Application Report

The RS-485 Design Guide

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ABSTRACT

As a short compendium for successful data transmission design, this application report discusses the important aspects of the RS-485 standard.

Trademarks

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1 Introduction

In 1983, the Electronics Industries Association (EIA) approved a new balanced transmission standard called RS-485. Finding widespread acceptance and usage in industrial, medical, and consumer applications, RS-485 has become the industry's interface workhorse.

This application report presents design guidelines for engineers new to the RS-485 standard that can help them accomplish a robust and reliable data transmission design in the shortest time possible.

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2 Standard and Features

RS-485 is an electrical-only standard. In contrast to complete interface standards, which define the functional, mechanical, and electrical specifications, RS-485 only defines the electrical characteristics of drivers and receivers that could be used to implement a balanced multipoint transmission line.

This standard, however, is intended to be referenced by higher level standards, such as DL/T645, for example, which defines the communication protocol for electronic energy-meters in China, specifying RS-485 as the physical layer standard.

Key features of RS-485 are:

- Balanced interface
- Multipoint operation from a single 5-V supply
- –7-V to +12-V bus common-mode range
- Up to 32 unit loads
- 10-Mbps maximum data rate (at 40 feet)
- 4000-foot maximum cable length (at 100 kbps)

3 Network Topology

The RS-485 standards suggests that its nodes be networked in a daisy-chain, also known as party line or bus topology (see Figure 3-1. In this topology, the participating drivers, receivers, and transceivers connect to a main cable trunk via short network stubs. The interface bus can be designed for full-duplex or half-duplex transmission (see Figure 3-2).

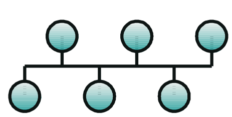


Figure 3-1. RS-485 Bus Structure

The full-duplex implementation requires two signal pairs, (four wires), and full-duplex transceivers with separate bus access lines for transmitter and receiver. Full-duplex allows a node to simultaneously transmit data on one pair while receiving data on the other pair.

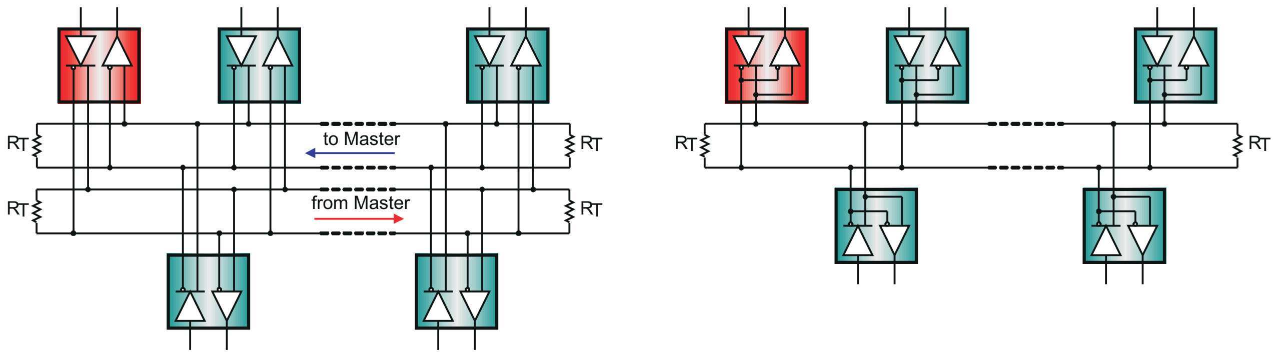


Figure 3-2. Full-Duplex and Half-Duplex Bus Structures in RS-485

In half-duplex, only one signal pair is used, requiring the driving and receiving of data to occur at different times. Both implementations necessitate the controlled operation of all nodes via direction control signals, such as Driver/Receiver Enable signals, to ensure that only one driver is active on the bus at any time. Having more than one driver accessing the bus at the same time leads to bus contention, which, at all times, must be avoided through software control.

4 Signal Levels

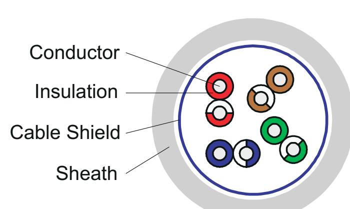
RS-485 standard conform drivers provide a differential output of a minimum 1.5 V across a 54-Ω load, whereas standard conform receivers detect a differential input down to 200 mV. The two values provide sufficient margin for a reliable data transmission even under severe signal degradation across the cable and connectors. This robustness is the main reason why RS-485 is well suited for long-distance networking in noisy environment.

Figure 4-1. RS-485 Specified Minimum Bus Signal Levels

5 Cable Type

RS-485 applications benefit from differential signaling over twisted-pair cable, because noise from external sources couple equally into both signal lines as common-mode noise, which is rejected by the differential receiver input.

Industrial RS-485 cables are of the sheathed, unshielded, twisted-pair type, (UTP), with a characteristic impedance of 120 W and 22–24 AWG. Figure 5-1 shows the cross-section of a four-pair, UTP cable typically used for two full-duplex networks. Similar cables, in two-pair and single-pair versions, are available to accommodate the low-cost design of half-duplex systems.



Cable :	Belden 3109A
Type :	4 - pair, 22 AWG PLCT/CM
Impedance :	120 Ω
Capacitance :	11 pF/ft
Velocity :	78% (1.3 ns/ft)

Figure 5-1. Example of RS-485 Communication Cable

Beyond the network cabling, it is mandatory that the layout of printed-circuit boards and the connector pin assignments of RS-485 equipment maintain the electrical characteristics of the network by keeping both signal lines close and equidistant to another.

6 Bus Termination and Stub Length

Data transmission lines should always be terminated and stubs should be as short as possible to avoid signal reflections on the line. Proper termination requires the matching of the terminating resistors, R_T, to the characteristic impedance, Z0, of the transmission cable. Because the RS-485 standard recommends cables with Z_0 = 120 W, the cable trunk is commonly terminated with 120-W resistors, one at each cable end (see Figure 6-1, left).

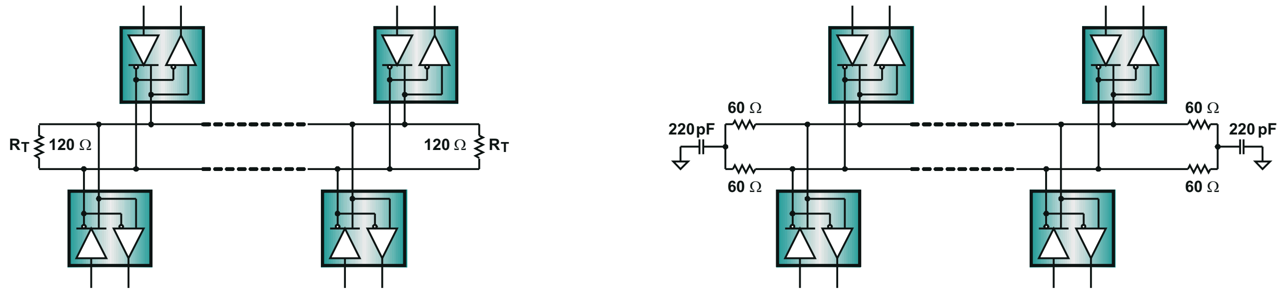


Figure 6-1. Proper RS-485 Terminations

Applications in noisy environments often have the 120-Ω resistors replaced by two 60-Ω, low-pass filters to provide additional common-mode noise filtering, (see Figure 6-1, right). It is important to match the resistor values, (preferably with 1% precision resistors), to ensure equal rolloff frequencies of both filters. Larger resistor tolerances, (i.e., 20%), cause the filter corner frequencies to differ and common-mode noise to be converted into differential noise, thus compromising the receiver's noise immunity.

The electrical length of a stub, (the distance between a transceiver and cable trunk), should be shorter than 1/10 of the driver's output rise time, and is given through:

$$L_{Stub} \leq \frac{t_r}{10} \times v \times c \tag{1}$$

Where:

- L_{Stub} = maximum stub length (ft)
- t_r = driver (10/90) rise time (ns)
- v = signal velocity of the cable as factor of c
- c = speed of light (9.8 x 10^8 ft/s).

Table 6-1 lists the maximum stub lengths of the cable in Figure 5-1, (78% velocity), for various driver rise times.

Table 6-1. Stub Length Versus Rise Time

DEVICE	SIGNAL RATE [kbps]	RISE TIME t_r [ns]	MAXIMUM STUB LENGTH [ft]
SN65HVD12	1000	100	7
SN65LBC184	250	250	19
SN65HVD3082E	200	500	38

Note

Drivers with long rise times are well suited for applications requiring long stub lengths and reduced, device-generated EMI.

7 Failsafe

Failsafe operation is a receiver's ability to assume a determined output state in the absence of an input signal.

Three possible causes can lead to the loss of signal (LOS):

1. **Open-circuit**, caused by a wire break or by the disconnection of a transceiver from the bus
2. **Short-circuit**, caused by an insulation fault connecting the wires of a differential pair to another

3. **Idle-bus**, occurring when none of the bus drivers is active.

Because these conditions can cause conventional receivers to assume random output states when the input signal is zero, modern transceiver designs include biasing circuits for open-circuit, short-circuit, and idle-bus failsafe, that force the receiver output to a determined state, under an LOS condition.

A drawback of these failsafe designs is their worst-case noise margin of 10 mV only, thus requiring external failsafe circuitry to increase noise margin for applications in noisy environments.

An external failsafe circuit consists of a resistive voltage divider that generates sufficient differential bus voltage, to drive the receiver output into a determined state. To ensure sufficient noise margin, V_{AB} must include the maximum differential noise measured in addition to the 200-mV receiver input threshold, V_{AB} = 200 mV + V_{Noise}.

$$R_B = \frac{V_{BUS\text{-}mim}}{V_{AB} \times (1/375 + 4/Z_0)} \tag{2}$$

For a minimum bus voltage of 4.75 V, (5 V – 5%), V_{AB} = 0.25 V, and Z_0 = 120 W, R_B yields 528 W. Inserting two 523-W resistors in series to R_T establishes the failsafe circuit shown in Figure 7-1.

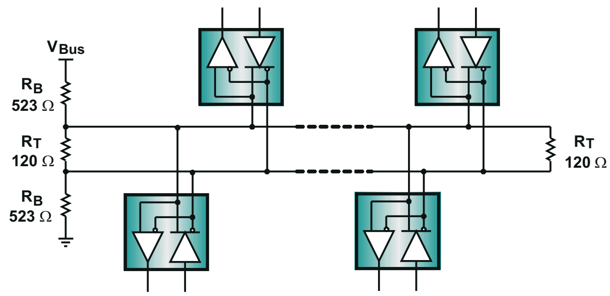


Figure 7-1. External Idle-Bus Failsafe Biasing

8 Bus Loading

Because a driver's output depends on the current it must supply into a load, adding transceivers and failsafe circuits to the bus increases the total load current required. To estimate the maximum number of bus loads possible, RS-485 specifies a hypothetical term of a unit load (UL), which represents a load impedance of approximately 12 kW. Standard-compliant drivers must be able to drive 32 of these unit loads. Today's transceivers often provide reduced unit loading, such as 1/8 UL, thus allowing the connection of up to 256 transceivers on the bus.

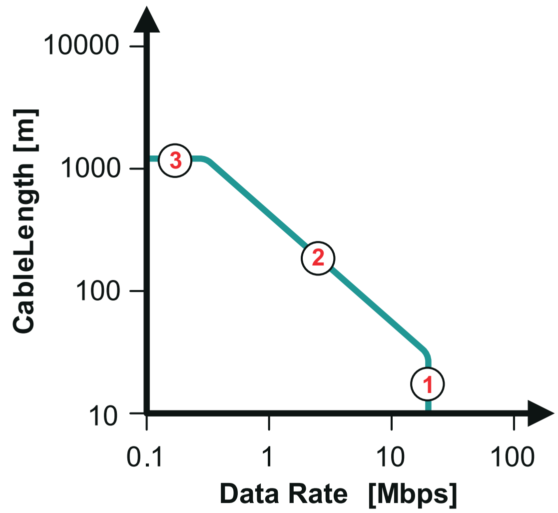
Because failsafe biasing contributes up to 20 unit loads of bus loading, the maximum number of transceivers, N, is reduced to:

$$N = \frac{32\ UL_{STANDARD} - 20\ UL_{FAILSAFE}}{UL\ per\ transceiver} \tag{3}$$

Thus, when using 1/8-UL transceivers, it is possible to connect up to a maximum of 96 devices to the bus.

9 Data Rate Versus Bus Length

The maximum bus length is limited by the transmission line losses and the signal jitter at a given data rate. Because data reliability sharply decreases for a jitter of 10% or more of the baud period, Figure 9-1 shows the cable length versus data rate characteristic of a conventional RS-485 cable for a 10% signal jitter.



A. Section 1 of the graph presents the area of high data rates over short cable length. Here, the losses of the transmission line can be neglected and the data rate is mainly determined by the driver's rise time. Although the standard recommends 10 Mbps, today's fast interface circuits can operate at data rates of up to 40 Mbps.

B. Section 2 shows the transition from short to long data lines. The losses of the transmission lines have to be taken into account. Thus, with increasing cable length, the data rate must be reduced. A rule of thumb states that the product of the line length [m] times the data rate [bps] should be < 10^7. This rule is far more conservative than today's cable performance and will therefore show less length at a given data rate than the graph presents.

C. Section 3 presents the lower frequency range where the line resistance, and not the switching, limits the cable length. Here, the cable resistance approaches the value fo the termination resistor. This voltage divider diminishes the signal by -6 dB. For a 22 AWG cable, 120 W, UTP, this occurs at approximately 1200 m.

Figure 9-1. Cable Length Versus Data Rate

10 Minimum Node Spacing

The RS-485 bus is a distributed parameter circuit whose electrical characteristics are primarily defined by the distributed inductance and capacitance along the physical media, which includes the interconnecting cables and printed-circuit board traces.

Adding capacitance to the bus in the form of devices and their interconnections lowers the bus impedance and causes impedance mismatches between the media and the loaded section of the bus. Input signals arriving at these mismatches are partially reflected back to the signal source distorting the driver output signal.

Ensuring a valid receiver input voltage level during the first signal transition from an output driver anywhere on the bus requires a minimum loaded bus impedance of $Z' > 0.4 \times Z_0$, which can be achieved by keeping the minimum distance, d, between bus nodes:

$$d > \frac{C_L}{5.25 \text{ x } C'} \quad (4)$$

Where C_L is the lumped load capacitance and C, the media capacitance (cable or PCB trace) per unit length.

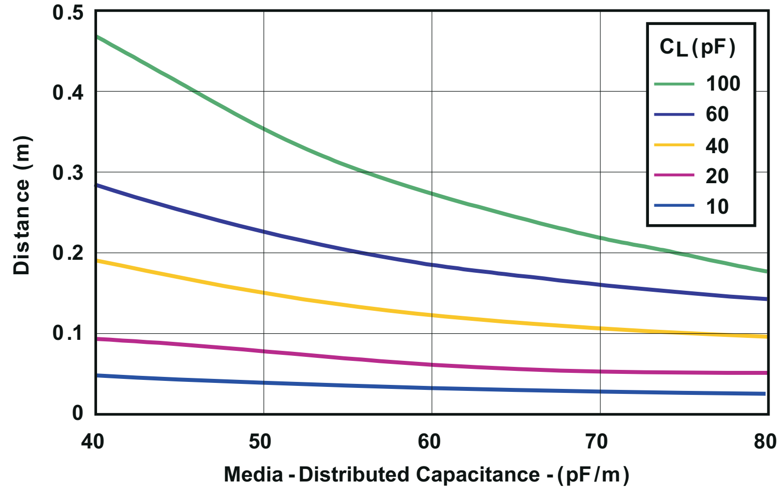


Figure 10-1. Minimum Node Spacing With Device and Media Capacitance

Equation 4 presents the relationship for the minimum device spacing as a function of the distributed media and lumped-load capacitance; Figure 10-1 shows this relationship graphically.

Load capacitance includes contributions from the line circuit bus pins, connector contacts, printed-circuit board traces, protection devices, and any other physical connections to the trunk line as long as the distance from the bus to the transceiver (the stub) is electrically short.

Putting some values to the individual capacitance contributions:

- 5-V transceivers typically possess a capacitance of 7 pF, whereas 3-V transceivers have approximately twice that capacitance at 16 pF. Board traces add approximately 0.5 to 0.8 pF/cm depending on their construction. Connector and suppression device capacitance can vary widely. Media distributed capacitance ranges from 40 pF/m for low capacitance, unshielded, twisted-pair cable to 70 pF/m for backplanes.

11 Grounding and Isolation

When designing a remote data link, the designer must assume that large ground potential differences (GPD) exist. These voltages add as common-mode noise, Vn, to the transmitter output. Even if the total superimposed signal is within the receiver's input common-mode range, relying on the local earth ground as a reliable path for the return current is dangerous (see Figure 11-1a).

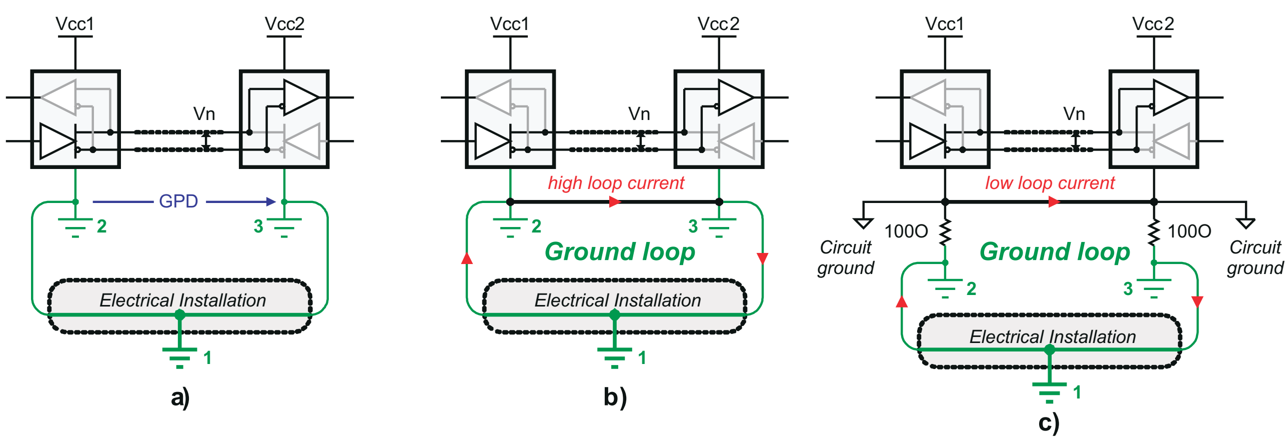


Figure 11-1. Design Pitfalls to be Aware off: a) High GPD, b) High Loop Current, c) Reduced Loop Current, Yet Highly Sensitive to Induced Noise Due to Large Ground Loop

Because remote nodes are likely to draw their power from different sections of the electrical installation, modification to the installation, (i.e., during maintenance work), can increase the GPD to the extent that the receiver's input common-mode range is exceeded. Thus, a data link working today might cease operation sometime in the future.

The direct connection of remote grounds through ground wire also is not recommended (see Figure 11-1b), as this causes large ground loop currents to couple into the data lines as common-mode noise.

To allow for a direct connection of remote grounds, the RS485 standard recommends the separation of device ground and local system ground via the insertion of resistors (Figure 11-1c). Although this approach reduces loop current, the existence of a large ground loop keeps the data link sensitive to noise generated somewhere else along the loop. Thus, a robust data link has not been established yet.

The approach to tolerate GPDs up to several kilovolts across a robust RS-485 data link and over long distance is the galvanic isolation of the signal and supply lines of a bus transceiver from its local signal and supply sources (see Figure 11-2).

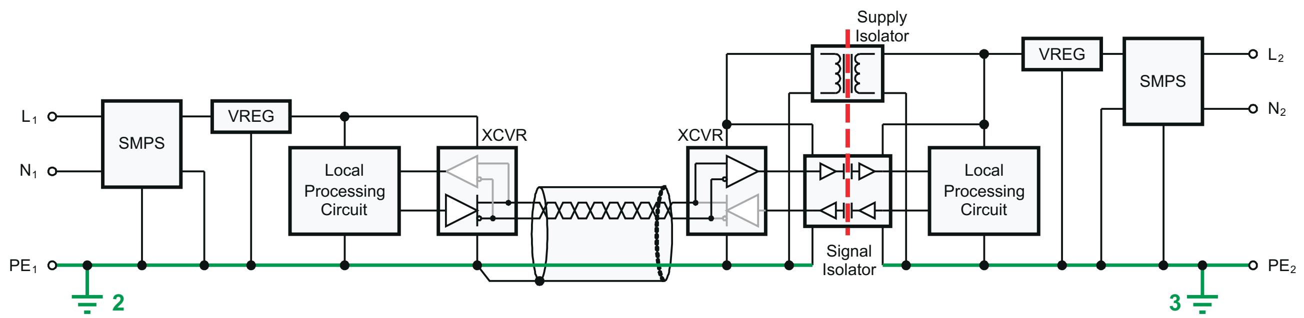


Figure 11-2. Isolation of Two Remote Transceiver Stations With Single-Ground Reference

In this case, supply isolators, such as isolated DC/DC converters, and signal isolators, such as digital, capacitive isolators, prevent current flow between remote system grounds and avoid the creation of current loops.

Whereas Figure 11-2 shows the detailed connection of only two transceiver nodes, Figure 11-3 gives an example for multiple, isolated transceivers. All transceivers but one connect to the bus via isolation. The non-isolated transceiver on the left provides the single-ground reference for the entire bus.

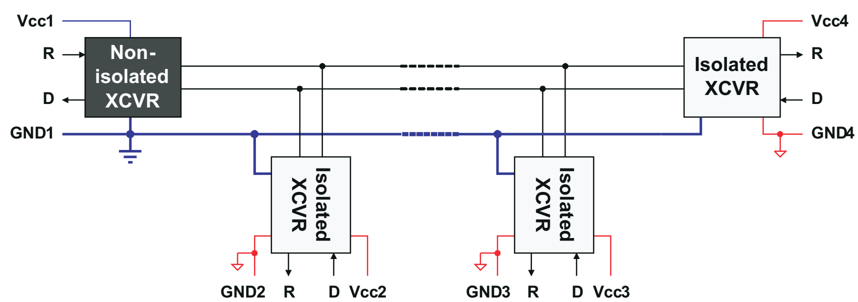


Figure 11-3. Isolation of Multiple Fieldbus Transceiver Stations

12 Conclusion

The objective of this application report is to cover the main aspects of an RS-485 system design. Despite the enormous amount of technical literature on the subject, this document's intent is to provide system designers new to RS-485 with design guidelines in a very comprehensive way.

Following the discussions presented in this document and consulting the detailed application reports in the reference section can help accomplishing a robust, RS-485-compliant system design in the shortest time possible.

Supporting the design effort, Texas Instruments provides an extensive product range of RS-485 transceivers. Device features include low EMI, low-power (1/8 UL), high ESD protection (from 16 kV up to 30 kV), and integrated failsafe functions for open-, short- and idle-bus conditions. For long-distance applications requiring isolation, the product range extends to unidirectional and bidirectional, digital isolators in dual, triple and quad versions (from DC to 150 Mbps), and isolated DC/DC converters
(with 3-V and 5-V regulated outputs), to provide the power supply across the isolation barrier.

12.1 References

Further information is available at www.ti.com by entering the blue literature numbers that follow into the Keyword Search field.

1. *Removing Ground Noise in Data Transmission Systems* application report (SLLA268)
2. *Interface Circuits for TIA/EIA-485 (RS-485)* design notes (SLLA036)
3. *Detection of RS-485 Signal Loss*, TI Analog Application Journal, 4Q 2006 (SLYT257)
4. *Overtemperature Protection in RS-485 Line Circuits* application report (SLLA200)
5. *Device Spacing on RS-485 Buses*, TI Analog Application Journal, 2Q 2006 (SLYT241)
6. *PROFIBUS Electrical-Layer Solutions* application report (SLLA177)
7. *A Statistical Survey of Common-Mode Noise*, TI Analog Application Journal, Nov 2000 (SLYT153)
8. *Failsafe in RS-485 Data Buses*, TI Analog Application Journal, 3Q 2004 (SLYT080)
9. *The RS-485 Unit Load and Maximum Number of Bus Connections*, TI Analog Application Journal, 1Q 2004 (SLYT086)
10. *Using Signaling Rate and Transfer Rate* application report (SLLA098)
11. *Operating RS-485 Transceivers at Fast Signaling Rates* application report (SLLA173)
12. *RS-485 for E-Meter Applications* application report (SLLA112)
13. *Failsafe in RS-485 Data Buses*, TI Analog Application Journal, 3Q 2004 (SLYT064)
14. *Use Receiver Equalization to Extend RS-485 Data Communication*s application report (SLLA169)
15. *The RS-485 Unit Load and Maximum Number of Bus Connections* application report (SLLA166)
16. *Comparing Bus Solutions* application report (SLLA067)
17. *RS-485 for Digital Motor Control Applications* application report (SLLA143)
18. *422 and 485 Standards Overview and System Configurations* application report (SLLA070)
19. *TIA/EIA-485 and M-LVDS, Power and Speed Comparison* application report (SLLA106)
20. *Live Insertion with Differential Interface Products* application report (SLLA107)
21. *The ISO72x Family of High-Speed Digital* Isolators application report (SLLA198)

13 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (October 2016) to Revision D (May 2021)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document	1

Changes from Revision B (May 2008) to Revision C (October 2016)	Page
• Changed Data Rate [bps] To: Data Rate [Mbps} in Figure 9-1	4

Application Report

SNLA034B–August 1993–Revised April 2013

AN-903 A Comparison of Differential Termination Techniques

ABSTRACT

The purpose of this application report is to remove some of the confusion that may surround signal termination. This discussion will focus attention upon signal termination only as it applies to differential data transmission over twisted pair cable. Common differential signal termination techniques will be presented and the advantages and disadvantages of each will be discussed.

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1 Introduction

Transmission line termination should be an important consideration to the designer who must transmit electrical signals from any point A to any point B. Proper line termination becomes increasingly important as designs migrate towards higher data transfer rates over longer lengths of transmission media. However, the subject of transmission line termination can be somewhat confusing since there are so many ways in which a signal can be terminated. Therefore, the advantages and disadvantages of each termination option are not always obvious.

This application report will discuss differential signal termination techniques. Each discussion will also include a sample waveform generated by a setup consisting of a function generator whose signals are transmitted across a twisted pair cable by a differential line driver and sensed at the far end by a differential line receiver. This application report will specifically address the following differential termination options:

- Unterminated
- Series/Backmatch
- Parallel
- AC
- Power (Failsafe)
- Alternate Failsafe
- Bi-Directional

For the purposes of discussion, popular TIA/EIA-422 drivers and receivers, such as the DS26LS31 and DS26LS32A, will be used to further clarify differential termination.

2 Unterminated

The selection of one termination option over another is oftentimes dictated by the performance requirements of the application. The selection criteria may also hinge upon other factors such as cost. From this cost perspective the option of not terminating the signal is clearly the most cost effective solution. Consider Figure 1, where a DS26LS31 differential driver and a DS26LS32A differential receiver have been connected (using a twisted pair cable) together without a termination element. Because there is no signal termination element, the DS26LS31 driver's worst case load is the DS26LS32A receiver's minimum input resistance.

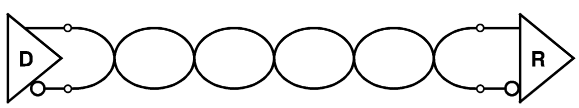


Figure 1. Unterminated Configuration

Since, TIA/EIA-422-A (RS-422) standard defines the DS26LS32A's minimum input resistance to be 4 kΩ, the driver's worst case load, as seen in Figure 1, is then 4 kΩ.

In the unterminated configuration, the DS26LS31 driver is only required to source a minimal amount of current in order to drive a signal to the receiver. This minimal DC current sourcing requirement in turn minimizes the driver's on chip power dissipation. In addition, the 4 kΩ driver output load results in a higher driver output swing (than if the driver was loaded with 100Ω) which in turn increases DC noise margin. This increase in noise margin further diminishes the possibility that system noise will improperly switch the receiver. To be sure that there is no confusion, noise margin is defined as the difference between the minimum driver output swing and the maximum receiver sensitivity. On the other hand, if a receiver was used which complies to TIA/EIA-485 (RS-485), the resulting noise margin would be even greater. This is because the minimum input resistance of an RS-485 receiver must be greater than 12 kΩ as compared to 4 kΩ for an RS-422 receiver.

The absence of a termination element at the DS26LS32A's inputs also ensures that the receiver output is in a known logic state when the transmission line is in the idle or open line state (receiver dependent). This condition is commonly referred to as open input receiver failsafe. This receiver failsafe bias is ensured by internal pull up and pull down resistors on the positive and negative receiver inputs, respectively. These pull up and pull down resistors bias the input differential voltage (V_{ID}) to a value greater than 200 mV when the line is, for example, idle (un-driven). This bias is significant in that it represents the minimum ensured V_{ID} required to switch the receiver output into a logic high state.

NOTE: A complete discussion of receiver failsafe can be found in the *AN-847 FAILSAFE Biasing of Differential Buses Application Report* (SNLA031).

There are, however, some disadvantages with an unterminated cable. The most significant effect of unterminated data transmission is the introduction of signal reflections onto the transmission line. Basic transmission line theory states that a signal propagating down a transmission line will be reflected back towards the source if the outbound signal encounters a mismatch in line impedance at the far end. In the case of Figure 1, the mismatch occurs between the characteristic impedance of the twisted pair (typically 100Ω) and the 4 kΩ input resistance of the DS26LS32A. The result is a signal reflection back towards the driver. This reflection then encounters another impedance mismatch at the driver outputs which in turn generates additional reflections back toward the receiver, and so on. The net result is a number of reflections propagating back and forth between the driver and receiver. These reflections can be observed in Figure 2.

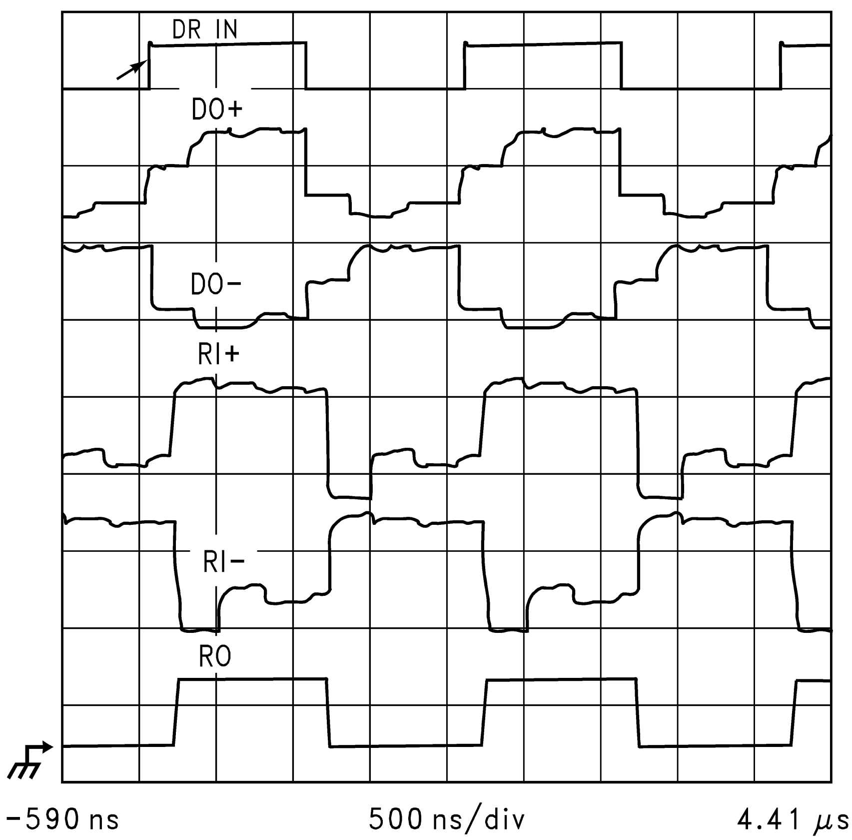


Figure 2. Unterminated Waveforms

The main limitation of unterminated signals can be clearly seen in Figure 2. A positive reflection is generated when the signal encounters the large input resistance of the receiver. These reflections propagate back and forth until a steady state condition is reached after several round trip cable delays. The delay is a function of the cable length and the cable velocity. Figure 2 shows that the reflections settle after three round trips. To limit the effect of these reflections, unterminated signals should only be used in applications with low data rates and short driving distances.

The data being transmitted should, therefore, not make any transitions until after this steady state condition has been reached. A low data rate ensures that reflections have sufficient time to settle before the next signal transition. At the same time, a short cable length ensures that the time required for the reflections to settle is kept to a minimum. The low data rate and short cable length dictated by the lack of termination is probably the most significant shortcoming of the unterminated option.

Low speed is generally characterized to be either signaling rates below 200 kbits/sec or when the cable delay (the time required for an electrical signal to transverse the cable) is substantially shorter than the bit width (unit interval) or when the signal rise time is more than four times the one way propagation delay of the cable (that is, not a transmission line). As a general rule, if the signal rise time is greater than four times the propagation delay of the cable, the cable is no longer considered a transmission line.

It should be mentioned that most differential data transmission applications provide for some kind of signal termination. This is because most differential applications transmit data at relatively high transfer rates over relatively long distances. In these type of applications, signal termination is critically important. If the application only requires low speed operation over short distances, an unterminated transmission line may be the simplest solution.

3 Series Termination

Another termination option is popularly known as either series or backmatch termination. Figure 3 shows this type of termination. The termination resistors, R_S, are chosen such that their value plus the impedance of the driver's output equal the characteristic impedance of the cable. Now as the driven signal propagates down the transmission line an impedance mismatch is still encountered at the far end of the cable (receiver inputs).

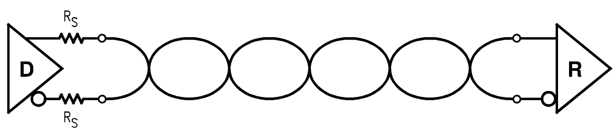


Figure 3. Series Termination Configuration

However, when that signal propagates back to the driver the reflection is terminated at the driver output. There is only one reflection before the driven signal reaches a steady state condition. How long it takes for the driven signal to reach steady state is still dependent upon the length of cable the signal must traverse. As with the unterminated option the driver power dissipation is still minimized due to the light loading presented by the 4 kΩ receiver input resistance. The driver loading remains unchanged from the unterminated option. In both cases the driver is effectively loaded with the receiver's input impedance. DC noise margin has again increased and the open input receiver failsafe feature is still supported for idle and open line conditions.

There are three major disadvantages in using series termination. First, the driver output impedances can vary, due to normal process variations, from one manufacturer to another and from one driver load to another. Should there be a problem which involves replacing line drivers, there is a chance that the designer might have to rework the board in order to ensure that the R_S matches the new driver's output impedance.

Second, series termination is commonly limited to only point to point applications. Consider the following example. If a second receiver (multidrop application) was located halfway between the driver and receiver at the far end of the cable, the noise margin seen by the middle receiver would change between the incident signal and the reflected signal. Such a problem would not exist in a point to point application where only one receiver is used with one driver.

Third, there is still an impedance mismatch at the receiver inputs. Again, this mismatch is caused by a signal propagating down a 100Ω cable suddenly encountering a 4 kΩ receiver input resistance. This impedance mismatch will continue to cause reflections on the transmission line as illustrated in Figure 4.

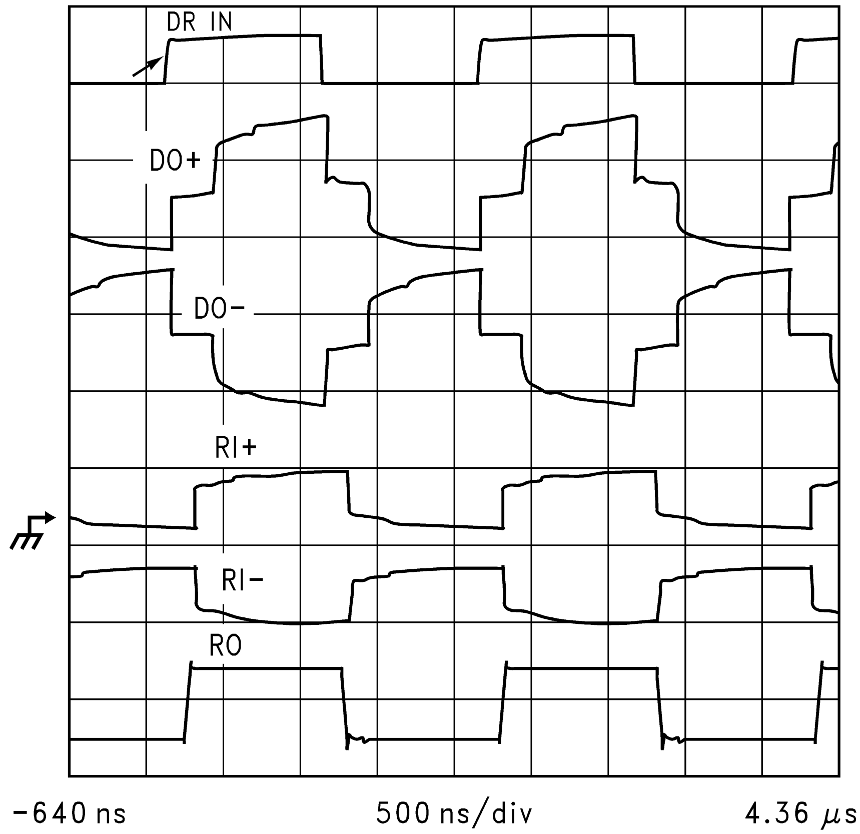


Figure 4. Series Termination Waveforms

Notice the reflections which result when the driven signal encounters an impedance mismatch at the receiver input. The reflection propagates back to the driver and is somewhat terminated by the driver's output impedance. The reflected signal is terminated because the combined impedance of the series resistor (R_S) and the driver's output impedance comes close to matching the characteristic impedance of the cable. In contrast with Figure 2 unterminated signal waveform, the waveform seen in Figure 4 is characterized by only one reflection.

In all it will take the signal one round trip cable delay to be reflected back towards the signal source. Since all reflections should be allowed to settle before the next data transition (to maintain data integrity), it is imperative that the round trip cable delay be kept much less than the time unit interval (TUI—defined to be the minimum bit width or the “distance” between signal transitions). In other words, series termination should be limited to applications where the cable lengths are short (to minimize round trip cable delays) and the data rate is low (to maximize the TUI). And to a lesser degree, the series termination option may not be the ideal choice from a cost perspective in that it requires two additional external components.

4 Parallel Termination

Parallel termination is arguably one of the most prevalent termination schemes today. In contrast to the series termination option, parallel termination employs a resistor across the differential lines at the far (receiver) end of the transmission line to eliminate all reflections. See Figure 5.

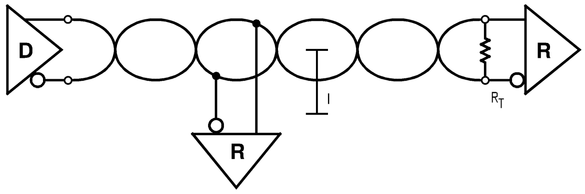


Figure 5. Parallel Termination Configuration

Eliminating all reflections requires that R_T be selected to match the characteristic impedance (Z_O) of the transmission line. As a general rule, however, it is usually better to select $R_T$such that it is slightly greater than Z_O. Over-termination tends to be more desirable than under-termination since over-termination has been observed to improve signal quality. R_T is typically chosen to be equal to Z_O. When over-termination is used R_T is typically chosen to be up to 10% larger than Z_O. The elimination of reflections permits higher data rates over longer cable lengths. Keep in mind, however, that there is an inverse relationship between data rate and cable length. That is, the higher the data rate the shorter the cable and conversely the lower the data rate the longer the cable. Higher data rates and longer cable lengths translate simply into smaller TUI's and longer cable delays. Unlike series termination where high data rates and long cable lengths can negatively impact data integrity, parallel termination can effectively remove all reflections; thereby removing all concerns about reflections interfering with data transitions. See Figure 6.

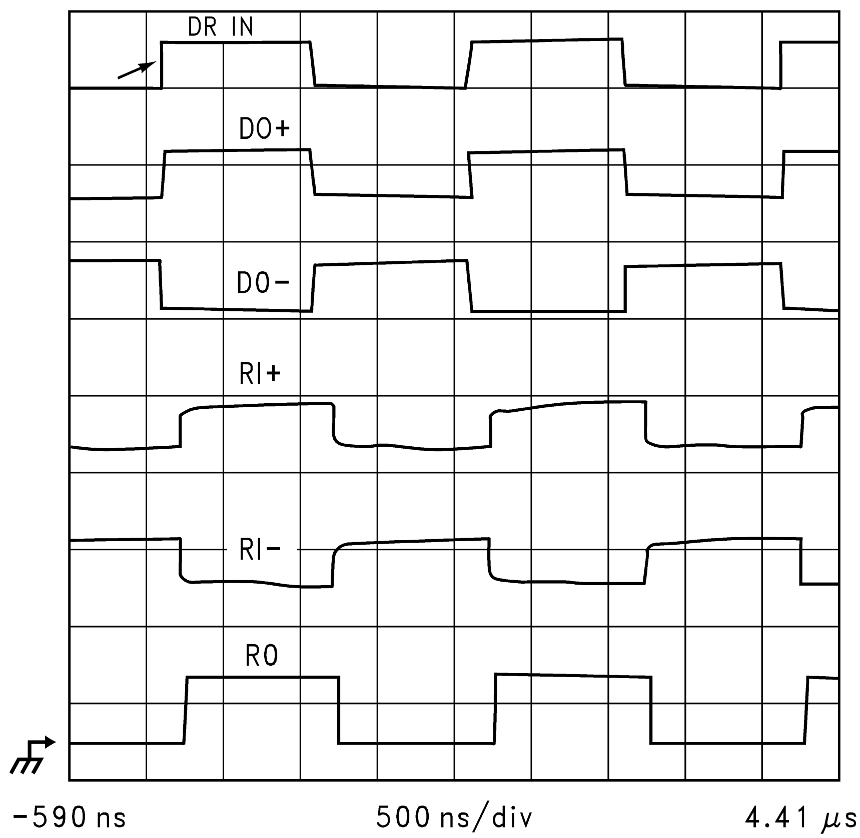


Figure 6. Parallel Termination Waveforms

As seen in Figure 6 both driver output and receiver input signals are free of reflections. Such results make parallel termination optimal for use in either high speed (10 Mb/s), or long cable length (up to 4000 feet), applications.

Another benefit the parallel termination provides is that both point to point and multidrop applications are supported. Recall that multidrop is defined as a distribution system composed of one driver and up to ten receivers spread out along the cable as defined in the TIA/EIA-422 standard. The parallel termination is located at the far end (opposite the driver) of the cable and effectively terminates the signal at that location, preventing reflections.

There are also disadvantages to parallel termination. Let's examine these disadvantages as they pertain to multidrop configurations. An intrinsic assumption to multidrop operation is that stub lengths, as measured by "I" in Figure 5, are minimized. Despite the fact that all receivers are effectively terminated with R_T, long stub lengths will once again reintroduce impedance mis-matches and reflections. So while parallel termination may remove reflections and permit multidrop configurations, it does place a restriction upon the stub lengths associated with these other receivers. Typically stubs should be kept to less that ¼ of the drivers rise time in length to minimize transmission line effects, and reflections.

TIA/EIA-422-A standard does recommend a 100Ω resistor to be used when the differential line is parallel terminated. Therefore, applications which use a TIA/EIA-422-A driver such as the DS26LS31 or DS26C31 are commonly terminated with 100Ω at the far end of the twisted pair cable. While the 100Ω parallel termination eliminates all reflections, the power dissipated by the driver will increase substantially with the addition of this resistor. This increased driver power dissipation is a major disadvantage of parallel termination. The absence of this termination resistor keeps driver power dissipation low for unterminated and series terminated drivers and is a major advantage of these two termination options.

Noise margin will also decrease with parallel termination. The relatively light loading (4 kΩ) of unterminated and series terminated drivers led to larger driver output swings. The heavier driver load (typically 100Ω) brought on by parallel termination reduces the driver's output signal swing. However, even with this reduction, there is ample noise margin left to ensure that the receiver does not improperly switch.

Recall the discussion earlier about receiver failsafe with the unterminated and series options. In both cases, open input receiver failsafe operation was ensured because of internal circuitry (receiver dependent) which biases the differential input voltage (V_{ID}) to a value greater than its differential threshold. Since the resulting bias voltage at the receivers inputs (V_{ID}), is greater than +200 mV, the output of the DS26LS32A receiver remains in a stable HIGH state. Unlike unterminated and series options, parallel termination cannot support open input receiver failsafe when the transmission line is in the idle state. This shortcoming of parallel termination is discussed in much greater detail later in the section which describes power and alternate failsafe termination (see AN-847 [SNLA031] for more of information on failsafe biasing differential buses).

5 AC Termination

The effectiveness of parallel termination is oftentimes countered by increased driver power dissipation and receiver failsafe concerns. The DC loop current required by the termination resistor, R_T (see Figure 5), is often too large in order to be useful for power conscious applications or for seldomly switched control lines. In asynchronous applications, parallel termination's is not able to ensure receiver failsafe during idle bus states which in turn makes the system susceptible to errors such as false start bits and framing errors. The primary reason for the AC termination, however, grew out of the need for effective transmission line termination with minimal DC loop current.

A representation of an AC terminated differential line is shown in Figure 7.

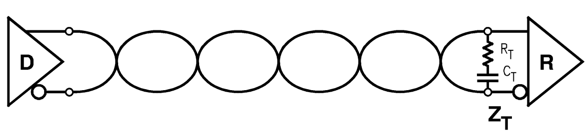


Figure 7. AC Termination Configuration

The value of R_T generally ranges from 100Ω–150Ω (cable Z_O dependent) and is selected to match the characteristic impedance (Z_O) of the cable. C_T, on the other hand, is selected to be equal to the round trip delay of the cable divided by the cable's Z_O.

$$C_T \le (\text{Cable round trip delay}) / Z_O \tag{1}$$

For this example:

Cable Length = 100 feet

Velocity = 1.7 ns/foot

Char. Impedance = 100Ω

Therefore, $C_T \le (100 \text{ ft} \times 2 \times 1.7 \text{ ns/ft})/100\Omega$ or $\le$ 3,400 pF

Further, the resulting R_C time constant should be less than or equal to 10% of the unit interval (TUI). In the example provided the maximum switching rate therefore should be less than 300 kHz. This termination should now behave like a parallel termination during transitions, but yield the expanded noise margins during steady state conditions. See Figure 8.

Figure 8 illustrates the tradeoff between parallel terminated and unterminated signals. There are no major reflections and driver power dissipation is reduced at the expense of a low pass filtering effect which essentially limits the application of AC termination to low speed control lines. Note that the frequency of the driven signal in Figure 8 is 300 kHz whereas it was 500 kHz for the other plots. This was done to maintain the ratio between bit time and the R_C time constant. The draft revision of RS-422-A will include AC termination as an alternative to parallel termination.

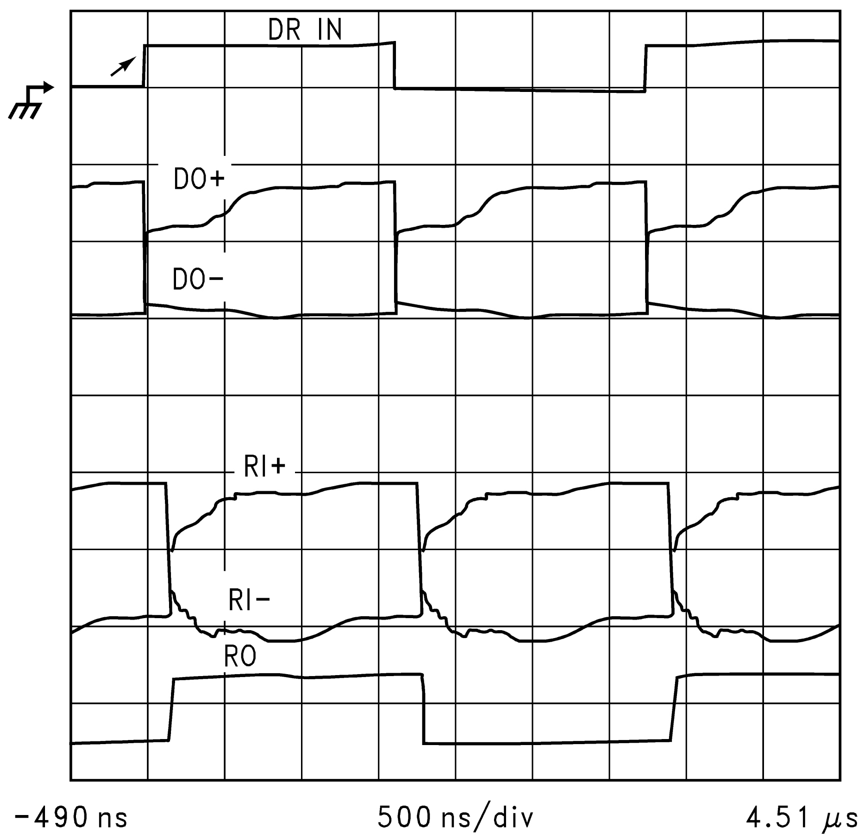


Figure 8. AC Termination Waveforms

The waveforms in Figure 8 should be viewed together with the following brief explanation of how AC termination works. When the driven signal transitions from one logic state to another, the capacitor C_T behaves as a short circuit and consequently, the load presented to the driver is essentially R_T. However, once the driven signal reaches its intended levels, either a logic HIGH or logic LOW, C_T will behave as an open circuit. DC loop current is now blocked. The driver power dissipation will then decrease. The load presented to the driver also decreases. This is due to the fact that the driver is now loaded with a large receiver input resistance typically greater than 4 kΩ; versus the typical R_T of 100Ω–120Ω. This reduced loading condition increases the signal swing of the driver and results in increased noise margin. The idle bus state also forces C_T into the open circuit mode. Once this takes place, the receiver's internal pull up and pull down resistors will bias the output into a known state. Therefore, besides minimizing DC loop current, preventing line reflections, and increasing noise margin, AC termination also supports open input receiver failsafe.

As with all the previously discussed termination options, there are disadvantages in using AC termination. AC termination introduces a low pass filtering effect on the driven signal which tends to limit the maximum data rate of the application. This data rate limitation is the result of the impact that R_T and C_T, together, have upon the driven signal's rise time. How much the data rate is limited is dependent upon the selection of R_T and C_T. Long R_C time constants will have a greater impact upon the driven signal's maximum data rate, and vice versa. Because of these data rate limitations, the transmission lines best suited for AC termination are typically low speed control lines where level sensitivity is desired over edge sensitivity. Finally, the part count required by AC termination can put it at a disadvantage in cost conscious applications.

6 Power Termination

Recall that AC termination is intended primarily to eliminate the large DC loop current inherent in parallel termination. The power termination, on the other hand, addresses parallel termination's inability to support receiver failsafe during the idle bus state. See Figure 9 for an illustration of a transmission line terminated using the power option.

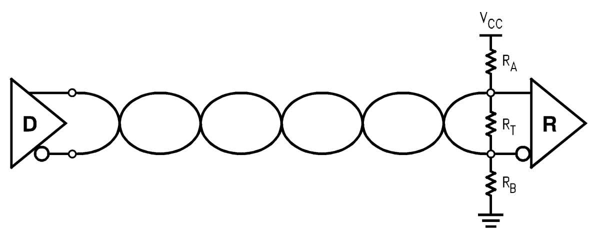


Figure 9. Power Termination Configuration

The lack of R_A and R_B, when the bus is idle, almost assures that the receiver output will not be in a known state. This is due to the insufficient voltage across R_T (on the order of 1 mV–5 mV) as caused by the receiver's internal high value pull up and pull down resistors. The presence of these internal pull up and pull down resistors will ensure receiver failsafe only for the open input condition. In order to switch the receiver into the logic high state, regardless of whether the bus is open or idle, a minimum of +200 mV (with respect to the inverted receiver input) must be developed across R_T. The sole purpose, then, of R_A and R_B is to establish a voltage divider whereby at least +200 mV will be dropped across R_T. A complete explanation of selection criteria for resistor values (R_A and R_B) can be found in AN-847 (SNLA031).

The addition of external receiver failsafe biasing resistors, however, does pose some concerns. The primary drawback relates to the increased driver loading with the addition of R_A and R_B. The increased driver loading decreases the driver's output swing and, in turn, reduces the noise margin. Higher driver power dissipation is also symptomatic of the increased driver loading since the driver must source the additional current required by the external failsafe network. One last concern is that the extra cost and subsequent handling of two additional resistors (excluding R_T) might outweigh power termination's advantages in some applications.

7 Alternate-Failsafe Termination

This version of failsafe termination is essentially an extension of power termination. The addition of R_C and R_D greatly enhances the receiver's ability to operate in harsher environments. See Figure 10.

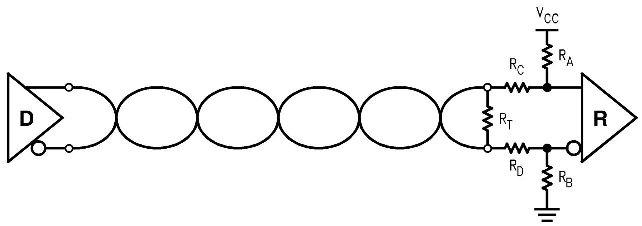


Figure 10. Alternate Failsafe Termination Configuration

The advantages of this failsafe termination point directly to this increased ruggedness. A transmission line terminated using the failsafe option will be able to withstand larger common mode voltages. A careful selection of R_C and R_D will determine how much more common mode voltage a line can endure. This is because R_C and $R_D$act as a voltage dividers between the receivers input resistance. The TIA/EIA-422-A standard allows for common mode shifting up to 7V in magnitude, however most integrated circuits support absolute maximum rating that exceed the ±7V limit. The DS26LS32A supports a ±25V ABS MAX input rating. Careful selection of resistors can allow common mode voltages in the 35V–45V range on the cable, while still honoring the 25V limit in the receiver input pins. R_C and R_D are typically 4.7 kΩ, while R_A and R_B are 47 kΩ. This provides 9.5 kΩ between the receiver input pins, and also allows the pull up and pull down resistors to be increased in value to 47 kΩ. This capability lends itself well to applications, such as factory control and building to building data transmission, where the common mode range can occasionally exceed ±7V.

Failsafe termination also ensures receiver failsafe for open, idle, as well as shorted line conditions. Of all the terminations options discussed, the failsafe option is the only one for which receiver failsafe can be ensured for shorted differential lines. Shorting the differential lines together merely shorts out R_T. In this short condition, the receiver will still see the series combination of R_C and R_D across its inputs. Receiver failsafe can, therefore, still be supported. The short condition just described yields another benefit of failsafe termination. The increased impedance between V_{CC} and ground, with the addition of R_C and R_D, also results in increased fault or short circuit current limiting.

While the addition of R_C and R_D improves the transmission line's ability to withstand larger common mode voltages, it might also negatively impact the receiver's sensitivity. Consider, for example, a TIA/EIA-422 receiver. The minimum differential input signal (V_{ID}) required to switch the receiver is normally |200 mV|. Depending on the values of R_C and R_D, it may be necessary to develop a minimum of +400 mV across R_T in order to ensure that there is at least 200 mV across the receiver input terminals. The other significant disadvantage with failsafe termination may be the number of resistors required to implement it. Five resistors per line may prove too costly.

8 Bi-Directional Termination

The last type of termination which will be discussed is known as bi-directional termination. Figure 11 shows a typically multipoint application composed of drivers, receivers, and transceivers. Bi-directional termination is parallel termination carried one step further. Bi-directional termination now permits multiple drivers (multipoint configuration) to be connected to the same twisted pair. With multiple drivers connected to the same twisted pair, data can now be transmitted in two directions. Keep in mind, however, that while data transmission can now take place in two directions, only half duplex transmission is allowed (as defined by TIA/EIA-485 standard). Multiple TIA/EIA-485 drivers cannot simultaneously drive the line since this would result in line contention. It should be mentioned that system timing should be carefully inspected to ensure that line contention does not occur. The advantages in using bi-directional termination are almost identical to those with parallel termination.

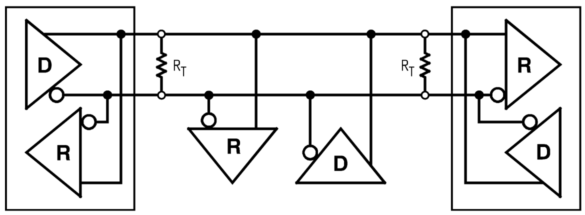


Figure 11. Bi-Directional Termination Configuration

These advantages include the prevention of signal reflections, and the ability to drive long transmission lines at high data rates. As with parallel termination, R_T should be selected so that it matches the characteristic impedance (Z_O) of the twisted pair cable.

The disadvantages in using parallel termination also extend to bi-directional termination. Receiver failsafe cannot be ensured due to the interaction between R_T and the receiver's open circuit failsafe network. Stub lengths must be minimized and an R_T must each be placed at both extreme ends of the line in order to minimize transmission line effects. However, when two termination resistors are placed at the far ends of the cable, the effective load of the driver is now 60Ω (since R_T is typically 120Ω). This “doubling” of the driver load, using bidirectional termination, has two effects. First, it places a greater demand upon the driver's ability to source current. As described above, a multipoint driver must be able to source approximately twice the amount of current that is required from a multidrop driver. A driver expected to meet this increased current demand naturally experiences greater power dissipation. And second, noise margin tends to be reduced since the driver's output levels tend to decrease with increased loading.

9 Conclusion

The advantages and disadvantages of unterminated lines and those with series, parallel, AC, power, failsafe, and bi- directional terminations were contrasted. It should now be clear that there is no one termination scheme which is suited for all applications. Table 1 provides a summary of the differential termination options discussed in this application report.

The termination scheme used will essentially be dictated by the needs of the system. Specifically, the choice of termination will depend upon the system's data transmission requirements.

Table 1. Termination Summary

Termination	Signal Quality	Data Rate	Comments
Unterminated	Poor	Low	Low Power
Series	Good	Low	Low Power
Parallel	Excellent	High	Single Resistor
AC	Good	Med.	Ideal for use on control lines
Power	Excellent	High	Failsafe bias for idle line
Alt. Failsafe	Excellent	High	Failsafe for open, shorted, and idle lines
Bi-Directional	Excellent	High	Ideal for bidirectional half duplex operation

10 Special Notes

The waveforms illustrated in this application report were acquired from laboratory testing of TIA/EIA-422 (RS-422) Drivers, and Receivers under the following conditions:

- DS26LS31 Quad Differential Driver
- DS26LS32A Quad Differential Receiver
- Cable = 100′, 24AWG, 100Ω, twp cable

  (Berk-Tek #520382)
- Driver input signal with f = 500 kHz,

  V_{IH} = 3.0V, V_{IL} = 0V,

  Duty cycle = 50%
- V_{CC}= 5.0V
- T_A= 25°C

The cable selected for this testing was supplied by Berk-Tek Inc. and represents a typical twisted pair cable commonly used in TIA/EIA-422 applications. Additional information on cables can be obtained from:

Berk-Tek Inc.

132 White Oak Road

New Holland, PA 17557

(717) 354-6200

The RS-422-A standard was developed by the Technical Recommendation (TR30.2) TlA/EIA committee on DTE-DCE Interfaces. Since publication of the revision A, the EIA (Electronic Industries Association) has aligned with the TIA (Telecommunications Industry Association), and future revisions and new standards carry the TlA/EIA prefix, replacing the familiar “RS” (for Recommended Standard) prefix. Revision “B” of RS-422-A is expected in late 1993, and will become TlA/EIA-422-B.

11 References

AN-108 Transmission Line Characteristics Application Report (SNOA746)

AN-806 Data Transmission Lines and Their Characteristics Application Report (SNLA026)

AN-807 Reflections: Computations and Waveforms Application Report (SNLA027)

AN-847 FAILSAFE Biasing of Differential Buses Application Report (SNLA031)

AN-1057 Ten Ways to Bulletproof RS-485 Interfaces

ABSTRACT

This application reports provides 10 considerations for your use of an RS-485 interface.

Contents

1 Introduction

Despite its widespread use, RS-485 is not as well understood as it should be. However, if you invest a little time on familiarizing yourself with the bus and pay attention to 10 aspects of your application, you'll find that designing rock-solid implementations is easy.

Recommended Standard 485 (RS-485) has become the industry's workhorse interface for multipoint, differential data transmission. RS-485 is unique in allowing multiple nodes to communicate bidirectionally over a single twisted pair. No other standard combines this capability with equivalent noise rejection, data rate, cable length, and general robustness. For these reasons, a variety of applications use RS-485 for data transmission. The list includes automotive radios, hard-disk drives, LANs, cellular base stations, industrial programmable logic controllers (PLCs), and even slot machines. The standard's widespread acceptance also results from its generic approach, which deals only with the interface's electrical parameters. RS-485 does not specify a connector, cable, or protocol. Higher level standards, such as the ANSI's SCSI standards and the Society of Automotive Engineers' (SAE's) J1708 automotive-communication standard, govern these parameters and reference RS-485 for the electrical specifications.

Although RS-485 is extremely popular, many system designers must learn how to address its interface issues. You should review 10 areas before you design an RS-485 interface into a product. Understanding the issues during system design can lead to a trouble-free application and can reduce time to market.

RS-485 addresses a need beyond the scope of RS-422, which covers buses with a single driver and multiple receivers. RS-485 provides a low-cost, bidirectional, multipoint interface that supports high noise rejection, fast data rates, long cable, and a wide common mode range. The standard specifies the electrical characteristics of drivers and receivers for differential multipoint data transmission but does not specify the protocol, encoding, connector mechanical characteristics, or pinout. RS-485 networks include many systems that the general public uses daily. These applications appear wherever a need exists for simple, economical communication among multiple nodes. Examples are gas-station pumps, traffic and railroad signals, point-of-sale equipment, and aircraft passenger seats. The Electronic Industries Association (EIA) Technical Recommendation Committee, TR30, made RS-485 a standard in 1983. The Telecommunications Industry Association (TIA) is now responsible for revisions. RS-485 is currently being revised. After successful balloting, the revised standard will become "ANSI TIA/EIA-485-A."

The 10 considerations that you should review early in a system design are:

- Mode and nodes
- Configurations
- Interconnect media
- Data rate vs cable length
- Termination and stubs
- Unique differential and RS-485 parameters
- Grounding and shielding
- Contention protection
- Special-function transceivers
- Fail-safe biasing

2 Mode and Nodes

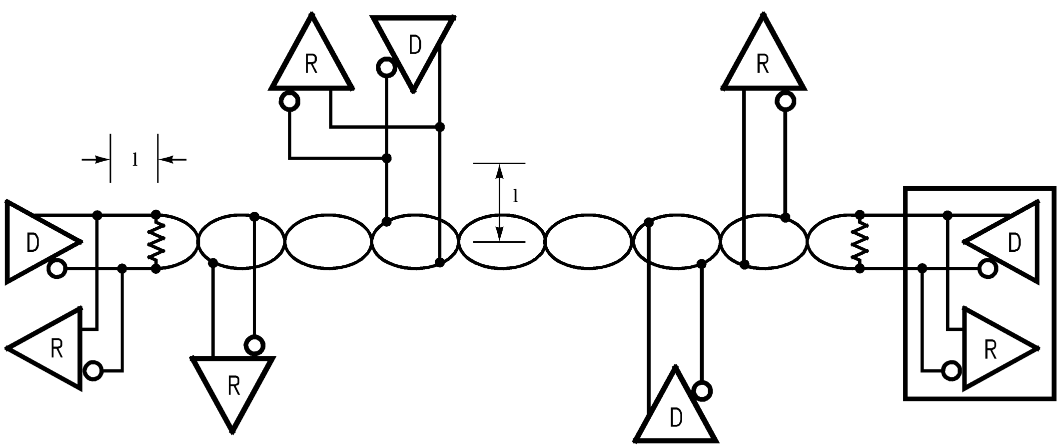
In its simplest form, RS-485 is a bidirectional half-duplex bus comprising a transceiver (driver and receiver) located at each end of a twisted-pair cable. Data can flow in either direction but can flow only in one direction at a time. A full-duplex bus, on the other hand, supports simultaneous data flow in both directions. RS-485 is mistakenly thought to be a full-duplex bus because it supports bidirectional data transfer. Simultaneous bidirectional transfers require not one but two data pairs, however.

RS-485 allows for connection of up to 32 unit loads (ULs) to the bus. The 32 ULs can include many devices but commonly comprise 32 transceivers. Figure 1 illustrates a multipoint bus. In this application, three transceivers—two receivers receivers and one driver—connect to the twisted pair. You must observe the 32-UL limitation, because the loads appear in parallel with each other and add to the load that the termination resistors present to the driver. Exceeding 32-UL loads excessively limits the drivers and attenuates the differential signal, thus reducing the differential noise margin.

RS-485 drivers are usually called "60 mA drivers." The name relates to the allowable loading. Developing 1.5V across the 60Ω termination load (120Ω at each end of the bus) requires 25 mA. The worst-case input current of a UL is 1 mA (at extreme common mode, explained later). Figure 2 shows the loading curve of a full UL. The worst-case UL input resistance is 10.56 kΩ, although a frequently quoted incorrect value is 12 kΩ. Thus, 32 ULs require 32 mA drive capability. Adding this current to the 25 mA for the terminations yields 57 mA, which rounds up to an even 60 mA. A driver that cannot supply the full 60 mA violates the standard and reduces the bus's performance. The resulting problems include reduced noise margin, reduction in the number of unit loads or allowable cable length, and limited common-mode voltage tolerance.

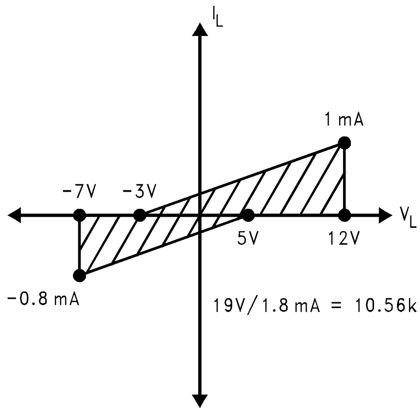
Designers frequently ask, "What is the maximum number of transceivers the bus allows?" The standard does not specify a maximum number of transceivers, but it does specify a maximum of 32 ULs. If a transceiver imposes one unit load, the maximum number of transceivers is also 32. You can now obtain transceivers with ½- and ¼-UL ratings, which allow 64 and 128 transceivers. However, these fractional-UL devices, with their high-impedance input stages, typically operate much more slowly than do single-UL devices. The lower speed is acceptable for buses operating in the low hundreds of kilobits per second, but it may not be acceptable for a 10 Mbps bus.

A solution exists for high-speed buses: You can use RS-485 repeaters to connect multiple buses end to end. In this setup, each bus must have no more than 32 loads. Directional control of the repeaters is complex, but hardware can handle it [1]. Therefore, a conservative estimate is that, without using special transceivers, a bus can include 32 transceivers.



An RS-485 bus supports two-way data transfer over a single pair of wires. A typical bus includes multiple nodes. Each transceiver includes a differential driver, D, and a differential receiver, R. The stub length is l. The bus is terminated only at the ends—not at each node.

Figure 1. Multipoint Bus



The loading of a transceiver must remain within the shading region to be one unit load.

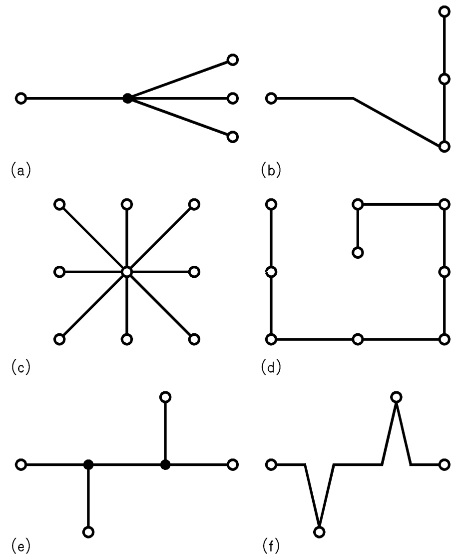
Figure 2. Loading Curve of a Full UL

> **CAUTION**
>
> Do not connect too many transceivers to the bus or lump too many transceivers too close together. The AC loading, which results mainly from the devices' pin I/O capacitance (usually about 15 pF), can alter the interconnect-medium impedance and cause transmission-line problems.

3 Configurations

Because RS-485 allows connecting multiple transceivers, the bus configuration is not as straightforward as in a point-to-point bus (RS-232C, for example). In a point-to-point bus, a single driver connects to one receiver alone. The optimal configuration for the RS-485 bus is the daisy-chain connection from node 1 to node 2 to node 3 to node n. The bus must form a single continuous path, and the nodes in the middle of the bus must not be at the ends of long branches, spokes, or stubs. Figure 3a, Figure 3c, and Figure 3e illustrate three common but *improper* bus configurations. (If you mistakenly use one of these configurations, you can usually make it work but only through substantial effort and modification.) Figure 3b, Figure 3d, and Figure 3f show equivalent daisy-chained configurations.

Connecting a node to the cable creates a stub, and, therefore, every node has a stub. Minimizing the stub length minimizes transmission-line problems. For standard transceivers with transition times around 10 ns, stubs should be shorter than 6 in. A better rule is to make the stubs as short as possible. A "star" configuration (Figure 3*c*) is a special case and a cause for concern. This configuration usually does not provide a clean signaling environment even if the cable runs are all of equal length. The star configuration also presents a termination problem, because terminating every endpoint would overload the driver. Terminating only two endpoints solves the loading problem but creates transmission-line problems at the unterminated ends. A true daisy-chain connection avoids all these problems.



Although you can make RS-485 buses with all of these configurations work, you should avoid the ones in (a), (c), and (e). Those in (b), (d), and (f), offer superior transmission-line performance.

Figure 3. Bus Configurations

4 Interconnect Media

The standard specifies only the driver-output and receiver-input characteristics—not the interconnection medium. You can build RS-485 buses using twisted-pair cables, flat cable, and other media, even backplane pc traces. However, twisted-pair cable is the most common. You can use a range of wire gauges, but designers most frequently use 24 AWG. The characteristic impedance of the cable should be 100Ω to 120Ω. A common misconception is that the cable's chatacteristic impedance (Z_0) must be 120Ω, but 100Ω works equally well in most cases. Moreover, the 120Ω cable's higher Z_0 presents a lighter load, which can be helpful if the cable runs are extremely long.

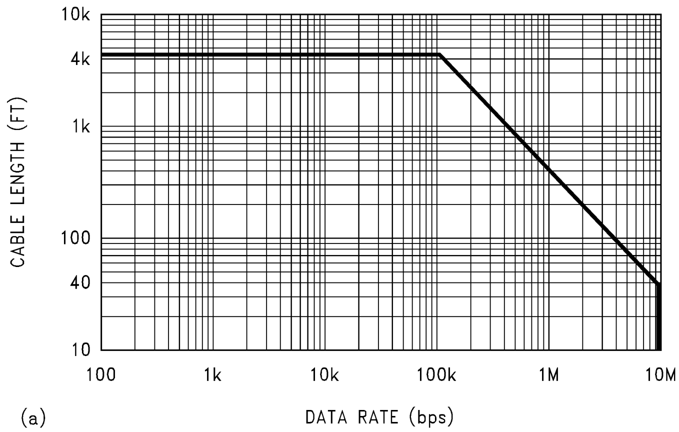
Twisted pair offers noise benefits over flat or ribbon cables. In flat cable, a noise source (usually a conductor carrying an unrelated signal) can be closer to one member of the conductor pair than to the other over an entire wiring-run length. In such cases, more noise capacitively couples to the closer conductor than to the more distant one, producing a differential noise signal that can be large enough to corrupt the data. When you use the twisted pair, the noise source is closest to each of the conductors for roughly half of the wiring-run length. Therefore, the two conductors pick up roughly equal noise voltages. The receiver rejects these voltages because they appear mainly as common mode.

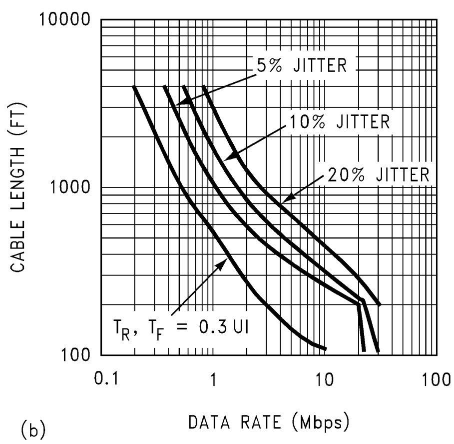
A special ribbon cable that is useful for noise reduction intermixes relatively long twisted sections with short flat sections. This cable provides the advantages of twisted pair between the flat sections and allows the use of insulation displacement connectors at the flat points.

5 Data Rate Vs Cable Length

You can transmit data over an RS-485 bus for 4000 ft (1200m), and you can also send data over the bus at 10 Mbps. But, you cannot send 10 Mbps data 4000 ft. At the maximum cable length, the maximum data rate is not obtainable: The longer the cable, the slower that data rate, and vice versa. Figure 4*a* shows a conservative curve of data rate vs cable length for RS-422 and RS-485. The two slopes result from different limitations. The maximum cable length is the result of the voltage divider that the cable's DC loop resistance and the termination resistance create. Remember, for differential buses, the loop resistance is twice as high as you might expect, because both conductors in the pair equally contribute.

The curve's sloped portion results from AC limitations of the drivers and the cable. Figure 4*b* shows four limits for a DS3695 transceiver that drives a common twisted-pair cable. Notice that the data rate vs cable length depends significantly on how you determine the necessary signal quality. This graph includes two types of criteria. The first is a simple ratio of the driver's transition time to the unit interval. A curve showing the results for the common 30% ratio defines the most conservative set of operating points.





As you increase the cable length, the maximum data rate decreases. The more jitter you can accept, the greater is the allowable data rate for a given length of cable.

Figure 4. Data Rate Vs Cable Length

Table 1. Special Transceivers Solve Special Problems

DS3696/A —Thermal shutdown reporting pin: This device provides an open collector pin that reports the occurrence of a severe bus fault that has caused a thermal shutdown of the driver (>150°C junction temperature).	**DS36276** —Fail-safe transceiver: Standard transceiver pinout with fail-safe detecting receiver, optimal for use with UARTs and asynchronous buses.	**DS36C279** —Ultra-low-power CMOS transceiver with automatic-sleep mode: Optimizes current with the automatic-sleep mode. With inactivity on the enable lines, I_{CC} drops to less than 10 µA.
DS3697 —Repeater pinout: Special pinout that internally connects a receiver port to a driver port. You need two of these devices for a bidirectional repeater.	**DS36277** —Fail-safe transceiver with active-low driver enable: Similar to the DS36276 but includes an active-low driver-enable pin. This feature allows a simplified connection to a UART and supports dominant-mode operation (use of the enable pin as the data pin).	**DS36C280** —Ultra-low-power CMOS transceiver with adjustable-slew-rate control: Adjustable driver slew rate allows tailoring for long stub lengths and reduced emissions.
DS3698 —Repeater pinout with thermal-shutdown pin: A repeater device that also provides the thermal-shutdown reporting pin.	**DS36C278** —Ultra-low-power CMOS transceiver: µA supply current and full RS-485 drive capability. One-fourth unit load allows up to 128 transceivers on the bus.	**DS36954** —Quad transceiver: Offers four independent transceivers in a single package. Useful for parallel buses.

A second method of determining the operating points uses eye-pattern (jitter) measurements. To make such measurements, you apply a pseudo random bit sequence (PRBS) to the driver's input and measure the resulting eye pattern at the far end of the cable. The amount of jitter at the receiver's threshold vs the unit interval yields the data point. Less jitter means better signal quality. Common operating curves use 5, 10, or 20% jitter. Above 50%, the eye pattern starts to close, and error-free data recovery becomes difficult [2]. The key point is that you can't obtain the maximum data rate at the maximum cable length. But, if you operate the bus within the published, conservative curves, you can expect an error-free installation.

6 Termination and Stubs

Most RS-485 buses require termination because of fast transitions, high data rates, or long cables. The purpose of the termination is to prevent adverse transmission-line phenomena, such as reflections. Both ends of the main cable require termination. A common mistake is to connect a terminating resistor at each node—a practice that causes trouble on buses that have four or more nodes. The active driver sees the four termination resistors in parallel, a condition that excessively loads the driver. If each of the four nodes connects a 100Ω termination resistor across the bus, the active driver sees a load of 25Ω instead of the intended 50Ω. The problem becomes substantially worse with 32 nodes. If each node includes a 100Ω termination resistor, the load becomes 3.12Ω. You can include provisions for termination at every node, but you should activate the termination resistors only at the end nodes (by using jumpers, for example).

Stubs appear at two points. The first is between the termination and the device behind it. The second is between the main cable and a device at the middle of the cable. Figure 1 shows both stubs. The symbol "l" denotes the stub length. Keep this distance as short as possible. Keeping a stub's electrical length below one-fourth of the signal's transition time ensures that the stub behaves as a lumped load and not as a separate transmission line. If the stub is long, a signal that travels down the stub reflects to the main line after hitting the input impedance of the device at the end of the stub. This impedance is high compared with that of the cable. The net effect is degradation of signal quality on the bus. Keeping the stubs as short as possible avoids this problem. Instead of adding a long branch stub, loop the main cable to the device you wish to connect. If you must use a long stub, drive it with a special transceiver designed for the purpose.

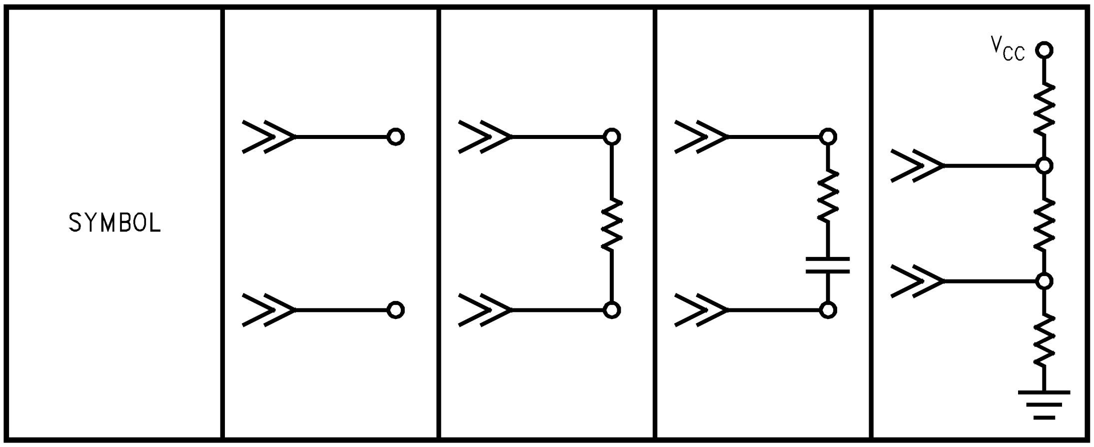
7 Termination Options

You have several options for terminating an RS-485 bus. The first option is no termination. This option is feasible if the cable is short and if the data rate is low. Reflections occur, but they settle after about three round-trip delays. For a short-cable, the round-trip delay is short and, if the data rate is low, the unit interval is long. Under these conditions, the reflections settle out before sampling, which occurs at the middle of the bit interval.

The most popular termination option is to connect a single resistor across the conductor pair at each end. The resistor value matches the cable's differential-mode characteristic impedance. If you terminate the bus in this way, no reflections occur, and the signal fidelity is excellent. The problem with this termination option is the power dissipated in the termination resistors.

If you must minimize power dissipation, an RC termination may be the solution. In place of the single resistor, you use a resistor in series with a capacitor. The capacitor appears as a short circuit during transitions, and the resistor terminates the line. Once the capacitor charges, it blocks the DC loop current and presents a light load to the driver. Lowpass effects limit use of the RC termination to lower data-rate applications [3].

Another popular option is a modified parallel termination that also provides a fail-safe bias. A detailed discussion of fail-safe biasing occurs later in the article. Figure 5 compares the four popular termination methods. The main point to remember is that, if you use termination, you should locate the termination networks at the two extreme ends of the cable, not at every node.



TERMINATION NAME:	UNTERMINATED	PARALLEL	RC TERMINATION	FAILSAFE
DATA RATE:	LOW	HIGH	MEDIUM	HIGH
SIGNAL QUALITY:	LIMITED	EXCELLENT	LIMITED	EXCELLENT
POWER:	LOW	HIGH	LOW	HIGH

RS-485 buses can use four methods of termination. Achieving the best electrical performance requires accepting higher power dissipation in the termination resistors.

Figure 5. Termination Methods

8 Unique Differential and RS-485 Parameters

Four parameters that are important to differential data transmission and RS-485 are V_{OD}, V_{OS}, V_{GPD}, and V_{CM}. Figure 6, Figure 7, and Figure 8 illustrate these parameters, which are not common in the world of single-ended signaling and standard logic families.

V_{OD} represents the differential output voltage of the driver across the termination load. The RS-485 standard refers to this parameter as "termination voltage" (V_T), but V_{OD} is also commonly used. You measure V_{OD} differentially across the transmission line—not with respect to ground. On long cable runs, the DC resistance attenuates V_{OD}, but the receivers require only a 200 mV potential to assume the proper state. Attenuation, therefore, is not a problem. At the driver output, V_{OD} is 1.5V minimum. The IC manufacturer should guarantee this voltage under two test conditions: The first uses a simple differential load resistor. The second includes two 375Ω resistors connected to a common-mode supply. These resistors model the input impedance of 32 parallel ULs, all referenced to an extreme common-mode voltage. To make the 1.5V limit in this test, the driver must source or sink roughly 60 mA. This test is difficult and is important, because it essentially guarantees the system's differential-noise margin under worst-case loading and common-mode conditions.

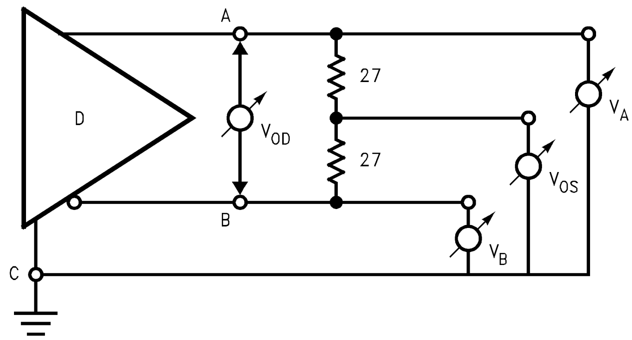
Data sheets for RS-485 drivers usually do not include V_{OL} or V_{OH} specifications. The driver's $V_{OL}$is typically around 1V. Even for CMOS devices, V_{OH} is slightly above 3V, because both the source and sink paths of the output structure include a series-connected diode, which provides the common-mode tolerance for an Off driver. Because V_{OL} is usually greater than 0.8V, an RS-485 driver is not TTL-compatible.

V_{OS} represents the driver's offset voltage measured from the center point of the load with respect to the driver's ground reference. V_{OS} is also called "V_{OC}" for output common-mode voltage. This parameter is related to V_{CM}.

V_{CM} represents the common-mode voltage for which RS-485 is famous. The limit is −7V to +12V. Common-mode voltage is defined as the algebraic mean of the two local-ground-referenced voltages applied to the referenced terminals (receiver input pins, for example). The common-mode voltage represents the sum of three voltage sources. The first is the active driver's offset voltage. The second is coupled noise that shows up as common mode on both signal lines. The third is the ground-potential difference between the node and the active driver on the bus. Mathematically,

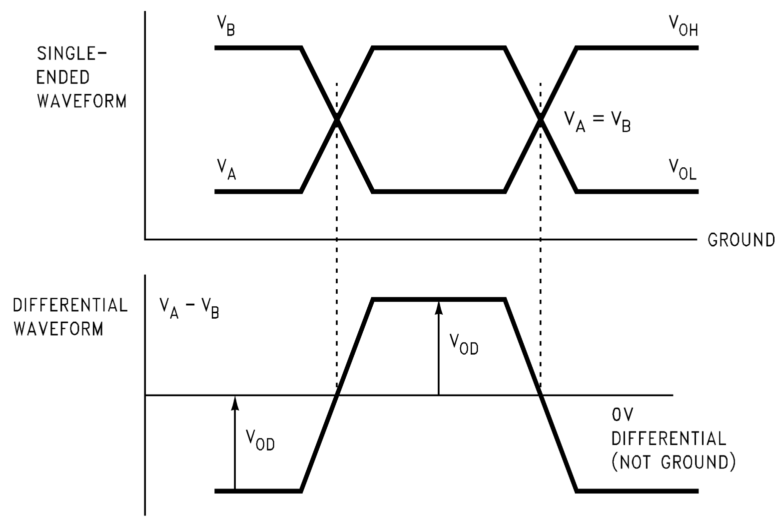
$$V_{CM} = V_{OS} + V_{NOISE} + V_{GPD}. \quad (1)$$

V_{GPD} represents the ground-potential difference that can exist between nodes in the system. RS-485 allows for a 7V shift in grounds. A shift of 7V below the negative (0V) power rail yields the −7V common-mode limit, whereas 7V above the 5V positive power rail yields the other common-mode limit of 12V. Understanding these parameters enables improved component selection, because some devices trade off certain parameters to gain others.



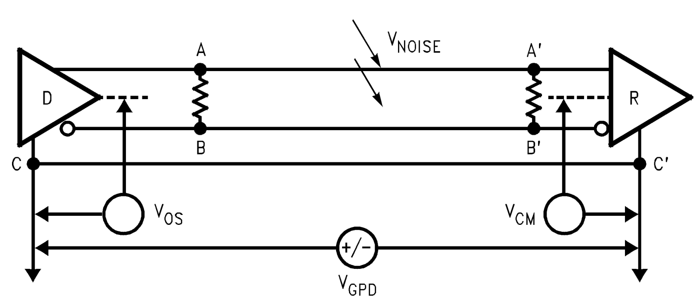
Because RS-485 buses are differential, they involve parameters that have no counterparts in single-ended systems.

Figure 6.



Although the voltages on the bus's two conductors vary symmetrically about a value that is halfway between the driver's Low and High output-state values, the differential voltage between the conductors varies about zero. In addition, the differential voltage swing is double the swing on either of the bus conductors.

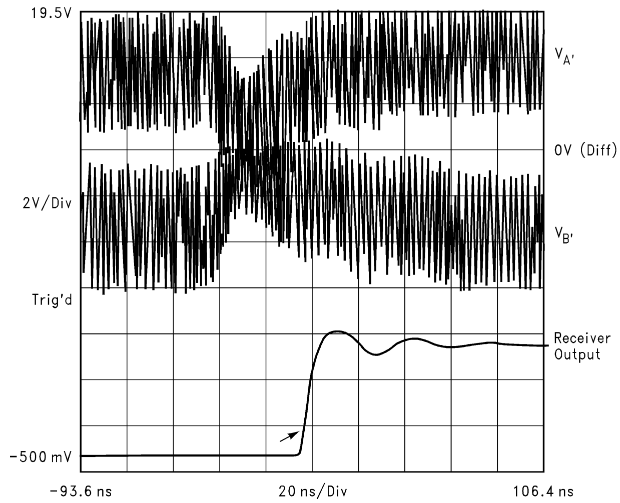
Figure 7.



The common-mode voltage, V_{CM}, is the average of the voltages at a driver's two outputs or a receiver's two inputs. You measure all voltages with respect to the driver's or receiver's common terminal.

Figure 8.

To further illustrate RS-485's common-mode noise-rejection capability, you can conduct the following test: Connect a driver to a receiver via an unshielded twisted-pair cable. Then, couple a noise signal onto the line, and, from the scope, plot the resulting waveform at the receiver input (Figure 9). The plot includes the receiver's output signal. Note that the receiver clearly detects the correct signal state, despite the common-mode noise. Differential transmission offers this high noise rejection; a single-ended system would erroneously switch states several times under these test conditions.



Because of the bus's differentail nature and the receiver's common-mode rejection, the receiver's output (lowest trace) is clean despite large common-mode noise voltages on both of the bus conductors.

Figure 9.

Table 2. Standards Related to RS-485

EIA RS-485 —Originally published in 1983, the multipoint standard specifies the concept of the unit load along with electrical characteristics of the drivers and receivers. It was developed from the RS-422 standard, adding multipoint capability, extended common-mode range, increased drive capability, and contention protection. It is an "electrical-only" standard that does not specify the function of the bus or any connectors.	**TIA/EIA-485-A (PN-3498)**—The TIA expects completion of the first revision to RS-485 this year (Project Number 3498). The goals of the revision are to clean up vague text and to provide additional information to clarify certain technical topics. This work will become the "A" revision of RS-485 once the balloting (approval) process is complete. In addition to the revision work, an application bulletin (PN-3615) is also in process. This document will provide additional application details and system considerations to aid the designer.	**ISO/IEC 8482.1993** —The current revision of this international standard maps closely to RS-485. The original ISO standard specified different limits and conditions. However, the 1993 revision changed many of these differences, and RS-485 and ISO 8482 are now similar.

9 Grounding and Shielding

Although the potential difference between the data-pair conductors determines the signal without officially involving ground, the bus needs a ground wire to provide a return path for induced common-mode noise and currents, such as the receivers' input current. A typical mistake is to connect two nodes with only two wires. If you do this, the system may radiate high levels of EMI, because the common-mode return current finds its way back to the source, regardless of where the loop takes it. An intentional ground provides a low-impedance path in a known location, thus reducing emissions.

Electromagnetic-compatibility and application requirements determine whether you need a shield. A shield both prevents the coupling of external noise to the bus and limits emissions from the bus. Generally, a shield connects to a solid ground (normally, the metal frame around the system or subsystem) with a low impedance at one end and a series RC network at the other. This arrangement prevents the flow of DC ground-loop currents in the shield.

10 Contention Protection

Because RS-485 allows for connecting multiple drivers to the bus, the standard addresses the topic of contention. When two or more drivers are in contention, the signal state on the bus is not guaranteed. If two drivers are on at the same time and if they are driving the same state, the bus state is valid. However, if the drivers are in opposite states, the bus state is undetermined, because the differential voltage on the bus drops to a low value within the receiver's threshold range. Because you do not know the driver states, you must assume the worst—namely, that the data on the bus is invalid.

Contention can also damage the ICs. If several drivers are in one state, a single driver in the opposite state sinks a high current (as much as 250 mA). This large current causes excessive power dissipation. A difference in ground potential between nodes only aggravates this dissipation. In this situation, the driver's junction temperature can increase beyond safe limits. The RS-485 standard recommends the use of special circuitry, such as a thermal shutdown circuit, to prevent such damage. Most RS-485 devices use this technique. The shutdown circuit disables the driver outputs when the junction temperature exceeds 150°C and automatically re-enables the outputs when the junction cools. If the fault is still present, the device cycles into and out of thermal shutdown until someone clears the fault.

Besides thermal shutdown, other current limiting is required to prevent accidental damage. If an active output is shorted to any voltage within the −7V to +12V range, the resulting current must not exceed 250 mA. In addition, the outputs of a driver must not sustain damage if they are shorted together indefinitely. (Entering thermal shutdown is allowed, of course.) Lastly, RS-485 drivers must source and sink large currents (60 mA). This situation requires outputs of rather large geometry, which provide robust ESD protection.

11 Special-Function Transceivers

You can handle many of the above-mentioned issues by using special transceivers, of which there are several types, differing in pinout or functions supported. The most common device is a standard transceiver (DS3695/DS75176B), which provides a two-pin connection to the RS-485 bus and a four-pin TTL interface (driver input, driver enable, receiver output, and receiver enable). Among the problems you can solve with an appropriate transceiver are these:

For ultra-low-power applications, the DS36C279 provides an auto-sleep function. Inactivity on the two enable lines automatically triggers the sleep mode, dropping the power-supply current to less than 10 μA. This characteristic is extremely valuable in applications that provide an interface connection but that are connected to their cables for down-loading only a small percentage of the time. This is the case for package-tracking boxes carried by many overnight-delivery services. With this sleep feature, idle transceivers do not consume precious battery current.

For applications that are asynchronous and based on a standard UART, fail-safe biasing is an issue. UARTs look for a low or a high state, and, between characters, the line usually remains high. With RS-485, this condition is troublesome, because, when there are no active drivers on the bus, the bus state is undetermined. (See Section 12 for a detailed discussion of fail-safe biasing.) In this case, the DS36276 simplifies the hardware design. This unique transceiver's receiver detects a high state for a driven high and also for the nondriven (V_{ID} = 0) bus state, thus providing the UART with the high state between characters and only valid start bits.

Although the discussion of configurations and the section on stubs advises minimizing stub length to avoid transmission-line problems, the application may not permit minimizing stub length. Another approach is to increase the driver's transition time to permit longer stubs without transmission-line effects. If you use the DS36C280, long stubs can branch off the main cable. This arrangement keeps the main cable short, whereas looping the cable back and forth to reach inconveniently located nodes would greatly increase the main-cable length. Besides allowing longer stubs, the slower edge rates generate lower emissions. Thus, this transceiver is also useful for applications that severely limit emitted noise.

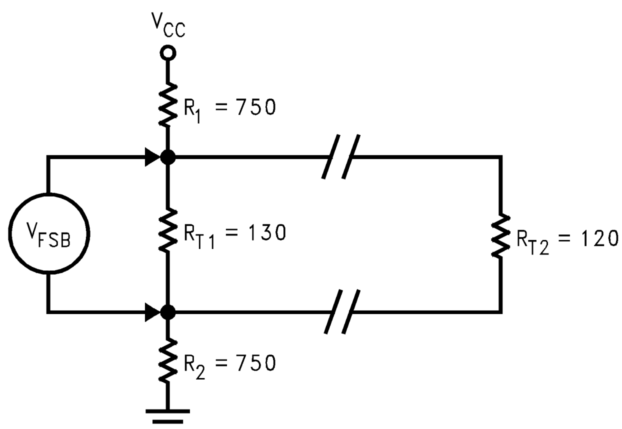
12 Fail-Safe Biasing

The need for fail-safe operation is both the principal application issue and most frequently encountered problem with RS-485. Fail-safe biasing provides a known state in which there are no active drivers on the bus. Other standards do not have to deal with this issue, because they typically define a point-to-point or multidrop bus with only one driver. The one driver either drives the line or is off. Because there is only one source on the bus, the bus is off when the driver is off. RS-485, on the other hand, allows for connection of multiple drivers to the bus. The bus is either active or idle. When it is idle with no drivers on, a question arises as to the state of the bus. Is it high, low, or in the state last driven? The answer is any of the above. With no active drivers and low-impedance termination resistors, the resulting differential voltage across the conductor pair is close to zero, which is in the middle of the receivers' thresholds. Thus, the state of the bus is truly undetermined and cannot be guaranteed.

Some of the functional protocols that many applications use aggravate this problem. In an asynchronous bus, the first transition indicates the start of a character. It is important for the bus to change states on this leading edge. Otherwise, the clocking inside the UART is out of sync with the character and creates a framing error. The idle bus can also randomly switch because of noise. In this case, the noise emulates a valid start bit, which the UART latches. The result is a framing error or, worse, an interrupt that distracts the CPU from other work.

The way to provide fail-safe operation requires only two additional resistors. At one end of the bus (the master node, for example), connect a pullup and pulldown resistor (Figure 10). This arrangement provides a simple voltage divider on the bus when there are no active drivers. Select the resistors so that at least 200 mV appears across the conductor pair. This voltage puts the receivers into a known state. Values that can provide this bias are 750Ω for the pullup and pulldown resistors, 130Ω across the conductor pair at the fail-safe point, and a 120Ω termination at the other end of the cable. For balance, use the same value for the pullup and pulldown resistors. [4] provides extensive details on this issue.

Forethought into these 10 areas before production greatly reduces the likelihood of problems. RS-485 is unique in its capabilities and requirements. Fully understanding these 10 issues leads to a rock-solid, trouble-free, multipoint differential interface that maximizes the benefits of RS-485 and provides the application with robust, rugged, highly noise-tolerant data communication.



Unless you do something to keep the situation from occurring, when no driver is driving the bus, the receivers cannot determine the bus state. Fail-safe biasing is a bus-termination method, which ensures that, even when no driver is active, a differential voltage large enough to unambiguously determine the bus state appears at the receiver inputs.

Figure 10.

13 References

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3. *AN-903 A Comparison of Differential Termination Techniques Application Report* (SNLA034)
4. *AN-847 FAILSAFE Biasing of Differential Buses Application Report* (SNLA031)
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