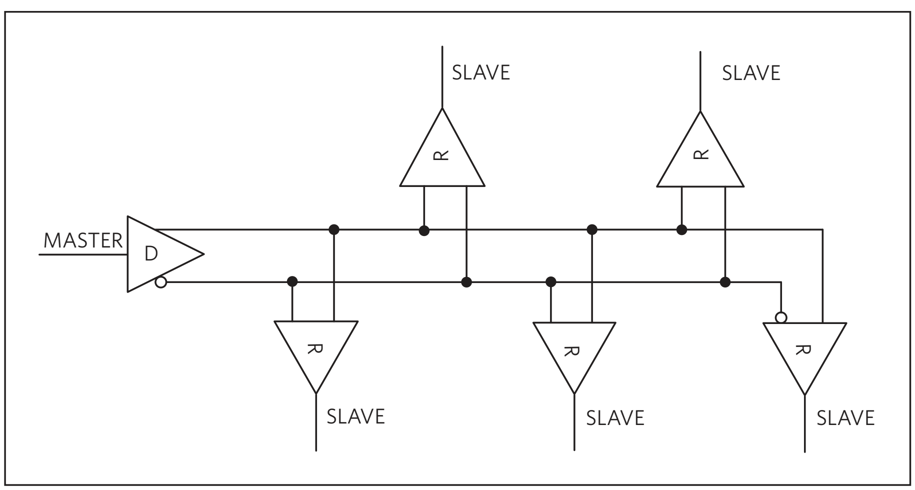

Figure 1. RS-422 multidrop bus

Although RS-485 and RS-422 are similar, they are not the same. There are some differences between these two standards that need to be noted when designing a system.

RS-422 is best suited for industrial environments that require only one bus master (driver). It provides a mechanism for transmitting data up to 10Mbps. RS-422 sends each signal using a twisted pair of wires to increase noise immunity and improve baud rate and cable length. RS-422 is specified for multidrop applications where only one transmitter is connected to, and transmits on, a bus of up to 10 receivers (Figure 1) according to TIA/EIA-422. Typical applications include process automation (chemicals, brewing, paper mills), factory automation (automotive and metal fabrication), HVAC, security, motor control, and motion control.

RS-485 offers greater flexibility when more than one bus master/driver is needed. It is an improvement over RS-422 because it increases the number of devices from 10 to 32 per TIA/EIA-485 and has a wider common mode (-7V to +12V versus ±7V) and slightly lower differential voltage range (±1.5 versus ±2V) to ensure adequate signal voltages under maximum load. With this enhanced multidrop capability, you can create networks of devices connected to a single RS-485 serial port. The greater noise immunity and multidrop capability make RS-485 the serial connection of choice in industrial applications that require multiple distributed devices networked to a PLC or other controllers for data collection, HMI, or similar operations. RS-485 is a superset of RS-422; thus, all RS-422 devices may be controlled by RS-485.

Typical applications for RS-485 are similar to those of RS-422: process automation (chemicals, brewing, paper mills), factory automation (automotive and metal fabrication), HVAC, security, motor control, and motion control. Thus, RS-485 is the more commonly used between the two standards due to its enhanced capability.

*The **RS-485** transceiver is the most popular interface for implementing the physical layer in harsh industrial and building automation networks for serial port communications.*

An In-Depth Look at RS-485

As mentioned earlier, TIA/EIA-485, commonly known as RS-485, is the most broadly used interface in industrial applications. RS-485 can be used over long distances up to 4000 feet and high speeds greater than 40 Mbps for shorter disances. The differential nature of RS-

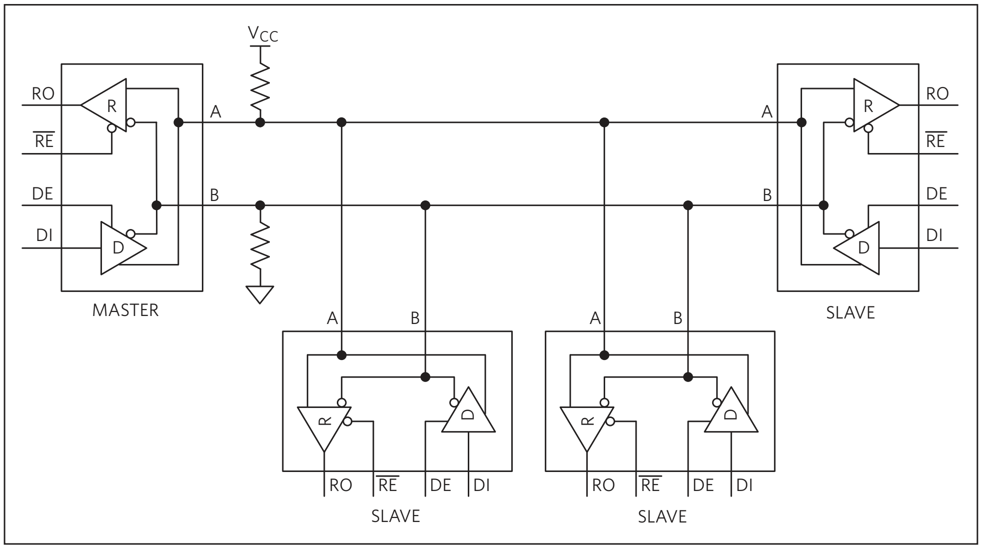

Figure 2. Multidrop half-duplex transceiver system commonly used in industrial applications

485 will enable long runs, but it will slow down as the cable length increases. In addition to the distance, data rate will be affected by the wire gauge and the number of nodes on the network. RS-485 with preempahsis like the MAX3291 can significantly improve on bandwidth and distance for applications that require it.

The RS-485 interface can be used in half-duplex mode with a single-pair transmission bus or full-duplex mode for simultaneous transmit-and-receive operations with a two-pair bus (4-wire). It can handle up to 32 drivers and up to 32 receivers in a half-duplex multidrop configuration. New devices have emerged that feature 1/4-unit-load, and even 1/8-unit-load receiver input impedances, such as the MAX13448E, which allows 128 to 256 receivers on the same bus. With this enhanced multidrop capability, you can create networks of devices connected to a single RS-485 serial port as shown in Figure 2.

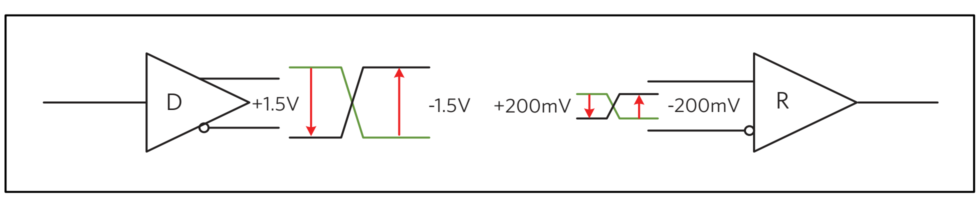

Figure 3. RS-485 minimum bus signal levels

The receiver input sensitivity is ±200mV. This means that to recognize a 1 or a 0 bit, the receiver must see signal levels greater than +200mV for zero and lower than -200mV for one (Figure 3). Noise that falls in the range between ±200mV is essentially blocked. The differential format produces effective common-mode noise cancellation. Minimum receiver input impedance is 12kΩ, and the driver output voltage is ±1.5V minimum, ±5V maximum.

Challenges of the Industrial Environment

Designers of industrial systems face many difficult challenges to assure robust operation in the face of environmental conditions that may damage the hardware or negatively affect the digital communications.

One example is automatic control of process machinery in factory automation. A process controller monitors and measures operational and environmental variables and sends actuation commands out to control devices or alarms. The controllers are usually microcontroller-based machines with architecture optimized to meet the needs of the factory and the application. Point-to-point data communication line in these systems are subject to harsh electrical environments.

DC-DC converters used in industrial applications include those with high input voltages and isolated power outputs. Many applications use 24V or 48V DC inputs to provide power to distributed applications that are not line powered. Once down converted to 12V or 5V, point-of-load conversion can be applied. Applications that maintain communications with remote sensors and actuators need protection against the effects of transients, EMI, and differing ground potentials.

Companies such as Maxim Integrated take great care in ensuring that ICs for industrial applications are robust and able to withstand harsh electrical environments. Maxim's RS-485 transceiver ICs feature internal protection such as high ESD-immunity, fault protection against large voltage spikes and hot-swap capability for error-free data transmission.

Protecting Systems from Harsh Electrical Environments

The following are protection features that may be incorporated into RS-485 transceivers.

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ESD is a serious industrial problem estimated to cause billions of dollars in damages annually.

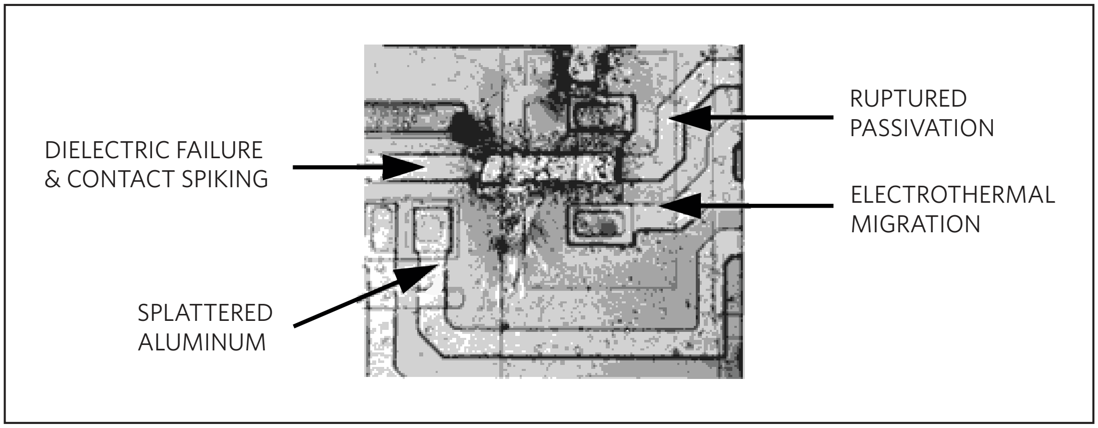

Figure 4. ICs with inadequate ESD protection are subject to catastrophic failure

Extended ESD

Electrostatic discharge (ESD), an overvoltage event, occurs when two materials with different electrical potentials make contact, transfer stored static charges, and generate a spark. ESD sparks are often produced by the interaction of people with their surroundings. These inadvertent sparks can change the properties of a semiconductor device, degrading or destroying it entirely. ESD can also threaten an electronic system when someone replaces a cable or even touches an I/O port. Discharges that accompany these routine events can disable the port by destroying one or more of the interface ICs (Figure 4). Such failures can be expensive—they raise the cost of warranty repairs while diminishing the product's perceived quality. ESD is a serious industrial problem estimated to cause billions of dollars in damages annually. ESD events that occur in the field can cause individual component failure and sometimes catastrophic system failures.

External ESD diodes and other discreet components can be used to protect data lines. Many IC devices integrate some degree of ESD protection and require no further external protection for the IC itself. Figure 5 shows a simplified functional diagram of a common integrated protection scheme. Voltage spikes at the signal input/output (I/O) are clamped to V_{CC} or GND and protect the internal circuitry. Many interface products and analog switches integrate ESD protection designed to comply with IEC 61000-4-2 standards.

Maxim Integrated has invested a substantial effort in developing ICs with robust internal ESD protection. Starting

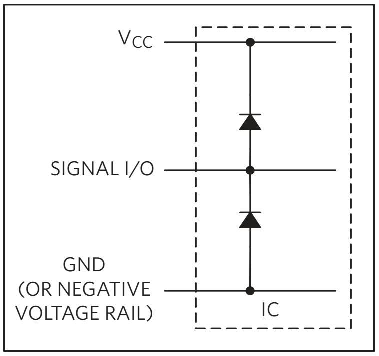

Figure 5. Simplified integrated ESD protection circuitry

with RS-232 and RS-485 interface ICs, Maxim has become a leader in ESD protection for interface transceivers. These devices withstand the application of IEC 61000-4-2 and JEDEC JS-001 ESD events directly to their I/O pins. This approach is robust, readily available, requires no external real estate, and costs less than most alternatives.

All Maxim devices incorporate ESD-protected structures on all pins to protect against electrostatic discharges encountered during handling and assembly. Transceivers with high ESD protection, such as the MAX3483AE/MAX3485AE family, feature ±20kV ESD protection on their transmitter-output and receiver-input pins. Not only will these transceivers not be damaged by ESD strikes less than their rated value, but they will continue to work normally without the need to cycle power. In addition, they are protected against ESD strikes while powered up, powered down, and in shutdown mode.

Fault Protection

The driver outputs/receiver inputs of RS-485 devices in industrial network applications often experience voltage faults resulting from stray voltage spikes. Faults are different from ESD events. While ESD events occur within a short time range less than 100ns, faults generally occur over a sustained period of approximately 200µs or longer. Faults, such as overvoltages, can be caused by wiring errors, loose connections, pinched or faulty cables, or even solder debris that causes the powerline to contact the data connection on the PCB or in the connector, can be exposed to high voltages for seconds or even minutes before failure. This can be catastrophic since many industrial power supplies exceed +24V. Any contact with a data line ensures the destruction of a standard, unprotected RS-485 transceiver.

To protect against these faults, ordinary RS-485 devices require costly discrete external protection circuitry or devices. Fault-protected RS-485 transceivers offer overvoltage protection as high

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Fail-Safe Receivers guarantee a logic-high receiver when the receiver inputs are opened or if all transmitters on a terminated bus are disabled.

Hot-Swap Circuitry eliminates false transitions on the data cable during initialization or connection to a live backplane.

as ±40V, ±60V, and even ±80V on communication bus lines. Maxim offers many fault-protected RS-485/RS-422 transceivers such as the MAX13442E–MAX13444E that can survive high DC voltages on the data pins. To reduce system complexity and the need for external protection, the driver outputs and receiver inputs of these fault-protected devices can withstand voltage faults of up to ±80V with respect to ground without damage. Protection is guaranteed regardless of whether the device is active, shut down, or without power. This makes them the most robust transceivers in the industry and, therefore, ideal for industrial applications. These devices are designed to survive overvoltage faults such as direct shorts to power supplies, miswiring faults, connector failures, cable crushes, and tool mis-applications.

True Fail-Safe Receivers

An important feature of many RS-485 transceivers is the true fail-safe circuitry, which guarantees a logic-high receiver output when the receiver inputs are opened or shortened, or if all transmitters on a terminated bus are disabled (high impedance). True fail-safe solved the problem of a collapsing bus by changing the receiver input threshold to a slightly negative differential voltage of -50mV and -200mV. This guaranteed logic-high is achieved by setting the receiver threshold between -50mV and -200mV. If the differential receiver input voltage (V_A - V_B) is greater than or equal to -50mV, RO is logic-high. If (V_A - V_B) is less than or equal to -200mV, RO is logic-low. In the case of a terminated bus with all transmitters disabled, the receiver's differential input voltage is pulled to ground by the termination. This results in a logic-high with a 50mV minimum noise margin. Unlike previous fail-safe devices, the -50mV to -200mV threshold complies with the ±200mV EIA/TIA-485 standard.

Hot-Swap Capability

Hot-swap circuitry eliminates false transitions on the data cable during circuit initialization or connection to a live backplane. Short-circuit current limiting and thermal-shutdown circuitry protect the driver against excessive power dissipation.

Inserting circuit boards into a hot, or powered, backplane may cause voltage transients on DE, DE/$\overline{RE}$, $\overline{RE}$, and receiver inputs A and B that can lead to data errors. For example, upon initial circuit board insertion, the processor undergoes a power-up sequence. During this period, the high-impedance state of the output drivers makes them unable to drive the transceiver enable inputs to a defined logic level. Meanwhile, leakage currents of up to 10µA from the high-impedance output, or capacitively coupled noise from V_{CC} or GND, could cause an input to drift to an incorrect logic state. To prevent such a condition from occurring, devices such as the MAX3440E-MAX3443E feature hot-swap input circuitry on DE, DE/$\overline{RE}$, and $\overline{RE}$ to guard against unwanted driver activation during hot-swap situations. When V_{CC} rises, an internal pulldown (or pullup for $\overline{RE}$) circuit holds DE low for at least 10µs and until the current into DE exceeds 200µA. After the initial power-up sequence, the pulldown circuit becomes transparent, resetting the hot-swap tolerable input.

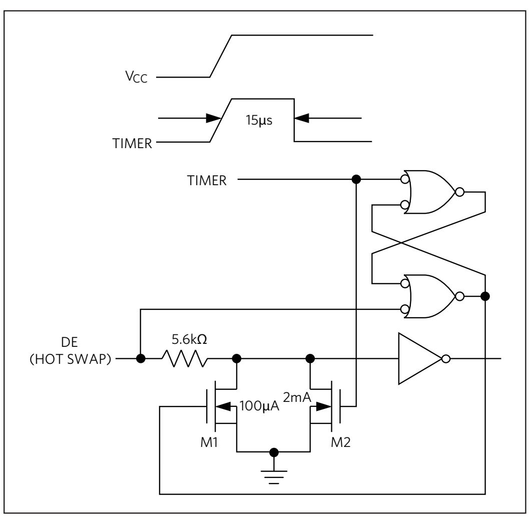

Figure 6. Simplified structure of the driver enable pin (DE)

How does this internal hot-swap circuitry work? At the driver-enable input (DE), there are two nMOS devices, M1 and M2 (Figure 6). When V_{CC} ramps from zero, an internal 15µs timer turns on M2 and sets the SR latch, which also turns on M1. Transistors M2, a 2mA current sink, and M1, a 100µA current sink, pull DE to GND through a 5.6kΩ resistor. M2 pulls DE to the disabled state against an external parasitic capacitance up to 100pF that may drive DE high. After 15µs, the timer deactivates M2 while M1 remains on, holding DE low against three-state leakage currents that may drive DE high. M1 remains on until an external current source overcomes the required input current. At this time, the SR latch resets M1 and turns off. When M1 turns off, DE reverts to a standard, high-impedance CMOS input. Whenever V_{CC} drops below 1V, the input is reset. A complementary circuit for $\overline{RE}$ uses two pMOS devices to pull $\overline{RE}$ to V_{CC}.

Conclusion

Industrial system applications, such as factory automation, are subjected to harsh electrical environments. It is vitally important for the system-level designer to take into account voltage transients from several sources when developing the hardware that will withstand these conditions. Most data communications networks rely on the robustness of the RS-485 protocol standard along with special safety features incorporated into the transceiver ICs to withstand these effects. Structures such as extended ESD protection, high-voltage fault protection, and hot-swap capability safeguard against these events to help maintain system reliability.

References

1. Application note 4491, *"Damage from a Lightning Bolt or a Spark—It Depends on How Tall You Are!"*
2. Application note 5260, *"Design Considerations for a Harsh Industrial Environment"*
3. Application note 639, *"Maxim Leads the Way in ESD Protection"*

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