

White Paper

RS-485 Transceiver Tutorial

Introduction

TIA/EIA-485 and TIA/EIA-422 (also known as RS-485 and RS-422) are wired communication standards published by the Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA). They use differential signaling to enable data transmission over long distances and in noisy industrial and factory automation environments. Differential signaling rejects common mode noise, and the recommended twisted pair cable ensures that most received interference is common mode. Long transmission distances increase the chance for ground potential differences, but the standards' wide common mode range (CMR) ensures that the network operates properly, even in the presence of fairly large common mode voltages.

As shown in Figure 1, the transmitter (Tx) and receiver (Rx) both have non-inverting (Y and A) and inverting (Z and B) pins. Half-duplex devices are used for bidirectional communication over a single cable, so the corresponding Rx and Tx terminals connect to the same IC package pin. Networks that utilize two cables for bidirectional communication employ full-duplex devices, where the Rx and Tx terminals connect to separate pins.

With the plethora of transceivers on the market, it can be challenging to pick the best, most cost effective device for your application. This in-depth white paper guides you through the choices and weighs key design considerations to help you pick the right transceiver. First, we'll review the most typical RS-485 ICs and explore the most common design considerations. Then, we'll examine electrostatic discharge (ESD) protection and compare the Human Body Model (HBM) and IEC61000-4-2 (IEC) standards. Finally, we'll discuss over voltage protection (OVP) and provide a snapshot of very high-speed transceivers (above 25Mbps) where data skew is critical.

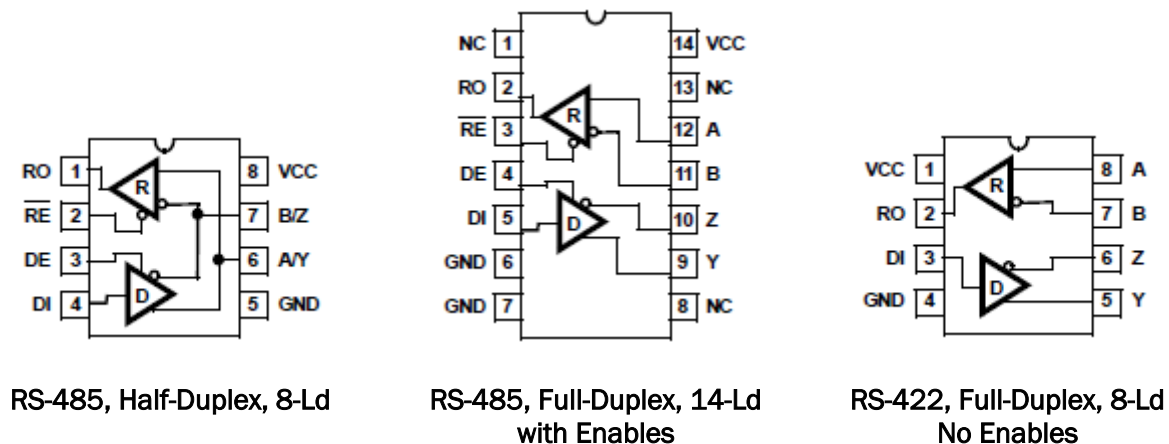


Figure 1. Typical RS-485 and RS-422 pinouts

RS-485 Requirements

The published RS-485 standard is 14 pages long. Here are some of its most important requirements:

- Differential signaling with a very sensitive ($\pm 200\text{mV}$) Rx, and a healthy $\pm 1.5\text{V}$ Tx differential output voltage (V_{OD}). This combination ensures a robust noise margin that tolerates the attenuation from long cables.
- The Tx must have an enable pin. RS-485 allows multiple drivers on the bus for true bidirectional transmission over a single cable, so each Tx must have tri-state output capability.
- High Tx output current to drive double terminated cables and long cables. High-speed bidirectional transmission over a single cable requires two terminations.
- Wide CMR of at least -7V to $+12\text{V}$. RS-485 enables networks up to 4000 feet long (1220m). A large CMR handles the ground potential differences that may occur over long distances, and tolerates larger induced bus voltages in noisy environments. This CMR also allows devices with different supply voltages to communicate on the same bus.
- A receiver input resistance of approximately $12\text{k}\Omega$. The standard allows up to 32 “one unit load” devices on the bus, and the load from each device (Tx or Rx) must be $\leq 1\text{mA}$ with a 12V bias on the bus.

RS-422 vs. RS-485

RS-422 is very similar to RS-485; however, RS-422 allows only one Tx on the bus, with a maximum of 10 Rx. This single Tx multiple Rx configuration is called a multi-drop, or broadcast, network. The one driver limitation eliminates the need for a Tx enable pin, which reduces the termination requirement to one 120Ω resistor, and necessitates the use of full-duplex transceivers, or separate Rx and Tx ICs. RS-422 is a much simpler network than the RS-485 network.

The RS-485 Receiver

A standard RS-485 Rx recognizes any differential voltage (Pin A – Pin B) $> +200\text{mV}$ as a logic 1, and any differential voltage below -200mV as a logic 0, and these input thresholds must be met over a wide CMR of -7V to $+12\text{V}$. Any Rx input voltage between -200mV and $+200\text{mV}$ (e.g., a 0V differential) is indeterminate. The large delta between the driver’s $\pm 1.5\text{V}$ differential output voltage and the receiver’s $\pm 200\text{mV}$ threshold yields good noise immunity and the ability to handle the attenuation from long cables. The standard allows 32 unit loads (UL) on a bus, where 1 UL is specified as a device drawing no more than 1mA with the bus at $+12\text{V}$ relative to GND.

The RS-485 Transmitter

The standard RS-485 Tx is a driver with differential outputs that is specified to deliver at least a 1.5V differential voltage into a 54Ω differential load. The 54Ω load is derived from the maximum allowed two 120Ω termination resistors in parallel with 32, 1 UL receivers. RS-485 families typically include drivers with output slew rates set to accommodate two to three data rates. Using the proper slew rate limited device for slower data rate applications minimizes electromagnetic interference (EMI) and reduces the impact from imperfect transmission line matching and termination.

Basic RS-485 Transceivers

Short, simple, low-node-count networks can often use low-cost RS-485 transceivers. Short networks won't pick up much common mode voltage (CMV), so they don't need more than the RS-485 standard CMR, nor should they need OVP. Simple networks with ≤ 32 nodes don't require fractional unit load devices, and if the cables aren't frequently connected and disconnected, then ESD protection may not be required. Nevertheless, some basic devices do include $\pm 8\text{kV}$ to $\pm 15\text{kV}$ Human Body Model ESD protection. RS-422 networks have a single, always enabled driver, so the bus is constantly driven, and bus biasing isn't required. If the bus is electrically short, meaning it doesn't need to be treated as a transmission line, or if the data rate is very slow, then bus terminations may not be required, and basic RS-485 transceivers work fine. However, problems may arise when terminations are required for multi-driver RS-485 systems.

Consider what happens in the circuit shown in Figure 2 when the bus is idle (no Tx actively driving the bus) as occurs when switching between Tx on the bus. With all Tx on the bus tri-stated, the differential termination resistor(s) collapse the bus voltage to nearly a 0V differential, which as previously described is an indeterminate voltage level. Presented with this voltage on the bus, an individual Rx may drive its output (R_o) to a 1, or to a 0, or worse yet it might oscillate. This is problematic because the microcontroller (MCU) monitoring R_o might interpret any high to low transition as a message "start-bit," and an oscillating R_o wastes valuable MCU bandwidth as it tries to service an endless stream of phantom messages.

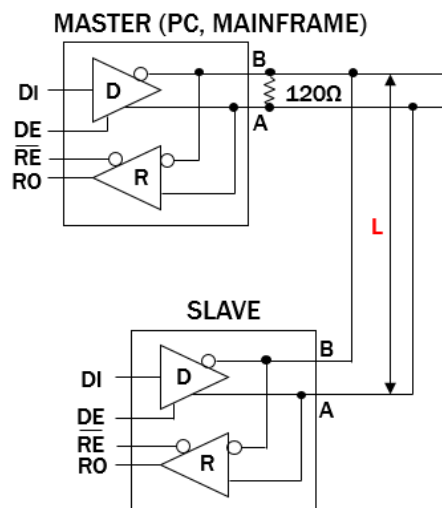


Figure 2. Terminated multi-driver bus

The traditional solution to the collapsing bus problem was to add bus biasing resistors as shown in Figure 3. The pull-up and pull-down resistors bias the differential bus voltage to a positive few hundred mV, which properly preserves a logic 1 level when the bus is idle. Unfortunately, this approach complicates the design task by requiring a tradeoff between the bus idle voltage for noise immunity and Tx loading, and adds a DC current path from V_{cc} to GND. To get the minimum (zero noise margin) $+200\text{mV}$ DC bias voltage across 60Ω (two parallel termination resistors) requires 3.33mA . With a 3.3V supply, the bias resistors needed to generate this current are 470Ω each, which is a pretty substantial load. This added Tx load may significantly reduce the number of transceivers allowed on the bus.

Newer, "full featured" RS-485 transceivers solve this problem by including a special failsafe function.

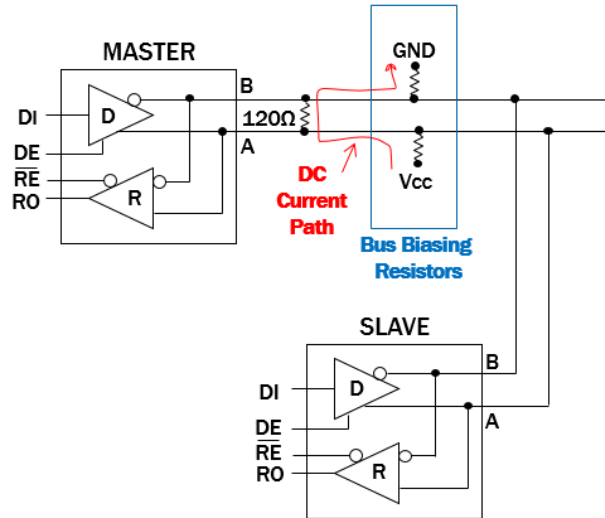


Figure 3. Bus biasing fixes idle problem, but introduces new issues

Full Featured RS-485 Transceivers

Newer RS-485 ICs are “full featured” transceivers that include an advanced Rx failsafe function, fractional unit loads and improved ESD resistance. Examples include Intersil’s ISL317XE transceiver family, which services 3.3V applications, and the ISL315XE family targeted for 5V applications.

Full Failsafe (FFS) Receivers

Although not a part of the RS-485 standard, one of the most important features added to RS-485 transceivers in the last two decades is the receiver full failsafe (FFS) function. FFS means that the Rx drives its output to a defined state (usually a logic 1) whenever the Rx inputs are floating, shorted together, or undriven and shorted by a termination resistor. As mentioned previously, this last condition occurs whenever a terminated, multi-Tx bus is not actively driven. The advent of the FFS Rx solved the collapsing bus problem by redefining the Rx input threshold. By changing the Rx input high threshold to a slightly negative differential voltage (typically -20mV to -50mV), the Rx now recognizes a 0V differential as a valid high input level. This change is still RS-485-compliant because any voltage > +200mV is still recognized as a high level and the negative Rx threshold remains unchanged. The FFS Rx eliminates the need for bus biasing, which allows the bus to be loaded with the maximum number of transceivers.

There are two disadvantages that can arise from using an FFS Rx. First, since the input threshold switching region has been cut in half from 400mV to approximately 200mV, it’s difficult to design much hysteresis into the Rx inputs. Thus, FFS Rx hysteresis runs about 20-40mV, while a non-FFS Rx may have $\geq 70\text{mV}$, so an FFS Rx has less noise immunity than a standard Rx. Second, the asymmetrical FFS switching points may cause duty cycle distortion on networks with slow bus transitions.

Fractional Unit Loads

As network node counts grew past 32, users of standard RS-485 devices had to add repeaters to break the network into 32 UL node segments. Full featured families solve this problem by implementing an Rx with a higher input resistance, allowing more devices on the bus while still complying with the RS-485 32mA

maximum load current requirement. 1/4th UL devices have input currents $\leq 250\mu\text{A}$, so 128 transceivers ($128 * 250\mu\text{A} = 32\text{mA}$) are allowed on the bus. 1/8th UL devices have input currents $\leq 125\mu\text{A}$, so you can have 256 devices on a bus. Disabled Tx load currents are usually negligible, so the Rx input resistance dominates the load calculation. The unit load concept is strictly a DC load constraint, so AC considerations (e.g., length of cable, spacing of nodes, or capacitance of nodes) may limit the node count to values less than what the UL allows.

Enhanced ESD Protection

Full featured transceivers also include some form of improved ESD protection on the bus pins. Bus pins typically connect to an exposed port on the exterior of a piece of equipment. This exposure makes the port especially susceptible to ESD events, and simply connecting a charged interface cable could destroy an unprotected transceiver.

Bus pin ESD protection is specified to one of two standards: the widely familiar Human Body Model standard that is common in the U.S., and the IEC61000-4-2 standard that is common in Europe, and is growing in worldwide acceptance. The HBM test emulates the types of ESD events seen during manufacturing and handling, while the IEC ESD test is an end-equipment test intended to harden equipment to ESD events seen in the field. The IEC ESD standard contains two test methods: a contact method, like HBM, and an air gap method. In the air gap method, a charged electrode is brought toward the pin-under-test, until the voltage discharges across the air gap to the pin. The contact method has the electrode contact the pin-under-test before charging the electrode.

The biggest differences between the HBM and IEC61000 standards are the component values in the discharge network (see Figure 4). The charge storage cap is 50% larger on IEC61000, and the series current limiting resistor is 330Ω vs. $1.5\text{k}\Omega$. This lower value resistor increases the peak ESD current by nearly a factor of five, resulting in a much more severe ESD test.

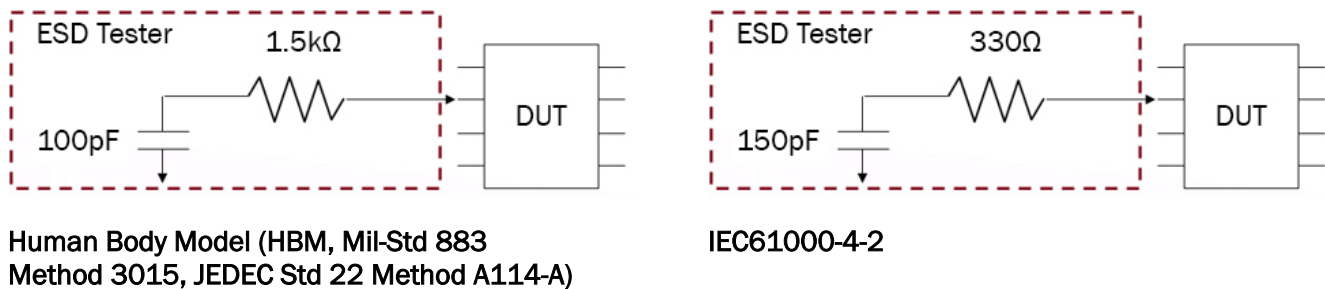


Figure 4. Human Body Model and IEC61000-4-2 discharge networks

Tables 1 and 2 highlight the differences between the HBM and the IEC ESD model, and as you can see, every parameter is more severe for IEC. In addition to the nearly 5X higher peak current, the pulse rise time is much faster forcing the on-chip protection circuit to respond more quickly, all of the pulse energy is delivered to the IC in less than half the time, and IEC requires 10 ESD pulses rather than three.

Table 1. Comparison of Human Body Model and IEC61000-4-2 parameters

PARAMETER	HBM	IEC61000
Number of applied pulses	1-3	10
Storage capacitor (C, Fig. 1)	100pF	150pF
Limiting resistor (R _s , Fig. 1)	1.5kΩ	330Ω
Maximum current (at 15kV)	10A	45A
Maximum rise time	10ns	1ns
Pulse duration	450ns	180ns

Table 2. Comparison of Human Body Model and IEC61000-4-2 classification levels

CLASSIFICATION LEVEL	HBM	IEC61000	
		AIR GAP METHOD	CONTACT METHOD
Level 1	±2kV	±2kV	±2kV
Level 2	±4kV	±4kV	±4kV
Level 3	≥ ±8kV	±8kV	±6kV
Level 4	N/A	≥ ±15kV	≥ ±8kV

As shown in Table 2, there are three classification levels for HBM and four levels for IEC ESD. The special ESD structures utilized in full featured transceivers allow them to meet the highest level for each of the standards. These high ESD structures protect the IC whether or not it is powered up, and without interfering with the RS-485 standard's -7V to +12V CMR. Adding IEC61000 ESD protection to interface ICs saves designers time and money by eliminating the need for board level protection, and minimizes field returns due to ESD damage.

Full Featured Transceivers with Large Differential Output Voltage (VOD)

Some standards, like Profibus DP, use RS-485 for the physical layer, but require a much larger 2.1V Tx V_{OD} for better drive and noise immunity. The 5V powered ISL3150E family from Intersil, for example, features a 2.4V minimum V_{OD}, which provides 900mV more noise immunity than standard RS-485 ICs, while the 40Mbps ISL3159E delivers a 2.1V minimum. Additionally, the large V_{OD} allows these transceivers to drive more than the two terminations required by the RS-485 standard. ISL315XE transmitters can drive the RS-485 required 1.5V V_{OD} into six to eight terminations (3-4x the RS-485 requirement), making them ideal for star configuration and other non-standard networks that require more than two terminations.

Over Voltage Protected Devices

Another application issue arises when power is routed in the same conduit as the data cable. Wiring errors, loose connections or even solder debris may cause the power line to contact the data connection on the PCB

or in the connector. With industrial power supplies commonly exceeding 20V, contact with a data line ensures the destruction of a standard, unprotected RS-485 transceiver. Enter the OVP, or fault protected, transceiver, which is designed such that the RS-485 bus pins can survive voltages much higher than those required by the RS-485 standard. OVP devices like the ISL3243XE and ISL3249XE offer over-voltage levels of ± 40 to ± 60 V and a wide common mode voltage range that's up to two times the range required by the RS-485 standard. Wider CMR allows for the common mode voltage pick-up that frequently occurs in long networks or noisy environments. Intersil OVP ICs are specified with CMRs from ± 15 V to ± 25 V, meaning that a transmitter and receiver continue communicating even when faced with large common mode voltages.

A key advantage of high voltage tolerant bus pins is that they ease the design of bus pin protection networks. If DC or transient bus voltages can exceed a transceiver's bus pin voltage rating, then external protection devices like transient voltage suppressor (TVS) ICs must be added to the transceiver design. The asymmetrical nature of the -7V to +12V standard CMR makes it difficult to use basic bidirectional TVS ICs. Choosing a ± 12 V TVS allows negative voltages to exceed the transceiver's -7V limit, while utilizing a ± 7 V TVS cuts off 40% of the standard's +CMR. Conversely, the symmetrical bus pin voltages of the OVP transceivers easily accommodate bidirectional TVS protection, and the protection is more robust because of the extra headroom between the TVS hard clamping voltage and the bus pin damage voltage. For example, when trying to protect an OVP device with a ± 25 V CMR, you simply pick a bidirectional TVS with a standoff voltage above ± 25 V, and below the OVP level. Keep in mind that TVS devices typically hard clamp at voltages 50% higher than their standoff voltage, so select the lowest TVS voltage that allows the needed CMR. TVS voltages in the range of ± 25 V to ± 40 V have been shown to give good protection for ± 60 V OVP ICs.

Coupled with the ± 16.5 kV HBM ESD, the OVP and wide CMR features make these devices some of the most robust RS-485 transceivers on the market. These are also full featured devices, so they are FFS, and present only a 1/4th UL to the bus.

Table 3. Intersil offers three 5V OVP families and two wide supply voltage 3-5V OVP families

FAMILY	CMR	DATA RATE	MORE INFO
ISL3247XE ± 60 V, basic 5V family	± 15 V	250kbps, 1Mbps or 15Mbps	The ISL3247XE is an improved replacement for OVP devices without an extended CMR
ISL3249XE ± 60 V, premier 5V family	± 25 V	250kbps, 1Mbps or 15Mbps	The ± 25 V CMR is the best of any OVP transceiver
ISL3248XE ± 60 V, premier 5V family	± 25 V	1Mbps	The ISL3248XE adds a cable invert (or polarity reversal) function to the ISL3249XE
ISL3243XE ± 40 V, basic 3V-5V family	± 15 V	250kbps or 1Mbps	The $V_{CC}=3.3$ V Tx V_{OD} of 1.35V is not RS-485 compliant
ISL3245XE ± 60 V, premier 3V-5V family	± 20 V	250kbps or 1Mbps	The $V_{CC}=3.3$ V Tx V_{OD} of 1.35V is not RS-485 compliant

OVP Devices with a Cable Invert Function

High node count RS-485 networks often end up with nodes miswired (e.g., data lines swapped), but testing and rewiring connectors is a manual, time consuming task. A better solution is to utilize RS-485 transceivers with a cable invert, or polarity reversal, function. Simply moving a jumper, or changing the state of a GPIO line, inverts the transceiver's polarity, allowing the miswired node to communicate properly on the bus.

With a traditional RS-485 transceiver, the receiver/transmitter A/Y pins are the non-inverting input, and the B/Z pins are the inverting connections. Reversing the connections from these pins to the bus inverts the received and transmitted data, resulting in unintelligible communications.

A transceiver with a polarity reversal function operates as a normal transceiver with the polarity reversal input in the inactive state, but the transceiver flips the polarity of the bus pins when the polarity select input is switched to the active state. Thus, the B/Z pins become the non-inverting pins, while A/Y become the inverting pins, so the transceiver now communicates properly, even though its bus connections are reversed. The ISL3248XE 5V family, and the 3-5V ISL32437E and ISL32457E all include the cable invert function.

One problem with prior cable invert functions is that the previously described inversion also inverts the full failsafe output state. Thus, activating the cable invert function causes the receiver to output a logic low when its inputs are floating or shorted together, which is the opposite of what the MCU expects. Intersil has solved this problem by implementing a patented function that maintains FFS whether the receiver is in normal or inverted polarity, making the Intersil devices easy to use.

Very High-Speed Transceivers (> 25Mbps)

Near real-time applications, such as robotics, motor control (e.g., EnDat2.2) and data acquisition, require the highest data rates (> 25Mbps) to minimize latency and to increase throughput. Very high data rates require low Tx and Rx skews to minimize duty cycle distortion, and low part-to-part skews enable high speed parallel applications (e.g., SCSI Fast-20 and Fast-40) where data skew is critical.

As an example of the importance of low skews, consider an Rx and Tx where each have skews of 5ns. Inputting a 100ns (10Mbps) pulse to either device results in an output pulse between 95ns and 105ns. If the skews are in the same direction (additive), then a bit sent between two MCUs may be as small as 90ns at the receive end. This is only a 10% distortion, but if the same Rx and Tx transmit a 40Mbps signal (25ns bit width) the same skews result in an unacceptable 40% pulse width distortion.

High-speed devices, like those from Intersil, offer maximum Rx and Tx skews at 1.5ns, and maximum part-to-part skew at 4ns. The ISL3179E (3V) and ISL3159E (5V) are specified at 40Mbps, while the ISL3259E (5V) operates at data rates up to 100Mbps. All parts have a 125 °C option (extended industrial range) to accommodate the high temperatures encountered in motor control applications, are available in MSOP and DFN packages for space constrained applications, and feature $\pm 15\text{kV}$ IEC ESD levels. Additionally, the ISL3159E and ISL3259E have a Tx $V_{OD} > 2.1\text{V}$, making them ideal for high speed Profibus DP networks.

Summary

Despite the large number of RS-485/RS-422 devices on the market, understanding common design problems – and the transceiver features developed to solve those problems – simplifies the designer's task of choosing the best RS-485 device for a particular application.

Next Steps

- [Find out more about Renesas' RS-485/RS-422 transceivers](#)
- [Use our parametric search to find the best RS-485 device for your application](#)

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