Theory Relating to:

# Serial Data Analysis

# Part 0

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**Eric Hamilton**

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[1] `$Header: d:/Binder4/sda0/RCS/SDA0.tex,v 1.2 2008-12-03 11:39:15-08 Hamilton Exp Hamilton $`

# 1 Protocol Standards

**"The great thing about standards is there are so many to choose from."**

This statement was made at a recent conference on fiber optics, and it holds true for electrical-interface standards as well. As serial-data standards tend to evolve separately within particular industries, we thus have more standards than we should.

The original RS standards were developed jointly by two, or more (their names have changed over the years), trade associations: the Electronic Industries Association (EIA) and the Telecommunications Industry Association (TIA). The EIA once labeled all its standards with the prefix "RS" (Recommended Standard). Many engineers continue to use this designation, but the EIA/TIA has officially replaced "RS" with "EIA/TIA" to help identify the origin of its standards. Today, various extensions of the RS-485 standard accommodate a large variety of applications.

There are several oscilloscope pictures in this note. They all show the same D Protocol command, Zoom In, with differing areas set up for measuring with the built in cursors of the oscilloscope.

In the following oscilloscope pictures, this is the description for the three displayed traces:

| Trace | Use |
|---|---|
| 1 | RS-422 + signal |
| 2 | RS-422 – signal |
| 3 | RS-232 signal |

Table 1: RS-232 *vs.* RS-422 Signals with a D Protocol "Zoom In" command

## 1.1 RS-232

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 to 20kbps, later enhanced to 1Mbps. Other RS-232 specifications include nominal ±5V transmit and ±3V receive (space/mark), 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, not multidroppable. Any RS-232 system must accommodate these constraints.

The RS-232 link was initially intended to support modem and printer applications on IBM PCs, however, it now enables a variety of peripherals to communicate with PCs. The RS-232 standard was defined as a single-ended standard for increasing serial-communication distances at low baud rates (<20kbps). Over the years the standard changed to accommodate faster drivers some of which offer 1Mbps data-rate capability. For RS-232 compliance, a transceiver must meet the electrical specifications listed in Table 2, page 3.

[2] `$Header: d:/Binder4/sda0/RCS/RSTypes.inc,v 1.3 2008-12-03 11:39:14-08 Hamilton Exp Hamilton $`

| RS-232 Summary of Major Electrical Specifications | | | | |
|---|---|---|---|---|
| Parameter | Conditions | Min | Max | Units |
| Driver Output Voltage, Open Circuit | | | 25 | V |
| Driver Output Voltage, Loaded | 3kΩ $< R_L <$ 7kΩ | ±5 | ±15 | V |
| Driver Output Resistance, Power Off | -2V < V < 2V | | 300 | Ω |
| Slew Rate | | 4 | 30 | V/$\mu$s |
| Maximum Load Capacitance | | | 2500 | pF |
| Receiver Input Resistance | | 3 | 7 | kΩ |
| Receiver Input Threshold: | | | | |
| Output = Mark (Logic 1) | | -3 | | V |
| Output = Space (Logic 0) | | | 3 | V |

Table 2: RS-232 Parameters

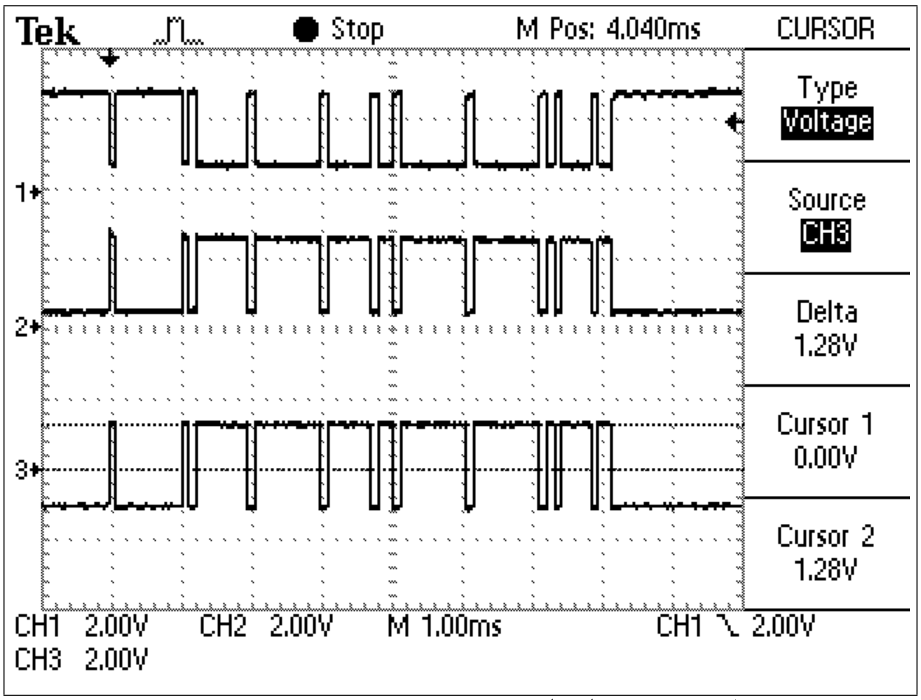


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Figure 1: RS-232, ground to high

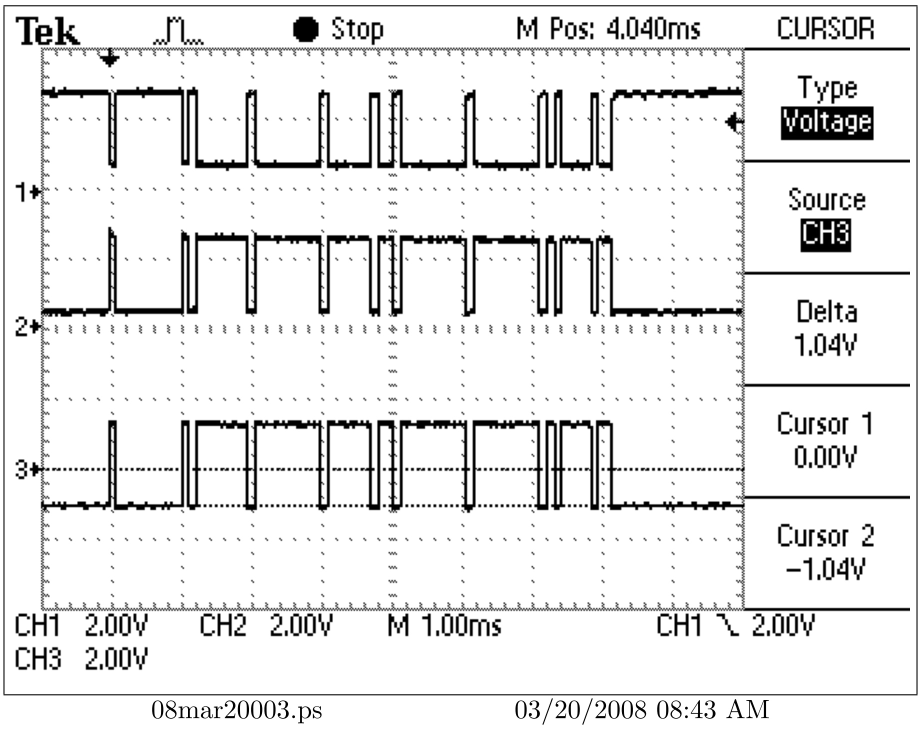


Figure 2: RS-232, ground to low

## 1.2 RS-422

RS-422 is a differential standard that allows transmission over much greater distances than RS-232 does. The higher input resistance of RS-422 inputs, combined with their higher drive capability, allows a connection of up to ten nodes. Another RS-422 advantage is the separate transmit and receive paths for which no direction control is needed. Any necessary handshaking between devices can be performed with software.

| **RS-422 Summary of Key Specifications** | | | | |
|---|---|---|---|---|
| Parameter | Conditions | Min | Max | Units |
| Driver Output Voltage, Open Circuit | | | ±10 | V |
| Driver Output Voltage, Loaded | $R_L = 100\Omega$ | 2<br>-2 | | V |
| Driver Output Resistance | A to B | | 100 | Ω |
| Driver Output Short-Circuit Current | Per output to common | | 150 | mA |
| Driver Output Rise Time | $R_L = 100\Omega$ | | 10 | % of bit width |
| Driver Common-Mode Voltage | $R_L = 100\Omega$ | | ±3 | V |
| Receiver Sensitivity | $V_{CM} < \pm 7$V | | ±200 | mV |
| Receiver Common-Mode Voltage Range | | -7 | 7 | V |
| Receiver Input Resistance | | 4 | | kΩ |
| Differential Receiver Voltage | Operational | | ±10 | V |
| | Withstand | | ±12 | V |

Table 3: RS-422 Parameters

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.

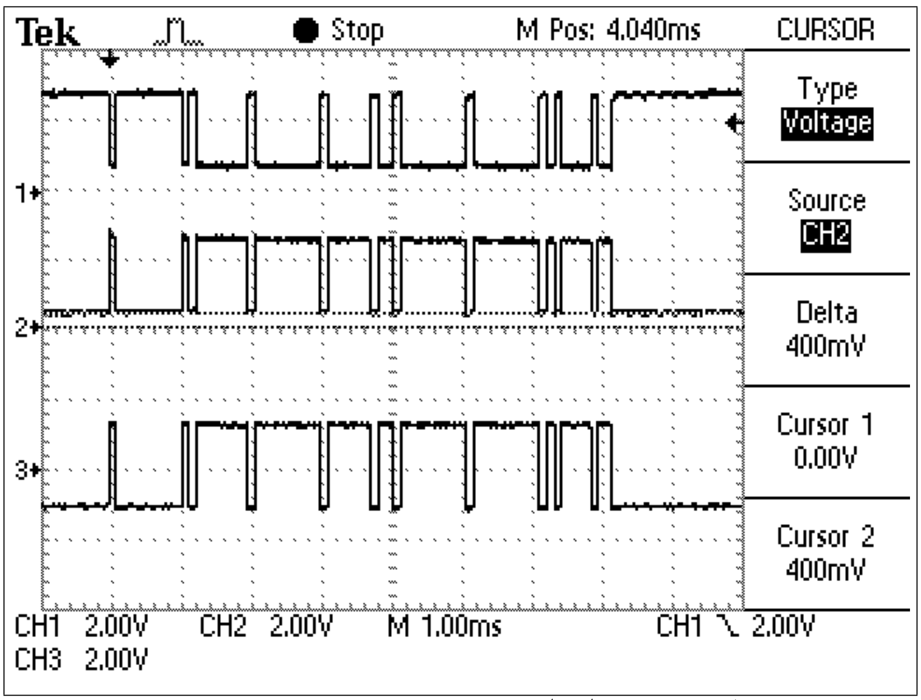


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Figure 3: RS-422–, ground to low

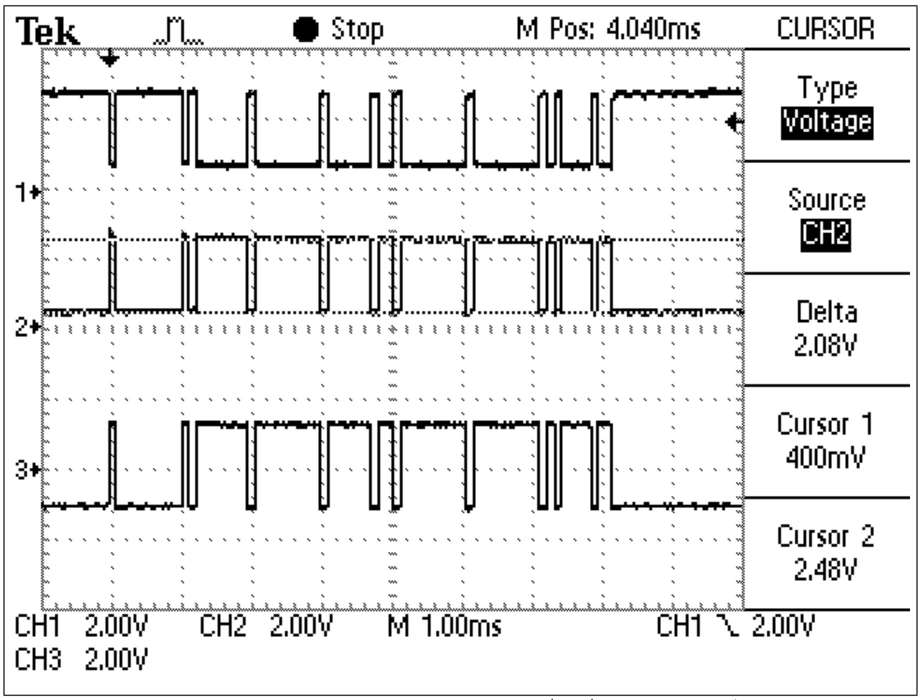


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Figure 4: RS-422–, low to high

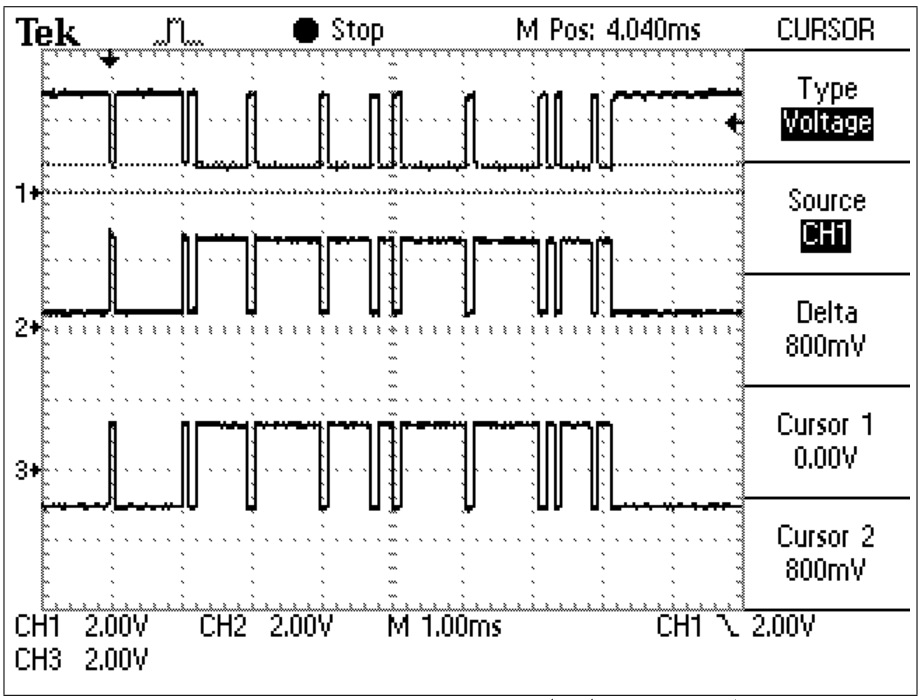


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Figure 5: RS-422+, ground to low

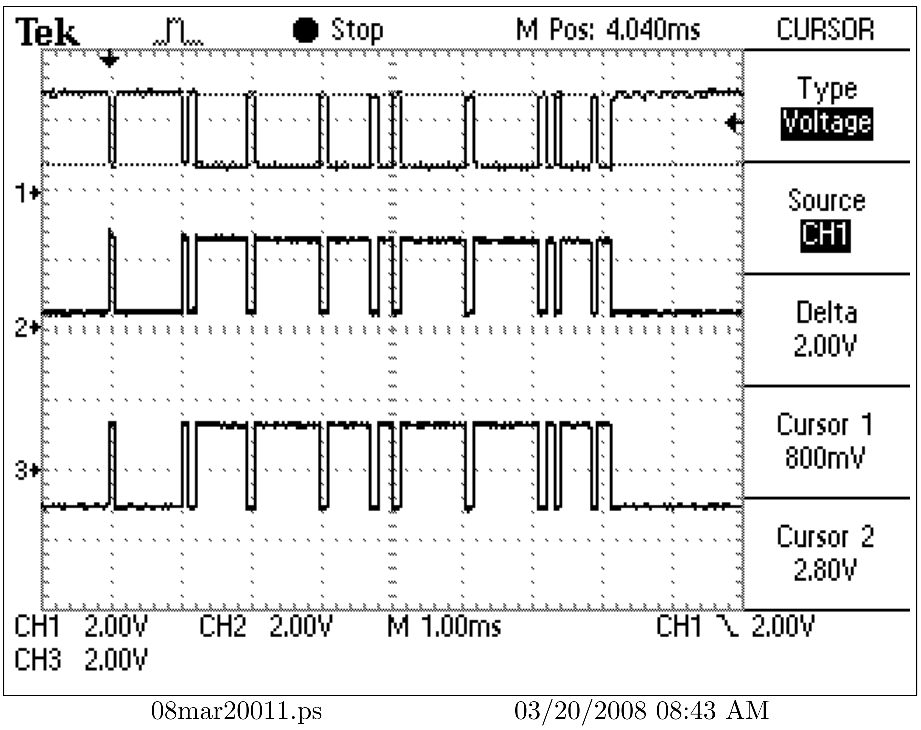


Figure 6: RS-422+, low to high

## 1.3 RS-485

RS-485 is a bidirectional, half-duplex standard featuring multiple ‘bussed’ drivers and receivers, in which each driver can relinquish the bus. It meets all RS-422 specifications, but is more robust. It has a higher receiver-input impedance and larger common-mode range (-7V to +12V).

| **RS-485 Summary of Key Specifications** | | | | |
|---|---|---|---|---|
| Parameter | Conditions | Min | Max | Units |
| Driver Output Voltage, Open Circuit | | 1.5<br>-1.5 | 6<br>-6 | V<br>V |
| Driver Output Voltage, Loaded | $R_L = 100\Omega$ | 1.5<br>-1.5 | 5<br>-5 | V<br>V |
| Driver Output Short-Circuit Current | Per output to common | | ±250 | mA |
| Driver Output Rise Time | $R_L = 54\Omega$<br>$C_L = 50\text{pF}$ | | 30 | % of bit width |
| Driver Common-Mode Voltage | $R_L = 54\Omega$ | | ±3 | V |
| Receiver Sensitivity | -7V < $V_{CM}$ < 12V | | ±200 | mV |
| Receiver Common-Mode Voltage Range | | -7 | 12 | V |
| Receiver Input Resistance | | | 12 | kΩ |

Table 4: RS-485 Parameters

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. Minimum receiver input impedance is 12kΩ, and the driver output voltage is ±1.5V minimum, ±5V maximum.

Drive capacity is 32 unit loads, i.e., 32 12kΩ receivers in parallel. For receivers of higher input impedance, the number of unit loads on one bus can be higher. 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 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 has become the best choice 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 receivers' higher input impedance allows more devices to be dropped on the lines.

RS-485 proper wiring: RS-485 specifies differential transmission, which requires two signal wires in addition to a ground wire (commonly a 24 AWG twisted pair) to transmit the signal. The two signal wires carry signals opposite in polarity, and greatly reduce the problems of radiated EMI and EMI pickup. The common characteristic impedance of this wire is 120Ω which is also the resistance used to terminate each end of the cable — in the interest of reducing reflections and other transmission-line effects.

RS-422 and RS-485 transceivers are often confused with each other; one is assumed to be a full-duplex version of the other. The electrical differences, however, in their common-mode ranges and receiver-input resistances make these standards suitable for different applications. As RS-485 meets all the RS-422 specifications, RS-485 drivers can be used in RS-422 applications. The opposite, however, is not true. The common-mode output range for RS-485 drivers is -7V to +12V, whereas the common-mode range for RS-422 drivers is only ±3V. The minimum receiver-input resistance is 4kΩ for RS-422 drivers and 12k for RS-485 drivers.

Differential RS-485 transmissions produce opposing currents and magnetic fields along each segment (wire) of a twisted-pair cable, thus minimizing the emitted electromagnetic interference (EMI) by cross-canceling the opposing fields around each wire. For transmissions through a long cable or at high data rates, the cable appears as a transmission line and should be terminated with the cable's characteristic impedance. This aspect of the RS-485 connection causes confusion. Does the line need to be terminated, and if so, how should it be terminated? If the designer is not the end user, should these questions be left for the installer to resolve? For most RS-485 transceivers, the simple choice between no termination and a simple point-to-point termination when the cable acts as a transmission line is to install a termination resistor across the A-B terminals is harmless. By default, the transmission line should be terminated at the last transceiver on the line (bus).

The load presented to an RS-485/RS-422 driver is quantified in terms of the unit load, which is defined as the input impedance for one standard RS-485 receiver (12kΩ). Thus, a standard RS-485 driver is capable of driving 32 unit loads (32 12kΩ loads in parallel) or 375Ω. The input impedance for certain RS-485 receivers is 48kΩ (1/4 unit load) or even 96kΩ (1/8 unit load), and as many as 128 or 256 respective receivers, can be connected to a single RS-485 bus. Any combination of receiver types can be connected together, provided their parallel impedance does not exceed 32 unit loads ($R_{Load} > 375\Omega$).

RS-485 is designed to be a balanced system. Simply put, this means there are two wires, other than ground, that are used to transmit the signal.

The system is called balanced, because the signal on one wire is ideally the exact opposite of the signal on the second wire. In other words, if one wire is transmitting a high, the other wire will be transmitting a low, and vice versa.

### 1.3.1 Fail-Safe

Deciding whether you need a termination resistor or not is only part of the problem in implementing an RS-485 system. Normally, an RS-485 receiver output is "1" if A > B by +200mV or more, and "0" if B > A by 200mV or more. In a half-duplex RS-485 network, the master transceiver tri-states the bus after transmitting a message to the slaves. Then, with no signal driving the bus, the receiver's output state is undefined, as the difference between A and B tends towards 0V. If the receiver output, RO, is "0," the slaves interpret it as a new start bit and attempt to read the following byte. The result is a framing error because the stop bit never occurs. The bus goes unclaimed, and the network stalls.

Unfortunately, different runs of chips can produce different output signals on RO for a 0V differential input. The prototype can work perfectly, however, certain nodes will fail in a later production run. To solve this problem, bias the bus. Biasing the bus ensures that the receiver output remains "1" when the bus is tri-stated.

## 1.4 Termination Resistors

Because of the high frequencies and the distances involved, proper attention must be paid to transmission-line effects. A thorough discussion of transmission-line effects and proper termination techniques is, however, are well beyond the scope of this application note. With this in mind, terminations will be briefly discussed in their simplest form as they relate to RS-485.

A terminating resistor is simply a resistor placed at the extreme end or ends of a cable. The value of the terminating resistor is ideally the same value as the characteristic impedance of the cable.

Knowing this about reflections, it is important to match the terminating resistance and the characteristic impedance as closely as possible. The position of the terminating resistors is also very important. Termination resistors should always be placed at the far ends of the cable.

As a general rule moreover, termination resistors should be placed at both far ends of the cable. Although properly terminating both ends is absolutely critical for most system designs, it can be argued that in one special case only one termination resistor is needed. This case occurs in a system when there is a single transmitter and that single transmitter is located at the far end of the cable. In this case there is no need to place a termination resistor at the end of the cable with the transmitter, because the signal is intended to always travel away from this end of the cable.

RS-485 receivers have no defined output for input levels between -200mV and +200mV. For the condition of 0V on the RS-485 side, a logic "High" is as probable on a receiver's TTL side as is a logic "Low". That ambiguity is present in a half-duplex connection if no master is transmitting or if the line has a loose connection. Placing a termination network at each end of the bus ensures defined output levels for non-failsafe PROFIBUS RS-485 transceivers.

## 1.5 Characteristic Impedance of Twisted-Pair Wire

Depending on the geometry of the cable and the materials used in the insulation, twisted-pair wire will have a "characteristic impedance" associated with it that is usually specified by its manufacturer. The RS-485 specification recommends, but does not specifically dictate, that this characteristic impedance be 120Ω. Recommending this impedance is necessary to calculate worst-case loading and common- mode voltage ranges given in the RS-485 specification. The specification probably does not dictate this impedance in the interest of flexibility. If for some reason 120Ω cable cannot be used, it is recommended that the worst-case loading (the number of transmitters and receivers that can be used) and worst-case common-mode voltage ranges be recalculated to make sure that the system under design will work. The industry-standard publication TSB89, Application Guidelines for TIA/EIA-485-A, has a section specifically devoted to those calculations.

## 1.6 RS-xxx comparisons

The RS-485 and RS-422 standards share many of the same attributes, and are often confused for that reason. The table below compares the different standards. The RS-485, which specifies bi-directional and half-duplex data transmission, is the only EIA/TIA standard that allows multiple receivers and drivers in "bus" configurations. Conversely RS-422 EIA/TIA standard specifies a single, unidirectional driver with multiple receivers. Therefore RS-485 parts are backward compatible and interchangeable with their RS-422 counterparts. However, RS-422 drivers should not be used in an RS-485 system for they cannot relinquish control of the bus. A side-by-side comparison of the various RS types are listed in Table 5, page 14.

| **RS-232, RS-422 and RS-485 Standards** | | | |
|---|---|---|---|
| | RS-232 | RS-422 | RS-485 |
| Mode of operation | Bipolar Unidirectional Multipoint | Differential Unidirectional Multipoint | Differential Full Duplex Multipoint |
| Allowed no. of Tx and Rx | 1 Tx, 10? Rx | 1 Tx, 10 Rx | 32 Tx, 32 Rx |
| Maximum cable length | 100ft length | 4000ft length | 4000ft length |
| Maximum data rate | 1Mbps | 10Mbps | 10Mbps |
| Minimum driver output range | $\pm$5V | $\pm$2V | $\pm$1.5V |
| Maximum driver output range | $\pm$15V | $\pm$5V | $\pm$5V |
| Maximum driver short-circuit current | — mA | 150mA | 250mA |
| Tx load impedance | — Ω | 100Ω | 54Ω |
| Rx input sensitivity | $> \pm$3V | $\pm$200mV | $\pm$200mV |
| Maximum Rx input resistance | $3 \rightarrow 7$kΩ | 4kΩ | 12kΩ |
| Rx input voltage range | $\pm 3 \rightarrow \pm 15$V | $\pm$7V | -7V to +12V |
| Rx logic high | >3V | >200mV | >200mV |
| Rx logic low | <3V | <200mV | <200mV |

Table 5: Comparisons between the different RS-xxx standards

## 1.7 Where Do the Protocols Best Fit?

1. RS-232: communication with modems, printers, and other PC peripherals. The typical maximum cable length is 100ft.

2. RS-422: industrial environments that require only one bus master (driver). Typical applications include process automation (chemicals, brewing, paper mills), factory automation (autos, metal fabrication), HVAC, security, motor control, and motion control.

3. 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.

## 1.8 References

This data was extracted from the following documents:

Application Note 723: `http://www.maxim-ic.com/an723`
Application Note 736: `http://www.maxim-ic.com/an736`
Application Note 763: `http://www.maxim-ic.com/an763`
Application Note 1833: `www.maxim-ic.com/an1833`
Application Note 3884: `www.maxim-ic.com/an3884`

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