APPLICATION NOTE 3884

# HOW FAR AND HOW FAST CAN YOU GO WITH RS-485?

*Abstract: Designers of industrial datacom systems often ask, What data rates can be reliably achieved over what distance, and how? The design trade-off has always been less distance at a higher rate, or greater distance at a lower rate. So, the crucial question is: How far can you reliably transmit and receive data at a specified data rate? The original publishing of this application note used the MAX3469 to demonstrate RS-485 performance, and that data is still valid. However, Maxim has raised the performance of RS-485 to 100Mbps with the introduction of products such as the MAX22500E. This application note shows how to go farther and faster.*

## Introduction

The various serial-datacom protocols range from RS-232 (EIA/TIA-232) to Gigabit Ethernet, and beyond. Though each protocol suits a particular application, in all cases you must consider cost and performance of the physical (PHY) layer. This article focuses on the RS-485 (EIA/TIA-485) protocol and the applications best suited to that standard. It also shows the ways that you can optimize data rates as a function of cabling, system design, and component selection.

Throughout this application note, we will use the "RS" nomenclature to refer to the respective ANSI EIA/TIA standards.

## Protocol Definitions

What is RS-485? How does it compare to other serial protocols, and for what applications are they best suited? The following overview compares the characteristics and capabilities of the RS-485 PHY with those of RS-232 and RS-422.[1]

RS-232 is a standard that originated as a communications guide for modems, printers, and other PC peripherals. It provided a single-ended channel with baud rates up to 20kbps, and later enhanced to 1Mbps. Other RS-232 specifications include nominal ±5V transmit and ±3V receive (space/mark) signal levels, 2V common-mode rejection, 2200pF maximum cable load capacitance, 300Ω maximum driver output resistance, 3kΩ minimum receiver (load) impedance, and 100ft (typical) maximum cable length. RS-232 systems are point-to-point only. Any RS-232 system must accommodate these constraints.

RS-422 is a unidirectional, full-duplex standard for electrically noisy industrial environments. It specifies a single driver with multiple receivers. The signal path is differential, and handles bit rates above 50Mbps. The receivers' common-mode range is ±7V, the driver output resistance is 100Ω maximum, and the receiver input impedance can be as low as 4kΩ.

## The RS-485 Standard

The original ANSI/EIA/TIA-485-A-1998 standard was approved in March 1998 to address the shortcomings of RS-232 and RS-422. RS-485 is a bidirectional, half-duplex standard featuring multiple "bused" drivers and receivers, in which each driver can relinquish the bus. It meets all RS-422 specifications, but is more robust including, for example, a higher receiver-input impedance and wider common-mode range (-7V to +12V).

Receiver input sensitivity is ±200mV, which means that to recognize a mark or space, a receiver must see signal levels above +200mV or below -200mV. The minimum receiver input impedance is 12kΩ (called a unit load), and the driver output voltage is ±1.5V minimum, ±5V maximum.

Drive capacity is 32 unit loads, i.e., 32 12kΩΩ receivers in parallel. Many receivers are designed with a higher input impedance, allowing the number of unit loads on one bus to be higher as well. Any number of receivers can be connected to the bus, provided that the combined (parallel) load presented to the driver does not exceed 32 unit loads (375Ω). The allowable driver load impedance is 54Ω (maximum), which, in a typical 24AWG twisted-pair environment, is 32 unit loads in parallel with two 120Ω terminators.

RS-485 is still the most widely used protocol for POS, industrial, and telecom applications. The wide common-mode range enables data transmission over longer cable lengths and in noisy environments such as the floor of a factory. Also, the high input impedance of the receivers allows more devices to be attached to the lines.

The maximum recommended data rate in the RS-485 standard from 1998 is 10Mbps, which can be achieved at a maximum cable length of 40ft (12m). The absolute maximum distance is 4000ft (1.2km) of cable, at which point, data rate is limited to 100kbps.These were the specifications made in the original standard, which by the time of this app note's publication is already 20 years old! Modern applications involving RS-485 often have data rates several times 10Mbps, and require higher speeds over longer distances. New RS-485 transceivers and cables are pushing the limit of RS-485 far beyond its original definitions.

Profibus and Fieldbus[2] are buses used mainly in industrial plants, and are an extension of RS-485. Plant wiring systems measure sensors, control actuators, collect and display data, and conduct data communications between the process control system and the network of sensors and actuators.

Profibus and Fieldbus are the overall system descriptions; RS-485 is the standard for the PHY layer of the network supporting them. Profibus and Fieldbus have slightly different specifications. Profibus requires a 2.0V minimum differential output voltage with a maximum bus load of 54Ω. Fieldbus requires a minimum differential output voltage of 1.5V, with a maximum load bus of 54Ω. Profibus can transmit data up to 12Mbps, vs. 500kbps for Fieldbus. Skew and capacitance tolerance are tighter in Profibus applications.

## Where Do These Protocols Best Fit?

- RS-232: communication with modems, printers, and other PC peripherals. The typical maximum cable length is 100ft.
- RS-422: industrial environments that require only one bus master (driver). Typical applications include process automation (chemicals, brewing, paper mills), factory automation (metal fabrication), HVAC, security, motor control, and motion control.
- RS-485: industrial environments for which more than one bus master/driver is needed. Typical

applications are similar to those of RS-422: process automation (chemicals, brewing, paper mills), factory automation (autos, metal fabrication), HVAC, security, motor control, and motion control.

## What Factors Limit the RS-485 Data Rate?

The following factors affect how far one can reliably transmit at a given data rate:

- Cable length: At a given frequency, the signal is attenuated by the cable as a function of length.
- Cable construction: Cat5,Cat5e, and Cat6 24AWG twisted pair are very common cable types used for RS-485 systems. Adding shielding to the cable enhances noise immunity, and thereby increases the data rate for a given distance.
- Cable characteristic impedance: Distributed capacitance and inductance slows edges, reducing noise margin and compromising the 'eye pattern'. Distributed resistance attenuates the signal level directly.
- Driver output impedance: If too high, this limits drive capability.
- Receiver input impedance: If too low, this limits the number of receivers that the driver can handle.
- Termination: A long cable can act like a transmission line. Terminating the cable with its characteristic impedance reduces reflections and increases the achievable data rate.
- Noise margin: Bigger is better.
- Slew rate of driver: Slower edges (lower slew rates) enable transmission over longer cable lengths, but reduce maximum achievable data rate.
- Point-to-Point vs. Multidrop: stubs created by the third or more devices on the bus limit achievable data rate, sometime severely.

## Some Empirical Data

### MAX3469

Let's consider an actual wired system (**Figure 1**). The cable shown is used commonly in RS-485 systems: EIA/TIA/ANSI 568 Cat5 twisted pair. The data rates obtained for cable lengths from 300ft to 900ft range from 1Mbps to 35Mbps.
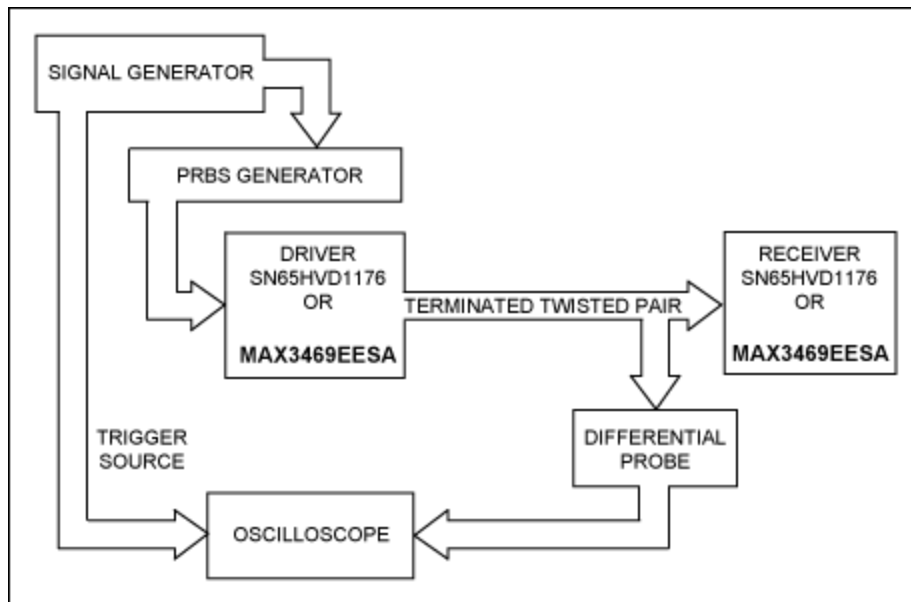


*Figure 1. Test setup.*

For system designers, the manufacturer of a transceiver is often not as important as the maximum data rate and longest distance that the RS-485 driver can drive a signal. The eye diagrams of a Maxim driver (the

MAX3469 in this case, **Figure 3**) and an equivalent driver from another manufacturer (**Figure 2**) can give an idea of a transceiver's abilities over distance and signal speed.
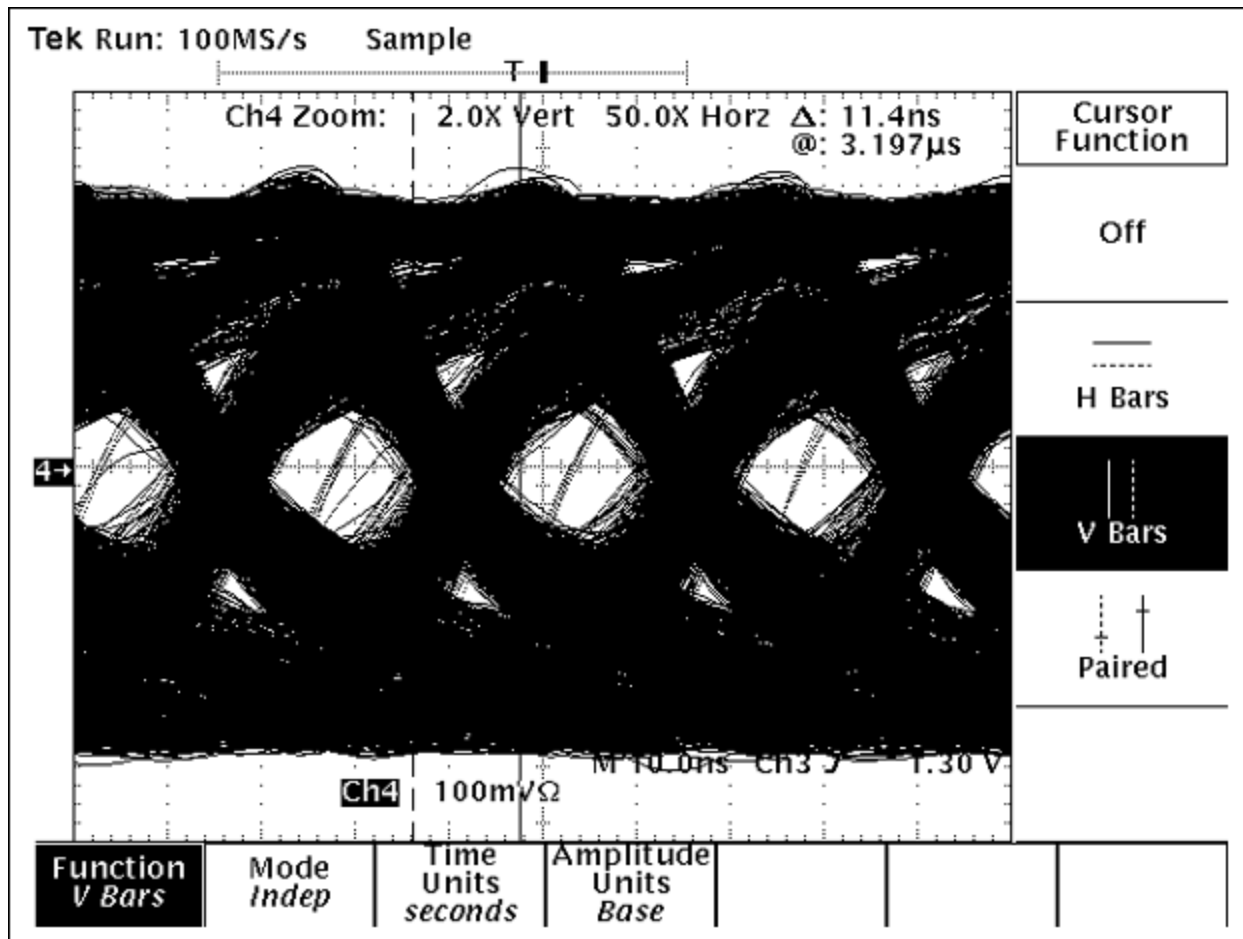


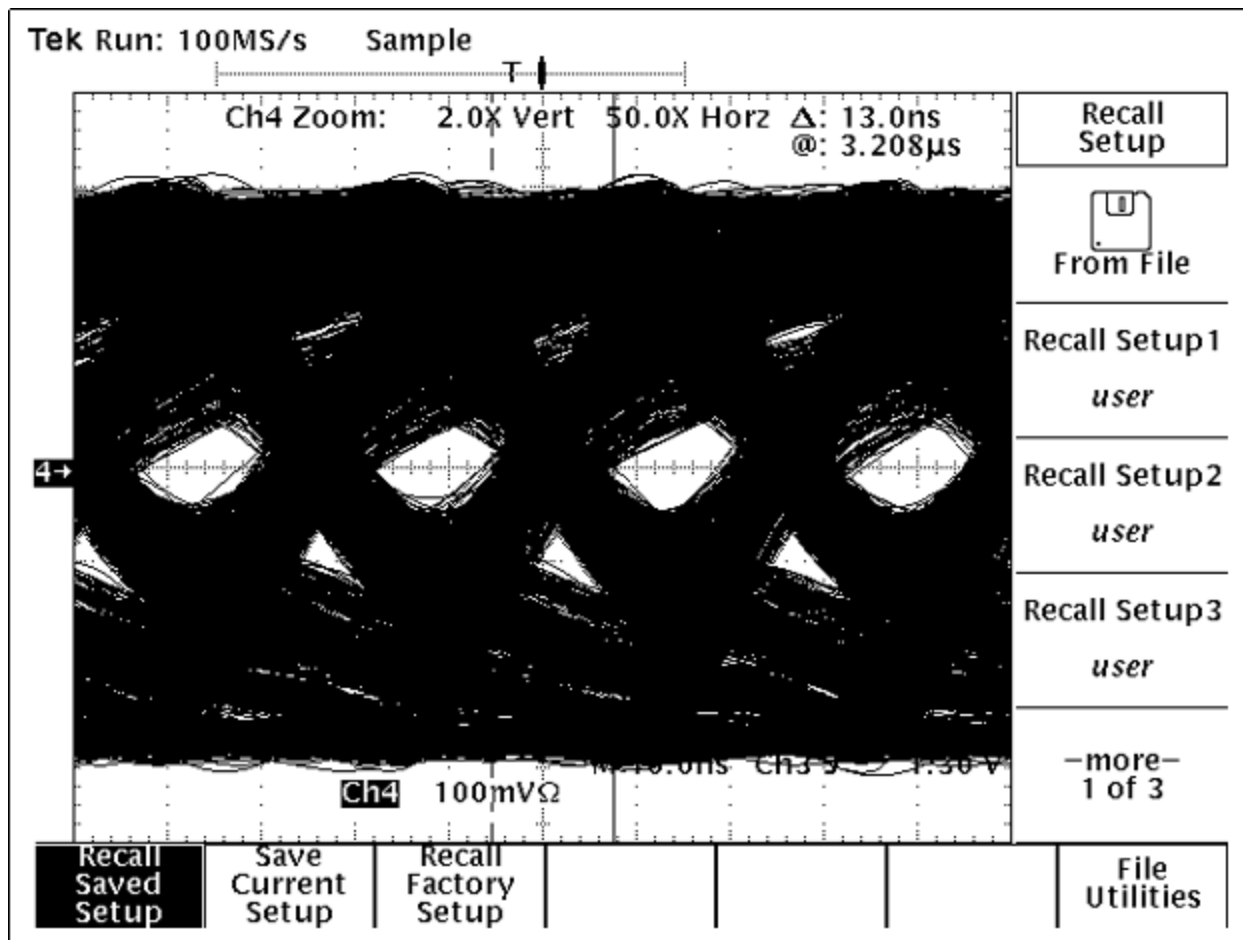Figure 2. Eye pattern for an RS-485 driver device comparable to the MAX3469 from Maxim.[3]

*Figure 3. Eye pattern for Maxim's MAX3469.*

Signal integrity is tested by observing the driver's differential output. Set the oscilloscope to look for trigger points between the 80mV and -400mV thresholds. (These thresholds are chosen because the receivers used in our testing have an input range of 20mV to -200mV, plus a noise margin.) When pulses (bits) begin to "run together", eye patterns can be used to determine the overall contributions of distortion, noise, and attenuation to the parameter called intersymbol interference (ISI).

ISI forces you to reduce the bit rate to a level that allows an adequate distinction between pulses. Tests of the Figure 1 circuit show a consistent and clear correlation between trigger points and eye patterns. The eye patterns exhibit 50% jitter, measured using methods documented in National Semiconductor's application note 977[4]. Data was taken measuring jitter at ±100mV differential (**Figure 4**) and 0V differential (**Figure 5**).
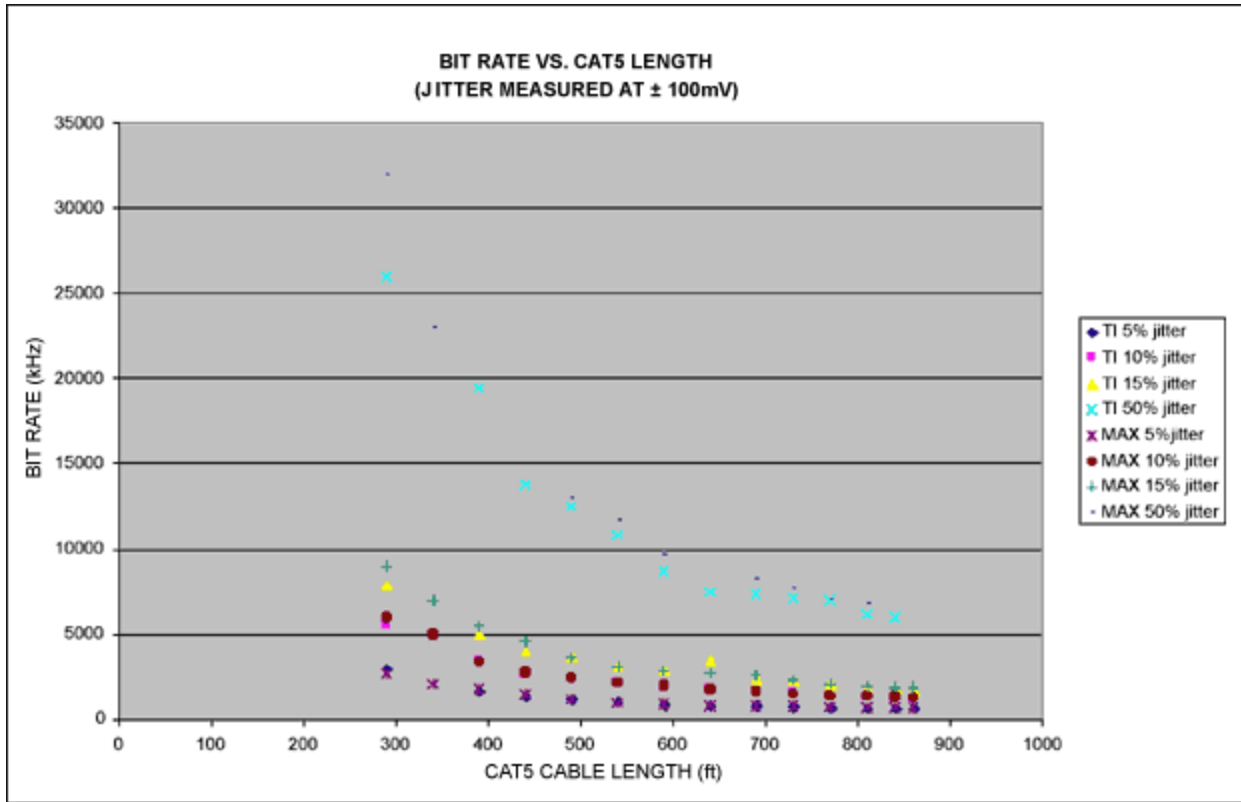
*Figure 4. Graph of jitter for a given bit rate and cable length. Jitter is measured at ±100mV differential.*
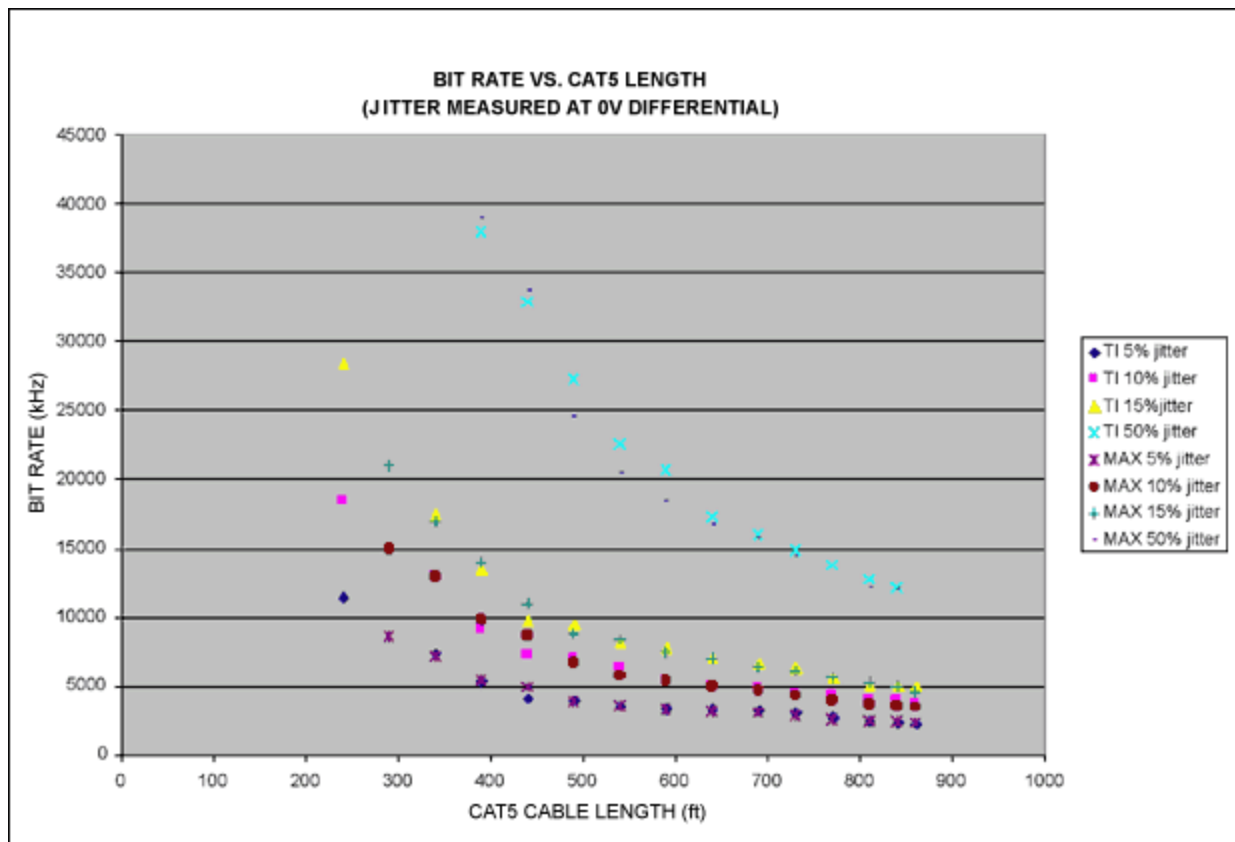
*Figure 5. Graph of jitter for a given bit rate and cable length. Jitter is measured at 0V differential.*

For a given point-to-point connection, the bit rate associated with a particular cable length can be illustrated at ±100mV differential (Figure 4) or 0V differential (Figure 5). Receiver input signals between +100mV and -100mV ensure that the receiver switches properly, because the input thresholds for differential signals are less than 200mV. (The data of **Figure 5** applies only to an ideal receiver, which switches at a 0V differential input.)

## Eye Diagrams and Failure Modes

At 39Mbps and 340 feet of Cat5 cable, the driver output of **Figure 2** exhibits an eye pattern in which signals cross in the middle of the eye—a condition indicating possible bit errors. The Maxim device at the same data rate, however, shows no such condition (**Figure 3**). The Maxim transceiver offers better performance due to symmetrical output edges and lower input capacitance.

The two drivers are comparable for the tests described above. At higher data rates over longer cable lengths, however, the Maxim driver is more robust. **Figure 9** provides an estimate of how fast and how far the Maxim part can drive data in a point-to-point network. Empirically, the appearance of bit errors corresponds approximately to the 50% jitter limit.

## Research Data from Various Sources

Generally accepted industry-wide maximums for distance and data rate are 4000feet and 10Mbps, but (of course) not at the same time. Combining the latest devices with careful system design, however, can provide higher throughput over longer cable lengths.

Preemphasis[5] is a technique that improves data rate vs. distance, and is applicable to RS-485 communications (**Figure 6**). RS-485 transceivers without driver preemphasis or receiver equalization generally acquire 10% jitter across 1700 feet of cable when operating at a fixed data rate of 1Mbps. Adding driver preemphasis at that rate doubles the distance to 3400ft without increasing the jitter. As an alternative, preemphasis can increase the data rate for a given distance. Drivers operating at 400kbps without preemphasis generally acquire 10% jitter over 4000ft. Adding preemphasis lets you transmit up to 800kbps for that distance.
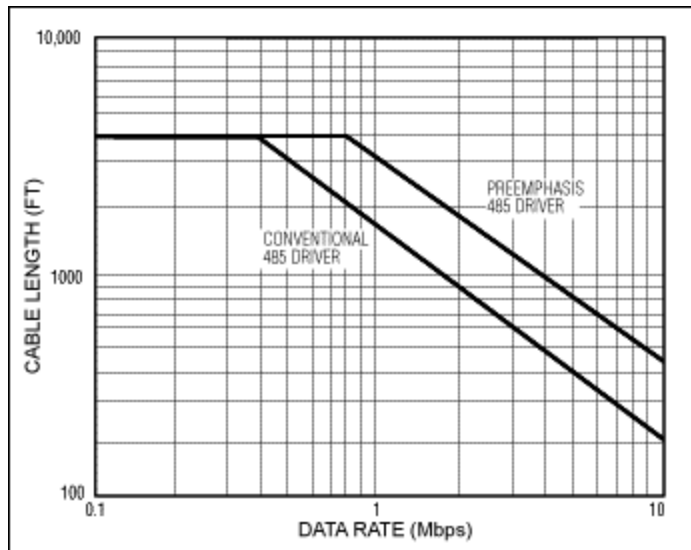


*Figure 6. Original Standard: Data rate vs. cable length.*

Another way to calculate maximum cable length for reliable transmissions is to use the attenuation vs. frequency table supplied by the manufacturer for Cat5 cable. A general rule for allowable attenuation is -6dBV over the run of cable. That value can be combined with the manufacturer's attenuation data to calculate maximum cable length for a given frequency.

## MAX14783E

The MAX14783E is designed for high-speed (up to 42Mbps) multidrop operation with high ESD protection of up to ±35kV HBM. With a 12kΩ input impedance, this device allows up to 32 transceivers (loads) on the bus. Maintaining multidrop operation and increasing the maximum data rate offers a more robust system design for reliable communication.

## MAX22500E

The MAX22500E, MAX22501E, and MAX22502E are point-to-point, half-(MAX22500E/MAX22501E) and full-duplex (MAX22502E) transceivers with integrated preemphasis (MAX22500E and MAX22502E only) optimized for up to 100Mbps data rates.

The MAX22500E (**Figure 6**) features the degree of preemphasis interval that is set by an external resistor. The logic interface is powered on a separate supply from the RS-485 transceiver, allowing for flexible logic levels between 1.8V and 5V.

The MAX22501E (**Figure 7**) does not include preemphasis or flexible logic levels, but offers a simple high-speed RS-485 interface capable of data rates up to 100Mbps. This product is best suited for electrically short cable runs, where the benefits of preemphasis are negligible.
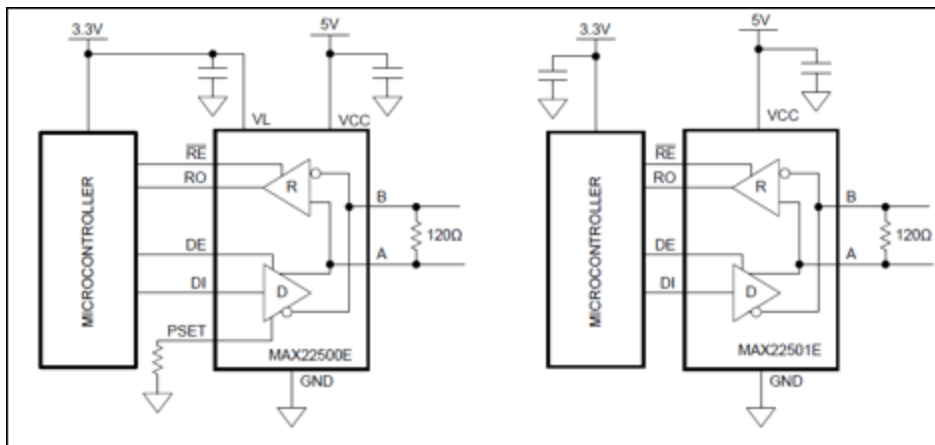
*Figure 7. MAX22500E and MAX22501E application circuits.*

MAX22502E (**Figure 8**) is a full-duplex transceiver capable of the same 100Mbps maximum data rate as MAX22500E and MAX22501E. It also features the integrated preemphasis that is set with an external resistor.
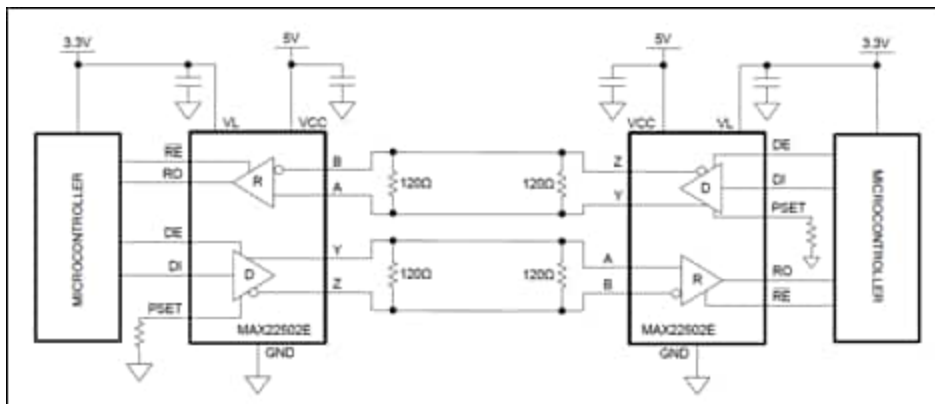


*Figure 8. MAX22502E application circuit.*

The need for preemphasis depends on the cable length. Long cables can distort signals at the receiving end, resulting in ISI. Preemphasis reduces ISI by boosting the differential signal amplitude at every transition edge, counteracting the high-frequency attenuation of the cable. Preemphasis is not required on short cables, but only minimally degrades the jitter on eye diagrams when using short cables. Note that data taken from MAX22500E in **Figure 8** demonstrates this relationship. These tests show the maximum data rate that can be transmitted over a length of TIA/EIA-568-B Cat6 cable while maintaining a bit-error rate less than one error per 100 million bits (BER<1E-08).
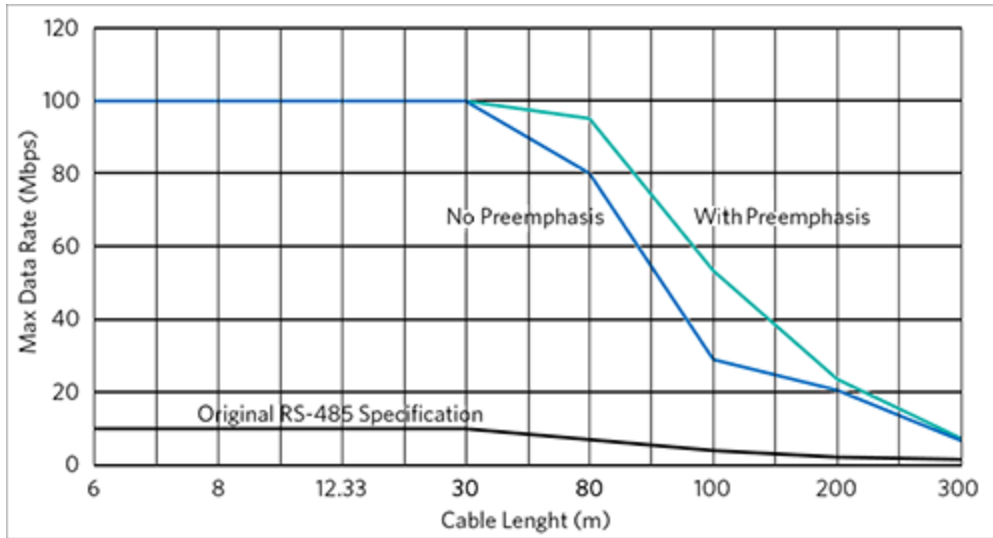
*Figure 9. Maximum data rate vs. cable length data from MAX22500E.*

## Tips and Tricks

Available RS-485 transceivers have several features that can enhance system performance:

- Preemphasis: Reduces ISI for communication over longer distances.
- Reduced unit-load receivers: Low-load devices are available down to 1/8 unit load, enabling up to 256 devices on one bus. Such devices also enable lower bus loading, which, in turn, allows a longer cable or higher data rate.
- High-speed devices: Currently available drivers are capable of data rates up to 100Mbps, with special attention to low propagation delay and low skew.
- ESD protection: This does not enhance data rate, but can be the difference between a working system and one with a data rate of zero (broken). Available devices offer built-in ESD protection to ±35kV.
- Proper wiring[6]: RS-485 specifies differential transmission, which requires two signal wires in addition to a ground wire (commonly a 24AWG twisted pair) to transmit the signal. The two signal wires carry signals differentially, and greatly reduce the problems of radiated EMI and EMI pickup due to the excellent common mode rejection. The common characteristic impedance of this wire is between $100\Omega$ and $120\Omega$, which is also the resistance used to terminate each end of the cable—in the interest of reducing reflections and other transmission-line effects. **Figures 10** and **11** illustrate properly wired systems.
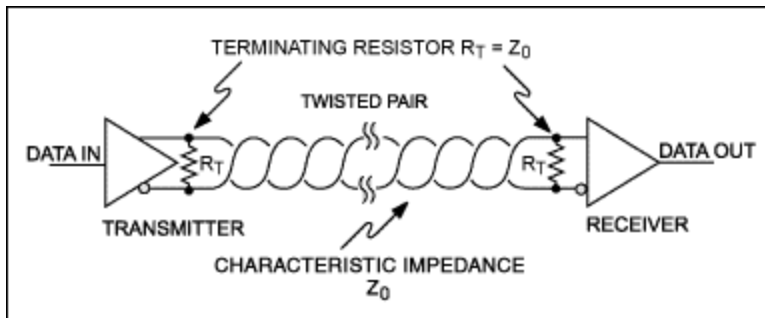

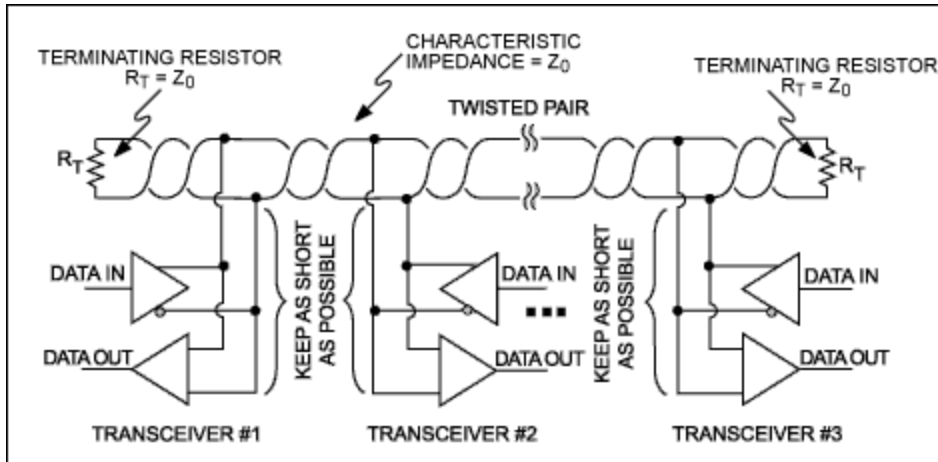*Figure 10. Single transmit, single receive network.*

*Figure 11. Multiple-transceiver network.*

## Conclusion

RS-485 networks can achieve reliable data transmissions in electrically noisy environments. By considering the trade-off between data rate and cable length, you can design a system that achieves data rates in excess of 100Mbps over cable lengths of hundreds of meters, and without repeaters.

**References**

1. For more general information, see the Maxim application note 736, "RS-485 Differential Data Transmission System Basics."
2. See the Maxim application note 1833, "Using RS-485/RS-422 Transceivers in Fieldbus Networks."
3. See the Texas Instruments *Databook*, "Data Transmission Circuits, Vol. 1," 1995/1996, pp. 4-9 to 4-24, and 4-37 to 4-48.
4. See Texas Instruments SNLA166, "LVDS Signal Quality: Jitter Measurements Using Eye Patterns Test Report #1."
5. For a more detailed discussion, see Maxim's application note 643, "Preemphasis Improves RS-485 Communications."
6. See the Maxim application note 763, "Guidelines for Proper Wiring of an RS-485 Network."

| Related Parts | | |
|---|---|---|
| MAX14783E | High-Speed 3.3V/5V RS-485/RS-422 Transceiver with ±35kV HBM ESD Protection | Free Samples |
| MAX22500E | 100Mbps Half-Duplex RS-485/RS-422 Transceivers for Long Cables | Free Samples |
| MAX22501E | 100Mbps Half-Duplex RS-485/RS-422 Transceivers for Long Cables | Free Samples |
| MAX22502E | 100Mbps Full-Duplex RS-485/RS-422 Transceiver for Long Cables | Free Samples |
| MAX3469 | +5V, Fail-Safe, 40Mbps, PROFIBUS RS-485/RS-422 | Free Samples |

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