FEATURE ARTICLE

BOB PERRIN

The Art and Science of RS-485

RS-485 has been around for a while and has quite a range of applications, but that doesn't stop some people from doing it wrong. If you're not too fond of homework, pay attention because Bob is going to share his notes on the RS-485 standard and explain what it takes to successfully implement an RS-485 network.

When you hear the phrase "multidrop network," RS-485 is probably the first thing that comes to mind. RS-485 has been around as an accepted standard since 1983 and is used in everything from point-of-sale equipment to factory-floor automation.

Often a system integrator or even a software engineer is given the task of assembling the RS-485 network. The reasoning is usually something like, "RS-485 is just a twisted pair of wires. How hard can that be to hook up?" The answer is, "Harder than you may think."

I've seen good engineers install unreliable RS-485 networks. There are usually two reasons why this happens. The first is a false assumption that the folks who wrote the RS-485 standard worked out all the details and tradeoffs so all that's left to do is string a couple of wires between each node. The second reason is ignorance of what the standard covers.

ARM YOURSELF

Before jumping headlong into any endeavor, it's a good idea to research your topic, and RS-485 is no different. Before sinking thousands of dollars into a network, get a hold of the documents listed in the references section and study them well.

Two documents that aren't free are the standard and the application guidelines for the standard. The full name of the RS-485 standard currently is TIA/EIA-485-A. The last revision was March 3, 1998. The Telecommunications Industry Association (TIA), in association with the Electronic Industries Alliance (EIA), also publishes a telecommunications systems bulletin (TSB89) entitled *Application Guidelines for TIA/EIA-485-A*.

The standard is 17 pages long and only defines the characteristics of the line drivers and receivers. Nothing is said about transmission lines and network topology. Three of the 17 pages comprise Annex A, which is an informative addendum to the standard but is not considered by the TIA/EIA to be part of the standard. Annex A offers only the briefest of guidelines regarding application of RS-485 devices.

TSB89 is 23 pages long and is dedicated to explaining how to apply the devices defined in TIA/EIA-485-A to a physical network.

Reading these two documents will rapidly cure anyone of blind faith in the RS-485 standard. Having the documents available for reference is handy when evaluating physical parts and performance tradeoffs in real applications.

RS-485 101

Before delving into the nitty gritty, let's first examine some general characteristics of a network built with drivers and receivers compliant with TIA/EIA-485-A.

RS-485 is a half-duplex multidrop network, which means that multiple transmitters and receivers may reside on the line. Only one transmitter may be active at any given time. TIA/EIA-485-A says nothing

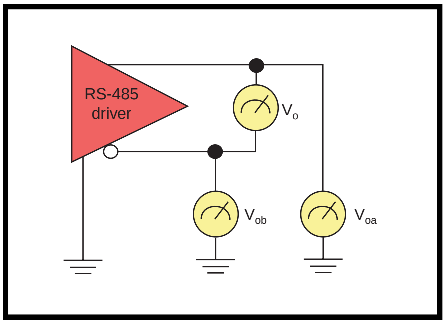


Figure 1—*The relationship between V_{OA}, V_{OB}, and V_O is carefully spelled out in TIA/EIA-485-A.*

about the communications protocol to be used on the network. The software engineer has the liberty to implement whatever type of network protocol is deemed applicable for the current project.

RS-485 transmission lines are differential in nature. There are two wires—A and B. The driver generates complementary voltages on A and B. Figure 1 shows how EIA-485-A defines V_{OA}, V_{OB}, and V_O. When V_{OA} is low, V_{OB} is high; when V_{OA} is high, V_{OB} is low. Most physical parts also have the ability to tristate both A and B.

Signals A and B are complementary, but this doesn't imply that one signal is a current return for the other. RS-485 is not a current loop.

The drivers and receivers must share a common ground. This is why "two-wire network" is a misnomer when applied to RS-485. More on this later.

Receivers are designed to respond to the difference between A and B. V_O is the differential voltage. Receivers must be sensitive to a 200-mV difference between V_{OA} and V_{OB}. Anything less than 200 mV is indeterminate.

RS-485 can support networks up to 5000' long and bit rates of up to 10 Mbps. Data rate must be traded off against cable length [1]. Figure 2 shows a graph fairly typical of the bit rates and line lengths you can expect. Performance will vary depending on cable type, termination, drivers and receivers used, EMI coupled into the system, and the physical geometry of the network.

TIA/EIA-485-A defines a unit load (UL) and declares that an RS-485 driver must be able to drive 32 ULs. The standard's authors anticipated that device manufacturers would implement receivers and transceivers (with the driver in the high-Z state) to present a single UL load to the line.

The natural conclusion and often-repeated myth is that an RS-485 network can only support 32 nodes. This is not true. Device manufacturers now sell 1/4 UL transceivers (DS1487) and even 1/8 UL parts (MAX1482).

Assuming each node presents 1/8 UL to the transmission line, an RS-485–compliant network may sport as many as 256 nodes (32 UL × 8 UL/node = 256 nodes).

By using repeaters, multiple networks can be chained together to accommodate virtually an unlimited number of nodes. The propagation delays will become significant for large networks with multiple repeaters and long transmission lines, and the data rate may become unacceptably low.

Some drivers are designed to have slow edge times. These are often referred to as slew-rate limited drivers. Slow edges have reduced high-frequency components associated with them. Longer edge times permit the use of longer cables and reduce the amount of EMI emitted by the network.

Now that we have a general understanding of what an RS-485 network is, let's examine some common pitfalls.

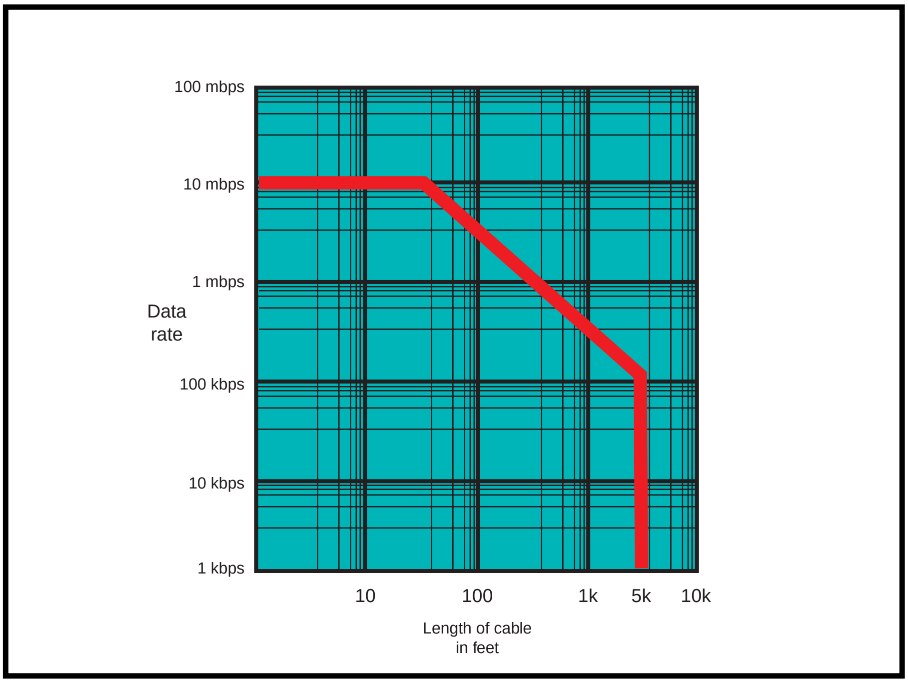


Figure 2—*Trading data rate for cable length is the unfortunate consequence of finite propagation delay on the transmission line.*

GETTING GROUNDED

Probably the least-understood issue associated with building robust RS-485 networks is proper grounding. Even though there are a number of good references on the topic, grounding seems to be misunderstood by many people [2, 3].

The common mode voltage (V_{cm}) is usually the parameter to be most concerned about. Figure 3 shows how V_{cm} is defined. TIA/EIA-485-A states, "Common-mode voltage (V_{cm}) is the sum of ground potential difference, generator (driver) offset voltage and longitudinally coupled noise voltage."

V_{noise} is coupled identically onto both wires. The result is usually referred to as common-mode noise. If a twisted pair is used, a useful simplification is to model V_{noise} as common mode.

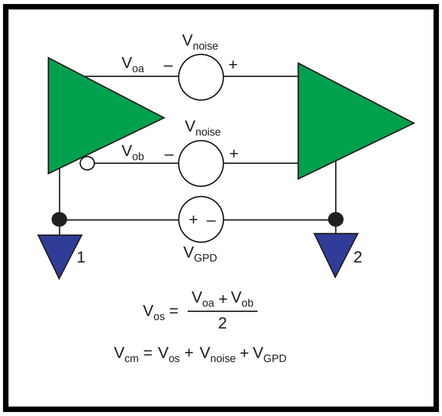


Figure 3—*Common-mode voltage at the receiver depends on three parameters, two of which (V_{noise} and V_{GPD}) require attention by the engineer.*

V_{GPD} is the parameter that seems to cause the most problems. The problem stems from the oversimplification that ground is a perfect conductor capable of absorbing infinite energy, which is far from the truth [4, 5].

Earth ground potentials from circuit to circuit in an industrial installation can vary several volts under normal conditions. These voltage potentials most often stem from current leaking from equipment into the ground system.

However, during electrical activity (lightning, etc.), potentials between grounds in different parts of a building can momentarily reach tens or hundreds of volts depending on the geometry of the electric fields. Potentials between grounds in different buildings can even reach thousands or hundreds of thousands of volts [5].

The practical ramification of this is that earth ground is a poor choice for referencing signal grounds on distributed network nodes. The best method for controlling V_{GPD} is to simply run a third wire for the purpose of referencing local signal grounds. Figure 4a illustrates this process.

A less desirable but commonly used method for referencing local signal grounds is illustrated in Figure 4b. This method provides a higher impedance connection between nodes, which means local grounds may drift farther apart than with the scheme in Figure 4a. However, if the local supplies are not isolated or if ground loops are a concern, you can use the current-limiting mechanism shown in Figure 4b.

Figure 4c shows another variation of the scheme shown in Figure 4b. Earth ground is used as the third wire. V_{GPD} between nodes will vary as the earth ground potential varies across the network installation.

The common-mode voltage allowable between drivers and receivers on an RS-485 network is +12 to –7 V. This setup provides 7 V of protection from each rail (assuming a 5-V system). If the earth ground system in Figure 4c only varies a few volts under normal conditions, then the network will function fine.

The problem comes when a voltage transient appears on the earth ground circuit, which might happen because ESD is discharged into the earth ground near a node. Or it may happen because lightning strikes nearby (perhaps half a mile away). Whatever the cause, V_{GPD}

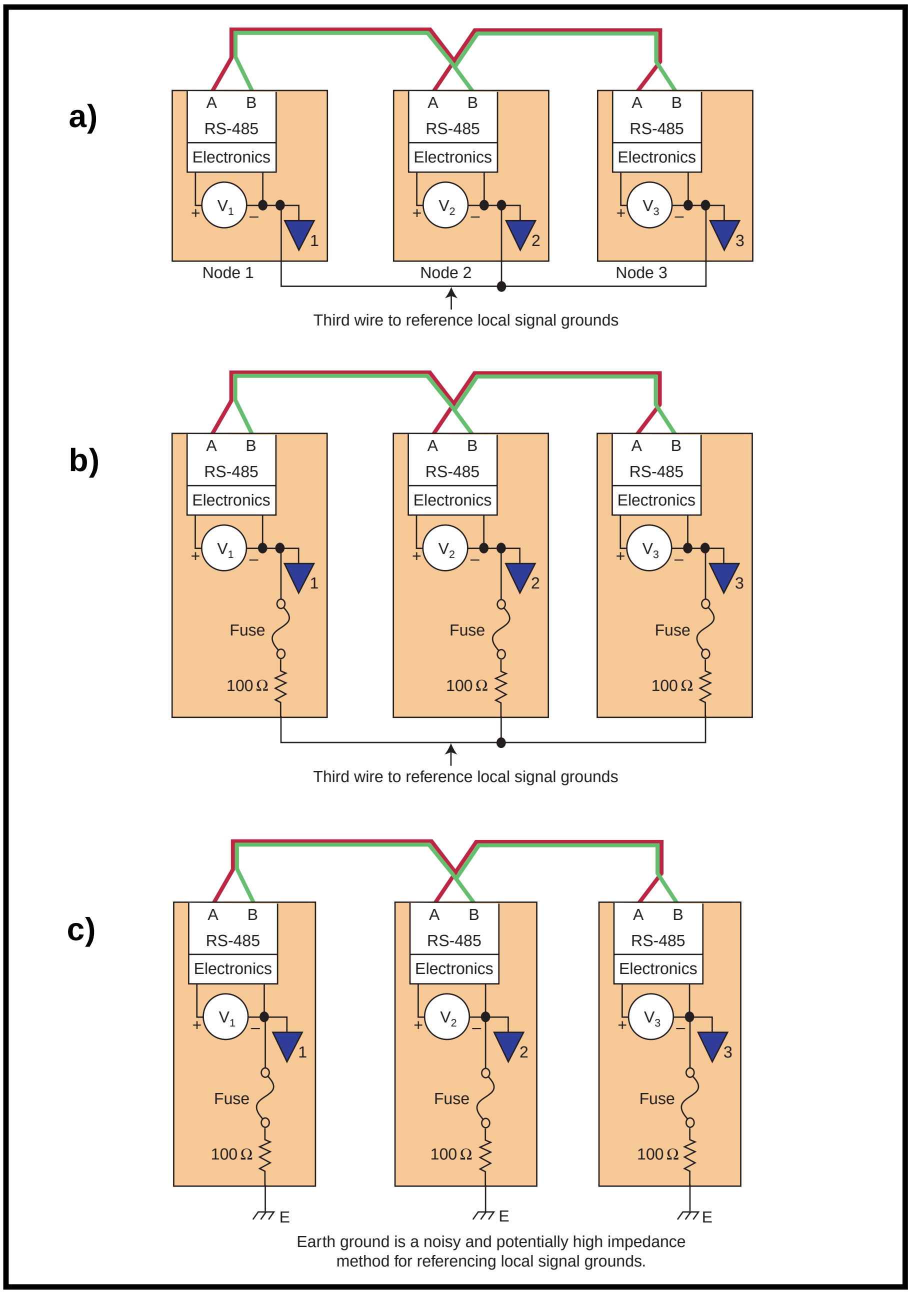


Figure 4a—*A dedicated conductor to reference signal grounds is the best method of controlling V_{GPD}.* **b—***The 100-ohm resistors limit current but allow larger V_{GPD}s to develop.* **c—***As a last resort, earth ground can be used to reference signal grounds.*

between earth grounds on a network will occur on a daily or weekly basis.

When the common-mode voltage on a node drifts beyond the allowable V_{cm} of +12 to –7 V, the node is no longer guaranteed to function. In fact, the drivers and receivers in the node may be subject to damage. It's up to the designer to protect the node from common-mode voltages beyond the silicon's rating.

One useful part for this is a transient voltage suppressor (TVS). As I understand it, TranZorb is a registered trademark of General Semiconductor referring only to their line of TVSs. The widespread use of "TranZorb" to refer to all TVSs is a tribute to General Semiconductor's early dominance in the market.

TVSs are silicon-based devices that utilize the nondestructive mechanism of avalanche breakdown to clamp high voltages. TVSs can be thought of as two back-to-back zener diodes that can momentarily dissipate hundreds or thousands of watts without ill effect.

Unlike metal oxide varistors (MOVs) and fuses, TVSs are not sacrificial components. With proper circuit design, TVSs can protect RS-485 networks indefinitely from momentary over-voltages.

SHIELDING

There is some debate over the value of a shield in RS-485 cable. The only cable that Belden Wire and Cable officially recommends for RS-485 (Belden 9841-9844) comes with a shield, like it or not. Likewise, Alpha Wire only recommends a shielded cable (Alpha 6222-6230) for use with RS-485 networks.

After talking with engineers at both Alpha and Belden, I concluded that they recommend shielded cables because a shielded cable will work for virtually all applications. Better to have a shield and not need it than to get a network wired and find you need a shield but don't have it.

That's all well and good if you sell cable or have lots of someone else's money to spend. Back in the real world, the tradeoffs of price versus performance must be considered. Shielded cable is often more expensive than unshielded cable and can be more difficult to physically work with.

RS-485 receivers have excellent common-mode rejection characteristics. By using twisted pair, all but the weirdest noise sources will be similarly coupled to each conductor. The differential nature of TIA/EIA-485-A receivers makes them operate remarkably well with horrible levels of common-mode noise on the network cables.

If your network cabling is run in a conduit or cable trays (as long as the data cable is separate from AC power cables), shielded network cable probably isn't a great concern. However, if you have network cables stapled to rafters, slung under conveyer belts, or terminated on an RS-485 box that monitors the temperature in a weld shop, shielded cable is for you.

If data integrity is of utmost importance, you're going to want to consider shielded cable. For example, if a serious corruption of packets or the network latency associated with straightening out the message stream would cause loss of product, shielded cable can be cheap insurance.

The most interesting application of shielded cable that I've heard about is an RS-485 network buried in a golf course. The network consists of buried sensors that detect the impact of golf balls on the course. The system had difficulty with network nodes being damaged by nearby lightning events. Once a shielded network cable was installed and earth grounded on each end, the failure rate dropped to an acceptable level. If your network is likely to be subjected to high-intensity fields, consider a shielded network cable.

Assuming you have a shield, the next question is, "What do I do with it?" To keep within the breadth of this article, the answer is, "It depends on the type of fields to which your network cable is being subjected." Henry Ott's book, *Noise Reduction Techniques in Electronic Systems* is a bible for engineers dealing with EMI/RFI issues [6]. I highly recommend this text to answer the question in detail.

TOPOLOGY

If the signals on the network are slow, the bit edges are long, and the cable runs are short, topology is not an issue. But, the question of network topology will crop up from time to time.

As soon as transmission-line effects begin to show up, there is only one simple topology for manag-

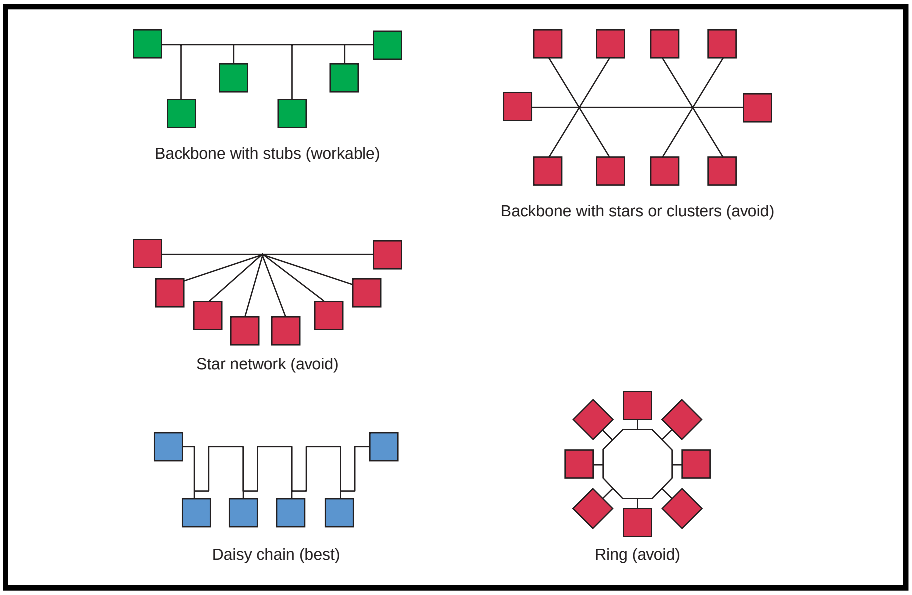


Figure 5—*Many common network topologies exist, but the daisy chain is the most reliable for RS-485 networks..*

ing them. Figure 5 shows several network topologies. Only the daisy chain is easy to manage reflections on.

This is not to say, for example, that it's impossible to implement a star configuration with RS-485 devices. Keeping reflections under control in a star topology is more art than science in a practical network. The best way to ensure a robust and reliable RS-485 network is to build it around a daisy-chain configuration.

There are several rules of thumb to follow when predicting if the line is long enough to be a transmission line. One common rule states that transmission-line effects will begin to occur when the signal rise time is less than 4× the one-way propagation delay of the cable [7].

Most twisted-pair have a propagation speed of 66–77% of the speed of light. Cable manufacturers publish this specification for their network cables. By knowing the approximate length of the network cable, the one-way propagation can be computed by knowing that *PropTime* equals *CableLength* divided by *PropSpeed*.

TERMINATION

Assuming the network cable is long enough for transmission-line effects to arise, what termination technique should be used to mitigate reflections?

There are quite a few termination methods available. National Semiconductor has published a 10-page application note that describes seven distinct techniques [7]. The four techniques that I will review are shown in Figure 6.

Unterminated networks are low power, low cost, and simple to build. The disadvantage, of course, is that data rates must be quite slow or cable length must be short for the network to operate reliably.

A parallel termination offers excellent data rates but is limited to networks that only have one driver. The driver must be located on one end of the network and the termination resistor must be located on the far end.

The resistor should have the same value as the characteristic impedance (Zo) of the transmission line. Cable manufacturers publish Zo for their network cables. The larger the Zo, the less power Rp (which is equal to Zo) must dissipate as heat.

The most common RS-485 twisted pairs have a Zo of 100–120 ohms. Category 5 (CAT-5) cable offers a 100-ohm Zo, typically has four pairs, and is widely available. The Belden RS-485 cables (9841-9844) have a Zo of 120 ohms. Alpha Wire cables (Alpha 6222-6230) have a Zo of 100 ohms.

The third termination technique is a bidirectional termination, which offers excellent signal integrity. With this technique, the line drivers can be anywhere on the network. The disadvantage is power consumption. This technique is probably the most reliable RS-485 termination technique.

The fourth and most dubious technique is called AC termination. The idea is to use the capacitor as a DC blocking element to reduce power consumption. In practice, I have never seen this technique do anything except butcher signal integrity. The National Semiconductor application note describes a design methodology for this type of termination [7]. I'm willing to believe this technique is useful in some applications, but I'm also pretty sure a fair degree of tweaking is required to get this system to function reliably.

The last subject related to termination is what to do with unused conductors in a data cable. Unused conductors will self-resonate and couple noise into the data wires. If the unused cables are left open, they will resonate at all sorts of strange frequencies. If they are grounded at one end, they will resonate at L/2. If they are grounded

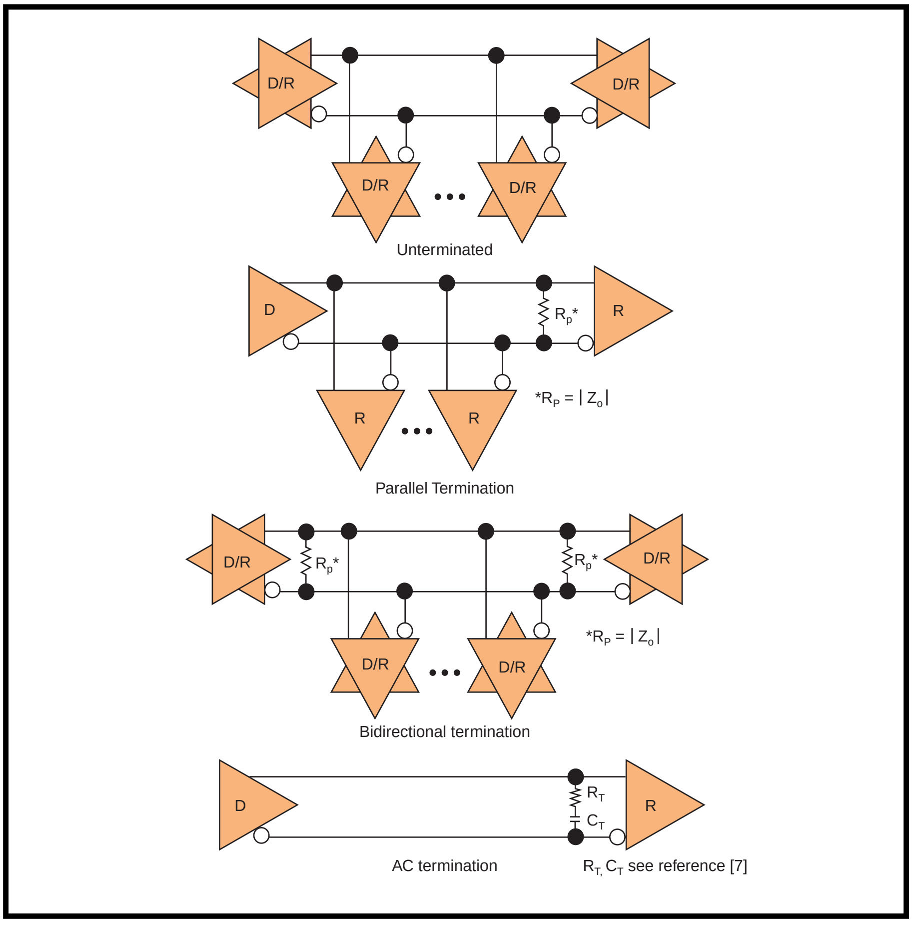


Figure 6—*Several termination methods are widely used on RS-485 networks*

at both ends, they resonate at L/4.

The best method for minimizing energy on an unused conductor is to dissipate the energy as heat. In short, terminate both ends of the unused conductor to ground with resistors (a bidirectional termination). The resistors should be equal to the characteristic impedance of the line.

IDLE-STATE BIASING

An article on RS-485 wouldn't be complete without mentioning idle-state biasing, also called failsafe biasing. Once again, National Semiconductor and John Goldie have the seminal treatise on the subject, and I would encourage you to refer to this existing work for analytical details [8].

RS-485 networks with multiple transmitters on the same communication channel rely on the line drivers to tristate when not talking. This arrangement allows the two conductors in the transmission line to float, which can cause the line receivers listening to the network to register false data. TIA/EIA-485-A purposely leaves the region of less than 200 mV of differential voltage as an undefined state.

To get around this situation, two resistors are often used to pull one line high while the other line is pulled low. This process is referred to as idle-state biasing because the line is said to be idle when it is not being actively driven by a transmitter.

The impact of the idle-state bias resistors on line termination must be considered, as should their physical location in the network. Depending on the application, it may be better to use a series of high-valued resistors distributed across many nodes than two smaller-valued resistors placed at the end of the line.

Another situation to consider is what happens when power goes down to a node with idle-state bias resistors installed. And likewise, what effect on the network's idle state is there when a node with failsafe biasing is removed from the network? These issues and more are adequately addressed by Goldie [8].

TRANSIENTS

ESD and capacitively or inductively coupled transients are a fact of life often overlooked when designing communication networks. Recently, I was part of an investigative team of engineers sent to a customer's site to assist in determining why 200–400 of their 4000 RS-485 nodes were going down daily. The problem turned out to be transient voltages on the data lines.

The network had a mix of RS-485–based equipment on it. Several different manufacturers supplied the various pieces of equipment. The failures were mostly isolated to RS-485 receiver chips but were not isolated to just our equipment.

The failures had existed at a nuisance level for several years. Then late last year, the customer experienced a drastic increase in failure rates. By the time we were called, 10% of their nodes were going down each day.

Over the last few years, several network consultants had been brought in to address the network failures. None of them met with much success. By the time we arrived, the failure rate was at a catastrophic level.

The customer had done almost everything by the book. The network cabling was commercial CAT-5. The network topology was straightforward. The lines were adequately terminated. Each node had a power supply isolated from earth ground. The network cable had a wire dedicated to connecting signal grounds between nodes.

Each individual network consisted of 50–150 nodes and each node used a 1-UL receiver. Although this violated TIA/EIA-485-A, an oscilloscope verified that the transmission lines were carrying nice clean square waves of reasonable magnitude and offsets. And besides, the receiver chips were blowing, not the transmitters.

Most of the receiver chips were dual or quad devices. Autopsies performed on the damaged chips revealed that often only one receiver on the chip was blown; the others were usually functional.

After a while, it was clear that transient voltages were finding their way onto the data lines. We were not able to identify any single source or to nail down any single coupling mechanism. Even if we were, the facility was fixed and we probably couldn't have altered the system to mitigate the source(s) or coupling mechanisms. We had to devise a method of eliminating the problem at the board level.

First, we had to find a method of mimicking the symptoms in the lab. To accomplish this, we used a Shaffner NSG-435 ESD gun to simulate transient events on the transmission lines. After building a small network in the lab and discharging energy into the data lines directly, we found that the most common receiver in the customer's system, a TI 75175 quad receiver, was always destroyed with a single 2-kV air-gap discharge into either or both data lines. We saw one part fail as low as 1 kV. The most common threshold seemed to be 1.4–1.7 kV.

It's interesting to note that a 1-kV air gap discharge is right on the edge of human perception. This means the receiver chips could be destroyed by ESD that may not even be noticeable to a human technician.

We tried two TVS schemes with the existing receivers. Both increased the ability of the receivers to tolerated transient events.

Figure 7a shows the simplest and most effective method. The circuit in Figure 7a seemed to protect the 75175s to about 8 kV. The tradeoff for good transient voltage protection is a fairly high capacitive loading. The TranZorbs used had an open-circuit capacitance of 500 pF.

Figure 7b shows our second experiment, which only protected the 75175s to about 4 kV. The circuit uses a bridge with a low capacitance (about 13 pF) in series with the TranZorbs. This is a fairly common circuit used to protect high-speed data lines.

Our experiments were done in haste, and although we maintained as much laboratory discipline as we could muster, further experiments should be run before the above thresholds of 4 and 8 kV are accepted as gospel. However, the results are certainly valid in a qualitative sense. Both TVS schemes provided significant improvement in the ability of the TI 75175 to withstand transient voltage events.

Our last experiment involved a Maxim part, the MAX3095. The datasheet for this part claims a ±15-kV protection using IEC1000-4-2 air-gap discharge, ±8 kV using IEC1000-4-2 contact discharge, and ±15 kV using the Human Body Model. Even though the Maxim part has only been out about a year, availability is good.

Using our ESD gun, we methodically zapped the Maxim part but were unable to destroy or even notably degrade the performance of any of the MAX3095 parts we tested. In a last ditch 4:30 A.M. attempt to get a failure point for the Maxim data set, we hammered one of the parts with 50 shots of 16.5-kV air-gap discharges. The NiCad battery pack on our ESD gun ran down, but the MAX3095 didn't even blink.

We only had a small group of five sacrificial Maxim chips. So, once again, the limited sample set puts the quantitative value of our data in the dubious column at best. However, it is clear qualitatively that the MAX3095 is a rugged little part.

Maxim is infamous for long lead times, super-high prices, and lackluster customer support, but I've never heard of Maxim lying on a datasheet. I'm not a fan of Maxim's aloof manner of doing business, but I do believe their datasheets and I'm totally sold on this little receiver.

Maxim has parts with high ESD ratings that are pin compatible with the widely used MC1488 and MC1489 parts for RS-232 applications, as well as other ESD-hardened interface parts.

In the end, we recommended trading out the TI 75175 for the MAX3095. These two parts are not pin-for-pin compatible in all applications, but for our customer's equipment, the MAX3095 dropped right into the existing 75175 sockets and fired up.

The MAX3095 is a $^1/_4$ UL part, which meant that we were also reducing the load on the network by 4×. The longest runs of 150 nodes were still slightly above the TIA/EIA-485-A allowable limit of 32 ULs (150/4- ~38). After installing the Maxim parts, the signal levels on all the transmission lines improved significantly.

At the time of this writing, our customer has over eight million machine hours on the MAX3095s and not a single failure of the Maxim parts. This was as close to a silver bullet as I've ever seen. Only time will tell if the MAX3095s will weaken with age and have to be placed on a preventative maintenance schedule, but it doesn't look like that will be the case.

I learned one other interesting lesson from this trip. Beware the local customs. The customer's maintenance crew was fairly sharp. Years ago, the technicians learned that the most delicate part was the receiver chip, so they adopted the custom of carrying tubes of these parts around and replacing the parts in situ.

This facility was one of the worst imaginable environments for ESD. Humidity was 10–17%. The crews were required to wear polyester uniforms and most of the facility was carpeted.

The maintenance personnel were not trained in basic ESD precautions. In the process of replacing damaged ICs, they were damaging the new ICs they were installing. Furthermore, the technicians would handle bare network cable during the repair, which meant they would discharge static electricity into the transmission, damaging other nodes on the network. Remember our lab tests where the TI 75175 failed at level of ESD that

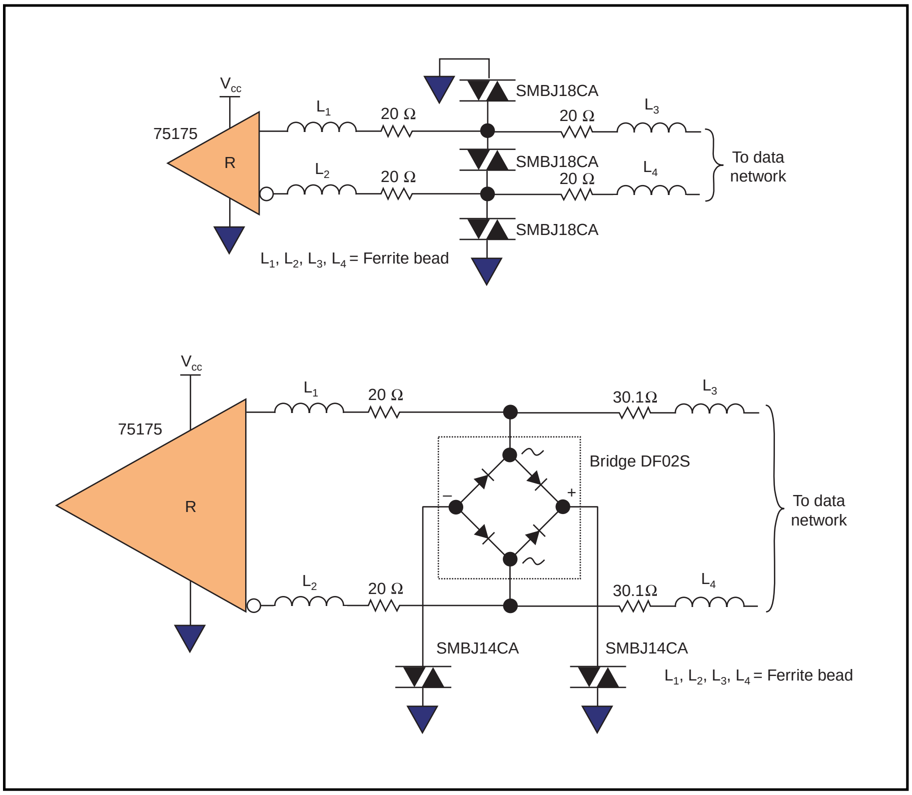


Figure 7a—*TVSs directly on the data line provide the highest level of protection and the highest capacitive loading of the transmission line.* ***b—****This is common circuit for protecting high-speed data lines.*

was barely perceptible to humans?

Also, cable contractors were often employed by the facility. These contractors would install or modify network cable to suit the needs of the facility's ever-changing geometry. The contractors were handling bare network cable, with hundreds of nodes connected, and using no ESD protocol.

Our customer has since trained their maintenance personnel in proper ESD protocol. As a matter of contract, outside cable consultants are required to undergo the same ESD training and exercises as the in-house staff. These procedures have significantly contributed to the reduction of failures.

REVIEW TIME

RS-485 is not difficult, but any workhorse requires care and feeding. Before starting your RS-485 project, arm yourself with the TIA/EIA-485-A and TSB-89 documents.

While designing, rely on the many examples others have published in articles and application notes. Keep an eye out for non-network-related problems like ESD, power-supply noise, and ground bounce. The currents switched at the drivers can be quite high. Also watch out for new parts like the MAX3095. They may be just what the doctor ordered for your future designs.

Engineering is simply keeping track of details and making tradeoffs. RS-485 is no different. We're lucky because most of the really ugly tradeoffs have been made by the standards. But you probably don't have to worry about having your job phased out as there are still plenty of other details left to keep track of.

Bob Perrin spends his days designing general-purpose C-programmable embedded controllers and troubleshooting customer system-level problems for Z-World (www.zworld.com). Over the last ten years, Bob has designed instrumentation for agronomy, soil physics, and water activity research. He was also the lead design engineer for an intrinsically safe line of workstations for use in explosive gas and particulate environments (class 1, divisions 1 and 2). For more articles by Bob, visit his online library at www.engineerbob.com.

REFERENCES

[1] J. Goldie, *Ten Ways to Bulletproof RS-485 Interfaces*, National Semiconductor, App note AN-1057, 1996.

[2] Robust DataComm, *Grounding and RS-422/485 (No Free Lunch!)*, Robust DataComm, App note 5, 1997.

[3] R. Morrison, *Grounding and Shielding Techniques in Instrumentation*, 3d ed., Wiley and Sons, New York, NY, 1986.

[4] R. Morrison, *Solving Interference Problems in Electronics*, Wiley and Sons, New York, NY, 1995.

[5] Robust DataComm, *Surge Management*, Robust DataComm, App note 18, 1997.

[6] H.W. Ott, *Noise Reduction Techniques in Electronic Systems*, 2d ed., Wiley and Sons, New York, NY, 1988.

[7] J. Vo, *A Comparison of Differential Termination Techniques*, National Semiconductor, App note AN-903, 1993.

[8] J. Goldie, *Failsafe Biasing of Differential Buses*, National Semiconductor, App Note AN-847, 1992.

SOURCES

RS-485 cable
Alpha Wire Co.
(800) 522-5742
(908) 985-8000
Fax: (908) 925-6923
www.alphawire.com

Belden Wire and Cable Co.
(800) 235-3361
(765) 983-5200
Fax: (765) 983-5294
www.belden.com

TransZorb
General Semiconductor
(516) 847-3113
Fax: (516) 847-3236
www.gensemi.com

MAX3095
Maxim Integrated Products
(408) 737-7600
Fax: (408) 737-7194
www.maxim-ic.com

NSG-435 ESD gun
Schaffner EMC, Inc.
(973) 379-7778
www.schaffner.com

TI 75175
Texas Instruments, Inc.
(800) 477-8924, x4500
(972) 995-2011
Fax: (972) 995-4360
www.ti.com

TIA/EIA-485-A, **TSB89-Application guidelines for TIA/EIA-485-A**
Global Engineering Documents
(800) 854-7179
(303) 397-7956
Fax: (303) 397-2740
global.ihs.com

National Semiconductor
(408) 721-5000
Fax: (408) 739-9803
www.national.com

Robust DataComm, Inc.
(612) 628-0533
www.robustdc.com

Ten Ways to Bulletproof RS-485 Interfaces

National Semiconductor
Application Note 1057
John Goldie
October 1996

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 Telecommunitcations 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, and
- Fail-safe biasing.

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.

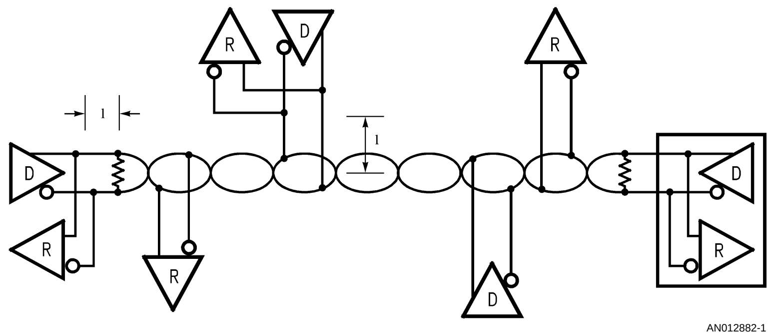
RS-485 allows for connection of up to 32 unit loads (ULs) to the bus. The 32 ULs can include many devices but commonly comprise 32 transceivers. *Figure 1* illustrates a multipoint bus. In this application, three transceivers — two receivers receivers and one driver — connect to the twisted pair. You 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.

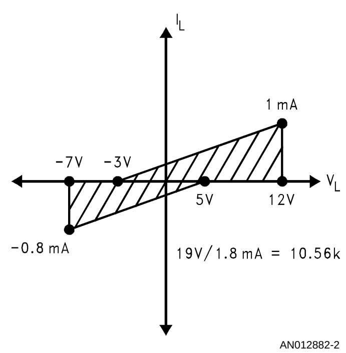
Note:

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 (Reference 1). Therefore, a conservative estimate is that, without using special transceivers, a bus can include 32 transceivers.



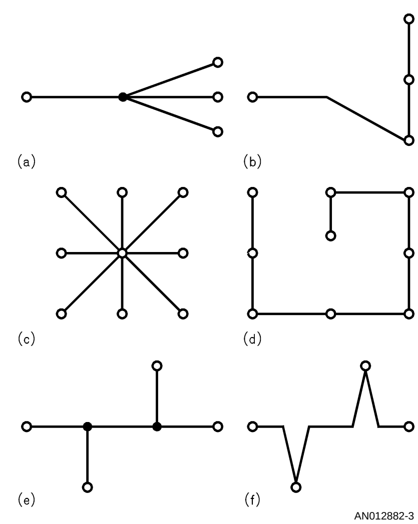
An RS-485 bus supports two-way data transfer over a single pair of wires. A typical bus includes multiple nodes. Each transceiver includes a differential driver, D, and a differential receiver, R. The stub length is l. The bus is terminated only at the ends — not at each node.

FIGURE 1.



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

FIGURE 2.



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.

A final word of 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.

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 3c*) 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.

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.

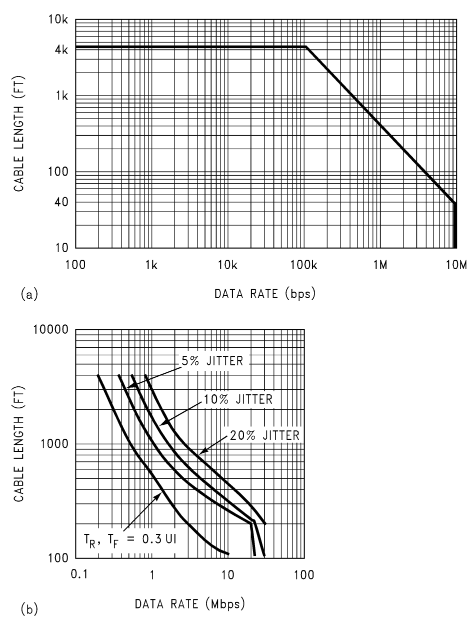
Twisted pair offers noise benefits over flat or ribbon cables. In flat cable, a noise source (usually a conductor carrying an unrelated signal) can be closer to one member of the conductor pair than to the other over an entire wiring-run length. In such cases, more noise capacitively couples to the closer 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.

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 4a* 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 4b* 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.

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 (Reference 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.

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.

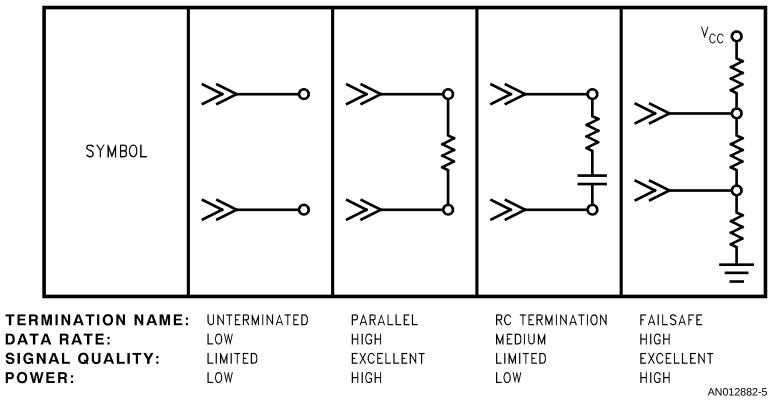
TERMINATION OPTIONS

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 seris 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, however (Reference 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.



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.

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 slighly 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.

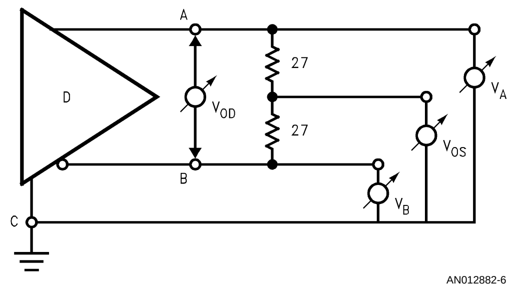
V_{OS} represents the driver's offset voltage measured from the center point of the load with respect to the driver's ground reference. V_{OS} is also called "V_{OC}" for output common-mode voltage. This parameter is related to V_{CM}.

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,

$$V_{CM} = V_{OS} + V_{NOISE} + V_{GPD}.$$

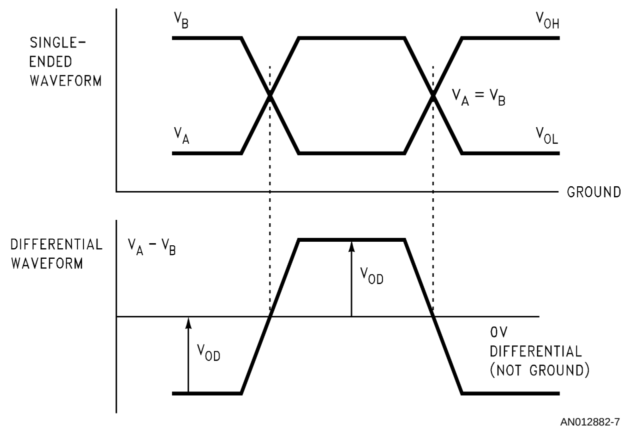
V_{GPD} represents the ground-potential difference that can exist between nodes in the system. RS-485 allows for a 7V shift in grounds. A shift of 7V below the negative (0V) power rail yields the −7V common-mode limit, whereas 7V above the 5V positive power rail yields the other common-mode limit of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

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.



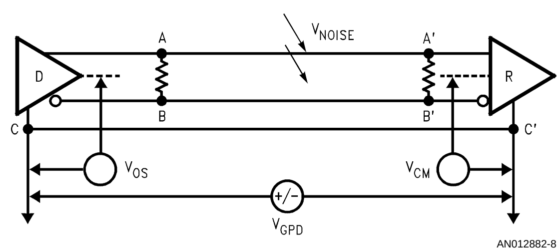
Because RS-485 buses are differential, they involve parameters that have no counterparts in single-ended systems.

FIGURE 6.



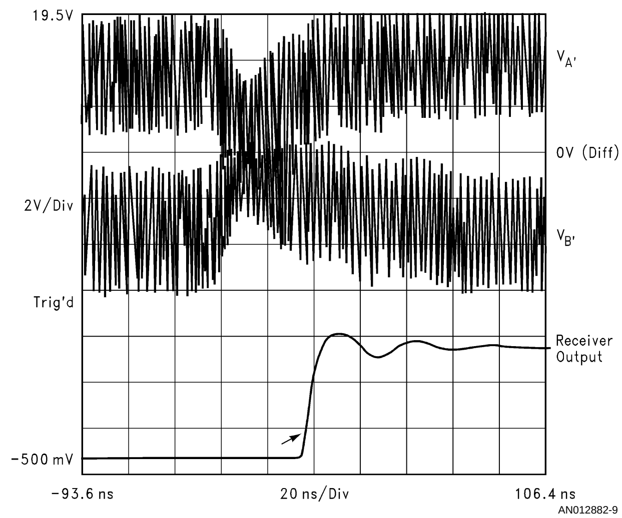
Although the voltages on the bus's two conductors vary symmetrically about a value that is halfway between the driver's Low and High output-state values, the differential voltage between the conductors varies about zero. In addition, the differential voltage swing is double the swing on either of the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



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.

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.

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.

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.

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 the following section 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.

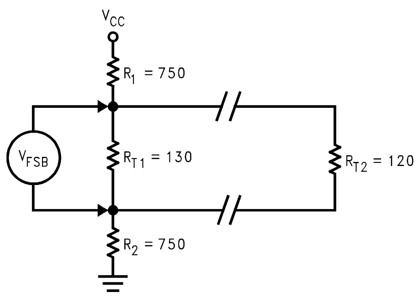
FAIL-SAFE BIASING

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. Reference 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.



AN012882-10

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.

REFERENCES

1. Murdock, G and J Goldie, "AN-702: Build a direction-sensing bidirectional repeater," *Interface Databook*, National Semiconductor Corp, 1996.

2. True, K, "AN-808: Long transmission lines and data-signal quality." *Interface Databook*, National Semiconductor Corp, 1996.

3. Vo, J. "AN-903: A comparison of differential-termination techniques," *Interface Databook*, National Semiconductor Corp, 1996.

4. Goldie, J, "AN-847: Fail-safe biasing of differential buses," *Interface Databook*, National Semiconductor Corp, 1996.

5. ANSI/TIA/EIA-422-B-1995, *Electrical characteristics of balanced-voltage digital-interface circuits*.

6. EIA RS-485-1983, *Electrical characteristics of generators and receivers for use in balanced digital-multipoint systems*.

7. Sivasothy, S, "AN-409: Transceivers and repeaters meeting the EIA RS-485 interface standard," *Interface Databook*, National Semiconductor Corp, 1996.

8. ISO/IEC 8482:1993, *Information technology — telecommunications and information exchange between systems — twisted-pair multipoint interconnections*.

Ten Ways to Bulletproof RS-485 Interfaces

AN-1057

National Semiconductor Corporation
Americas
Tel: 1-800-272-9959
Fax: 1-800-737-7018
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 1 80-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 1 80-530 85 85
English Tel: +49 (0) 1 80-532 78 32
Français Tel: +49 (0) 1 80-532 93 58
Italiano Tel: +49 (0) 1 80-534 16 80

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: sea.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5620-6175
Fax: 81-3-5620-6179