

RS-485

Design Guidelines

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October 2010

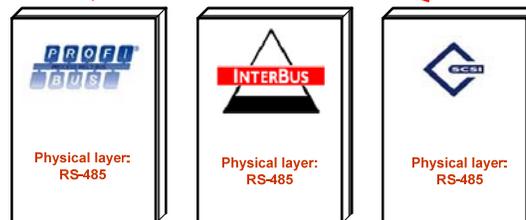
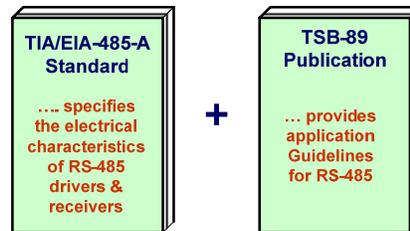
Standard Designation, Purpose & Features

1983

RS-485 → **TIA/EIA-485**

Key Features

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



Standard & 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 multi-point transmission line.

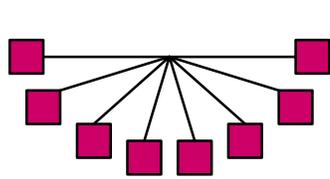
This standard, however, is intended to be referenced by higher level standards, such as DL/T645 for example, which defines the communication protocol for electronic energy-meters in China, specifying RS-485 as the physical layer standard.

Further examples include PROFIBUS, INTERBUS and SCSI.

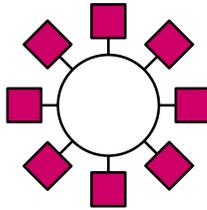
Key features of RS-485 are:

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

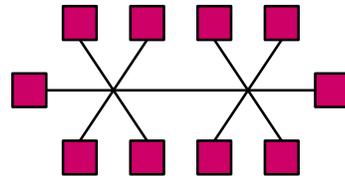
Suggested Network Topology



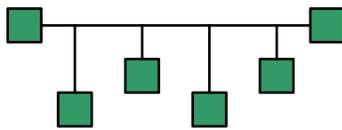
Star network (avoid)



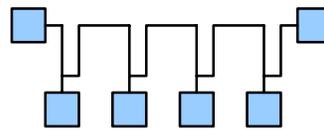
Ring network (avoid)



Backbone with stars or clusters (avoid)



Backbone with stubs (works)

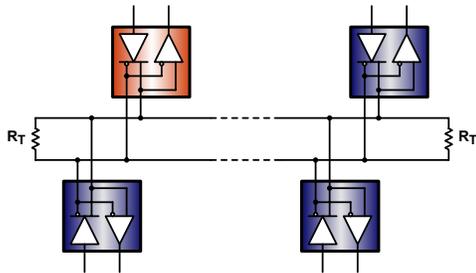


Daisy chain (best)

Network Topology

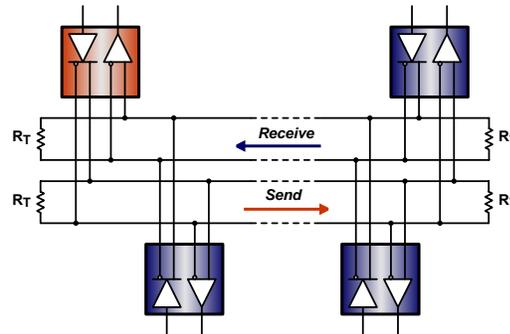
RS-485 suggests its nodes to be networked in a daisy-chain, or bus topology. In this topology the participating drivers, receivers, and transceivers connect to a main cable trunk via short network stubs. The interface bus can be designed for full-duplex or half-duplex transmission.

Half-Duplex & Full-Duplex



Sequential transmitting and receiving
over one signal pair

Vast majority of applications uses
Half - Duplex

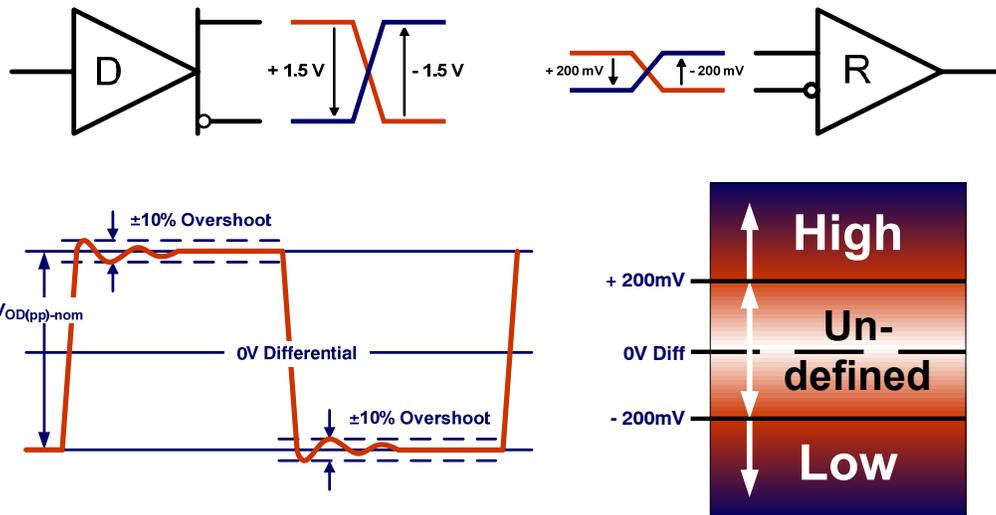


Simultaneous transmitting and receiving
over two signal pairs

The full-duplex implementation requires two signal pairs, (4 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.

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.

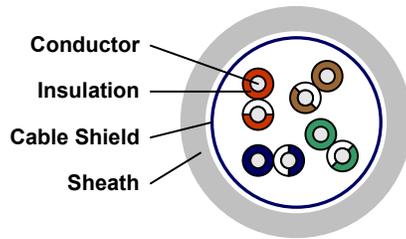
Signal Levels



Signal Levels

RS-485 standard conform drivers provide a differential output of minimum 1.5V across a 54 Ω load, while 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.

Cabling



Cable : Belden 3109A

Type : 4 - pair, 22 AWG PLCT/CM

Impedance : 120 Ω

Capacitance : 11 pF/ft

Velocity : 78% (1.3 ns/ft)

- Belden Wire and Cable Company, www.belden.com
- CommScope, www.commscope.com
- General Cable Corporation, www.generalcable.com
- Madison Cable Corporation, www.madisoncable.com
- Handbook of Wiring, Cabling, and Interconnecting for Electronics, Charles A. Harper, ed., McGraw-Hill, New York, 1972.
- Introduction to Copper Cabling, John Crisp, Newnes (Elsevier Science), Oxford, 2002.

Cable Type

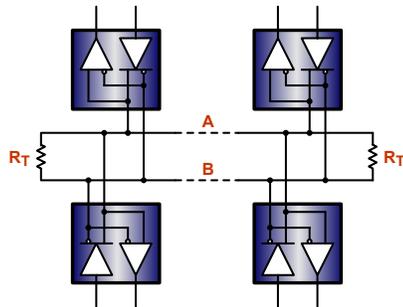
RS-485 applications benefit from differential signaling over twisted pair cable, because noise from external sources couples equally into both signal lines as common-mode noise, which is rejected by the differential receiver input.

Industrial RS-485 cables are of the sheathed, unshielded, twisted pair type, (UTP), with a characteristic impedance of 120 Ω and 22 – 24 AWG.

The slide above shows the cross section of a 4-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.

Apply these Terminations

Parallel Termination



$$R_T = Z_0$$

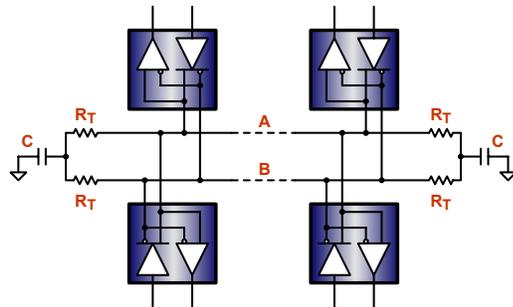


Minimized Reflections



Causes large DC Currents

Parallel Termination with
Common-Mode Filter



$$R_T = Z_0/2$$

$$C = 1/(2nf_{s-max} \cdot R_T)$$



Filters Common-mode Noise



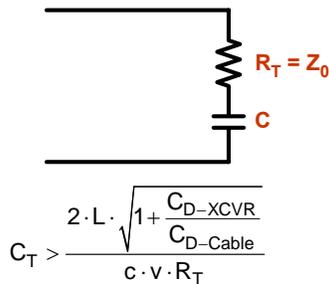
Requires Precision Resistors

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, Z_0 , of the transmission cable. Because RS-485 recommends cables with $Z_0 = 120 \Omega$, the cable trunk is commonly terminated with 120Ω resistors, one at each cable end (see left diagram).

Applications in noisy environment often have the 120Ω resistors replaced by two 60Ω low-pass filters to provide additional common-mode noise filtering, (right diagram). It is important to match the resistor values, (preferably with 1% precision resistors), to ensure equal roll-off 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.

Avoid these Terminations

AC Termination

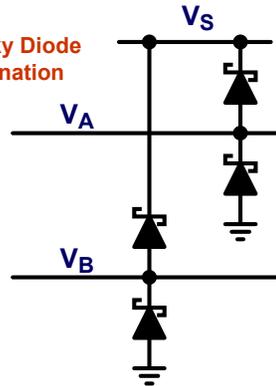


Avoids DC Currents



- Increases Signal Jitter
- Requires low Data Rate

Schottky Diode Termination



- Independent of Z_0 ,
- Applicable along the bus



- Expensive
- Works only for $V_{Signal} > V_{FW}$

AC termination blocks DC, thus saving considerable power. The RC circuit however can act as an edge generator causing significant overshoot and undershoot.

Depending on the previous data pattern, data on the line may exhibit time jitter. This occurs if a long string of like bits causes the line and the capacitor to charge to the maximum level of the driver's output voltage. Then a subsequent data bit of the opposite polarity takes longer than normal to cross the receiver threshold because it starts from a greater potential than normal.

Since the AC termination performance is dependent upon the termination line length, this type of termination does not perform well in environments where multiple sources are distributed along the line.

Schottky diode termination maintains signal integrity by clamping overshoot and undershoot caused by reflections.

No impedance matching is involved in diode termination. Power dissipation is extremely small compared to resistive termination. Effects of reflections like overshoot, undershoot, and time jitter are mitigated by good diode characteristics. Schottky diodes can be placed at any point along the line at which reflections originate.

Diode response at the switching frequency needs to be verified as the existence of multiple reflections can effect subsequent signal launches.

The diode's effectiveness decreases as signaling levels decrease. This is due to the inherent forward voltage drop, which can vary between diode types from 0.65V to more than 1V.

Stub Length Definition

$$L_{\text{Stub}} \leq \frac{t_r}{10} \cdot v \cdot c$$

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 ($9.8 \cdot 10^8$ ft/s)

Device	Signal rate [Mbps]	Rise time t_r [ns]	Max. Stub length [ft]
SN65HVD1176	40	2	0.15
SN65HVD21	5	20	1.5
SN65HVD12	1	100	7.6
SN65LBC184	0.25	250	19
SN65HVD3082E	0.2	500	38

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:

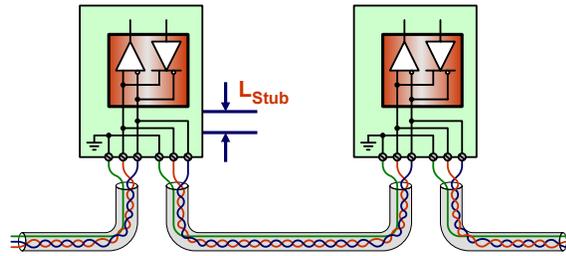
$$L_{\text{Stub}} \leq v \cdot c \cdot t_r / 10.$$

The table above lists the maximum stub lengths for various driver rise times when a cable with 78% velocity is used.

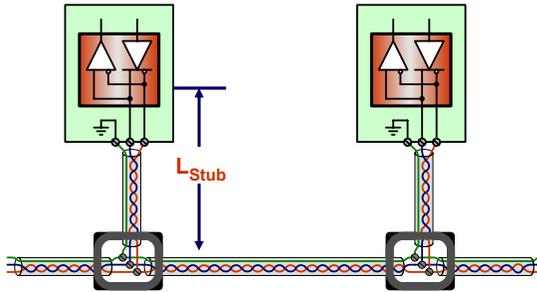
Note, drivers with long rise time are well suited for applications requiring long stub lengths and reduced, device generated EMI.

Stub Length Differences

Daisy Chain

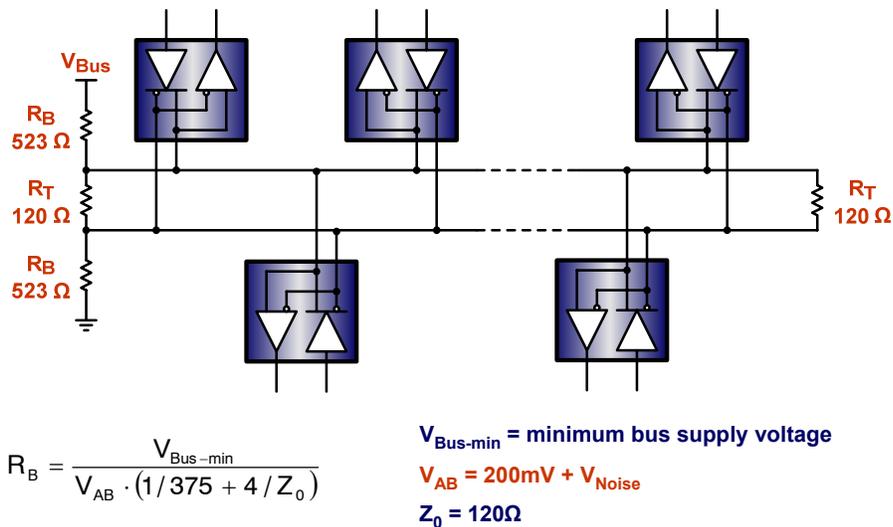


Junction
Boxes



Because a stub begins where the node connection branches off the main cable trunk, the sub lengths between a daisy chain network and a backbone network using junction boxes can differ significantly.

Failsafe Biasing



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.

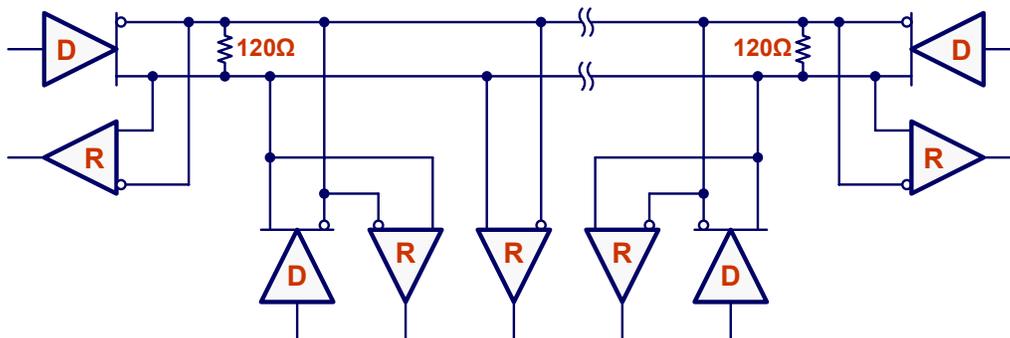
A drawback of these failsafe designs is their worst-case noise margin of < 100 mV, thus requiring external failsafe circuitry to increase noise margin for applications in very noisy environments.

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, $V_{AB} = 200 \text{ mV} + V_{Noise}$.

The values for the failsafe bias resistors, R_B , are calculated for worst-case conditions, that is, maximum noise at minimum supply.

For a minimum bus voltage of 4.75 V, (5 V - 5%), $V_{AB} = 0.25 \text{ V}$, and $Z_0 = 120 \Omega$, R_B yields 528 Ω . Inserting two 523- Ω resistors in series to R_T establishes the failsafe circuit shown above.

Bus Loading



Maximum Bus Loading without Failsafe = 32 Unit Loads ($\approx 32 \times 12\text{k}\Omega$)

*However, Maximum Bus Loading
with Failsafe decreases to :*

$$N = \frac{32 \text{ UL}_{\text{STANDARD}} - 20 \text{ UL}_{\text{FAILSAFE}}}{\text{UL per Transceiver}}$$

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 k Ω . 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.

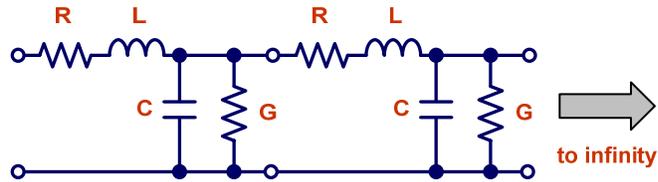
$$N = 32\text{UL} / 1/8\text{UL} = 256.$$

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

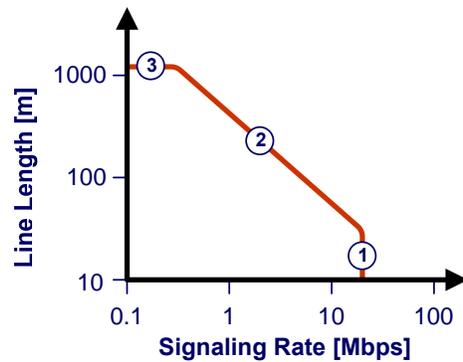
$$N = (32 \text{ UL}_{\text{Standard}} - 20 \text{ UL}_{\text{Failsafe}}) / \text{UL per Transceiver}.$$

Cable Length versus Data Rate

Transmission Line Model



Cable Length vs Data Rate
Characteristic of an RS-485 Cable
@ 10% Jitter



Data Rate versus Bus Length

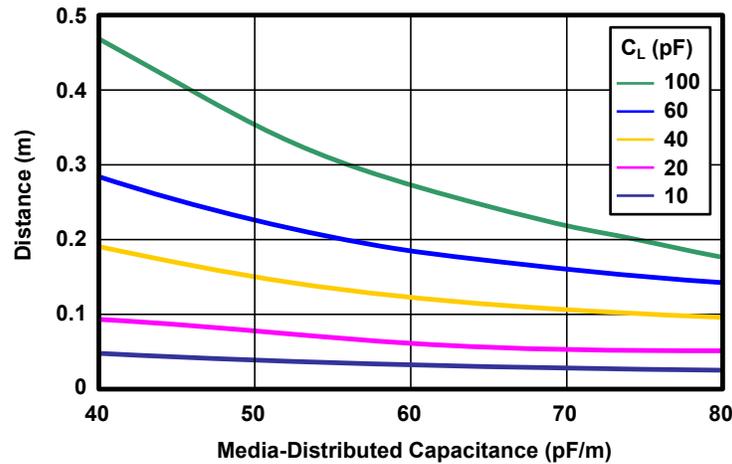
The maximum bus length is limited by the transmission line losses and the signal jitter at a given data rate. Because data reliability sharply decreases for a jitter of 10% or more of the baud period, the slide above shows the cable length versus data rate characteristic of a conventional RS-485 cable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

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. While the standard recommends 10 Mbps, today's fast interface circuits can operate at data rates of up to 40 Mbps.

Section 2 shows the transition from short to long data lines. Now 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 [ft] times the data rate [Mbps] should be smaller than 3×10^7 .

Section 3 presents the lower frequency range where the line resistance, and not switching limits the cable length. Here the cable resistance approaching the value of the termination resistor. This voltage divider diminishes the signal by -6dB. For an 22 AWG, 120 Ω , UTP this occurs at around 1200 m.

Minimum Node Distance



$$d > \frac{C_L}{5.25 \cdot C}$$

C_L is the lumped load capacitance

C , the media capacitance per unit length

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 $Z' > 0.4 \cdot Z_0$, which can be achieved by keeping the minimum distance, d , between bus nodes:

$$D > C_L / (5.25 \times C),$$

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

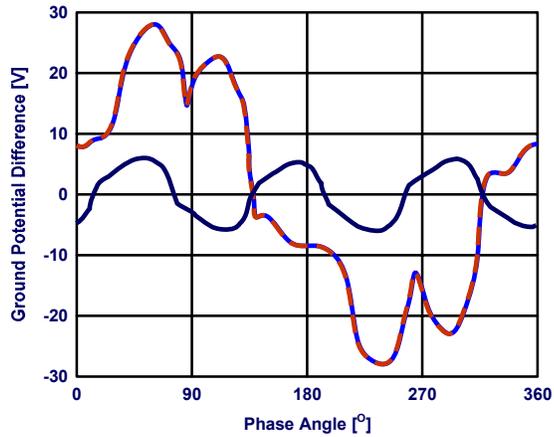
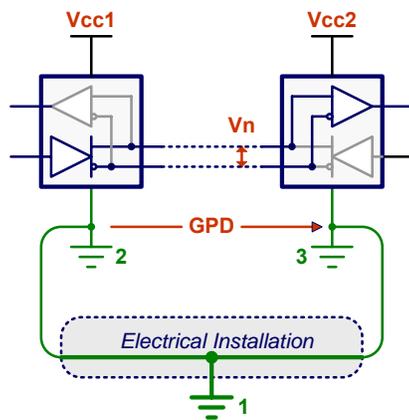
While the equation above presents the relationship for the minimum device spacing as a function of the distributed media and lumped-load capacitance, Slide 14 shows this relationship graphically.

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, while 3-V transceivers have about twice that capacitance at 16 pF. Board traces add about 0.5 to 0.8 pF/cm depending upon 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.

Ground Potential Difference (GPD)



Large GPDs add as noise voltage to the signal and, if exceeding the receiver input common-mode range, will damage or destroy the device.



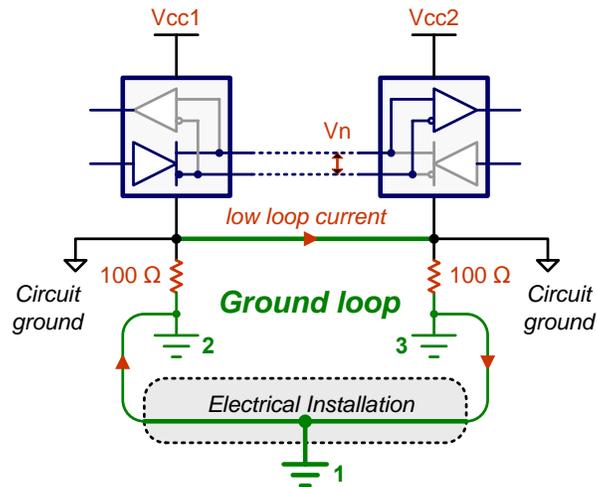
Use a ground wire !

Grounding & Isolation

When designing a remote data link, the designer must assume that large ground potential differences, (GPDs), exist. These voltages add as common-mode noise, V_n , 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.

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.

Grounding



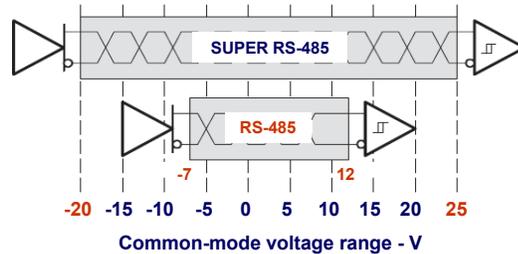
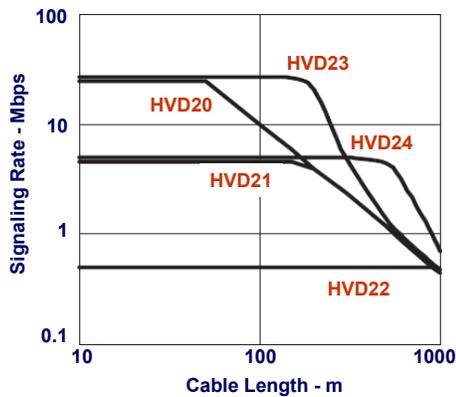
Connecting the local grounds (2) and (3) directly causes large loop currents to flow.

Limit this current by inserting resistors between local ground and circuit ground !

The direct connection of remote grounds through a ground wire is also not recommended, 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. While 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.

HVD2x Transceivers for high GPDs



Where common-mode voltages exceed the -7V to 12V range, specified by RS-485, the HVD2x family of Super RS-485 transceivers can help.

The transceivers in the HVD2x family offer performance far exceeding typical RS-485 devices. In addition to meeting all requirements of the TIA/EIA-485-A standard, the HVD2x family operates over an extended range of common-mode voltage, and has features such as high ESD protection, wide receiver hysteresis, and failsafe operation. This family of devices is ideally suited for long-cable networks, and other applications where the environment is too harsh for ordinary transceivers.

These devices are designed for bidirectional data transmission on multipoint twisted-pair cables. Example applications are digital motor controllers, remote sensors and terminals, industrial process control, security stations, and environmental control systems.

These devices combine a 3-state differential driver and a differential receiver, which operate from a single 5-V power supply. The driver differential outputs and the receiver differential inputs are connected internally to form a differential bus port that offers minimum loading to the bus.

This port features an extended common-mode voltage range making the device suitable for multipoint applications over long cable runs.

The **HVD20** provides high signaling rate (up to 25 Mbps) for interconnecting networks of up to 64 nodes.

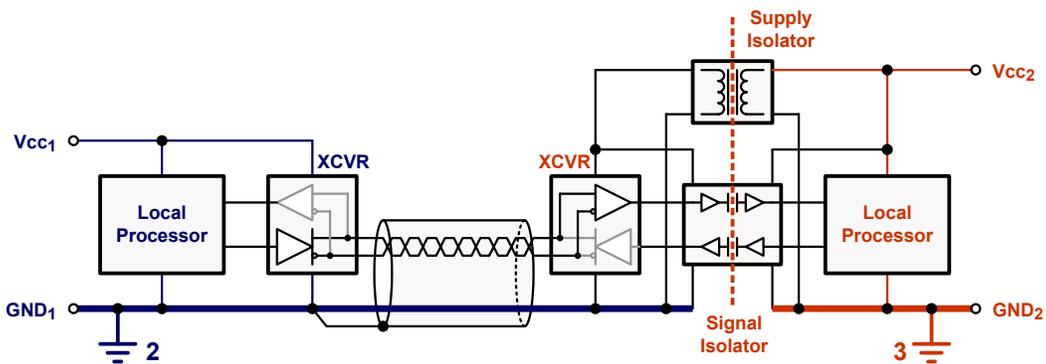
The **HVD21** allows up to 256 connected nodes at moderate data rates (up to 5 Mbps). The driver output slew rate is controlled to provide reliable switching with shaped transitions which reduce high-frequency noise emissions.

The **HVD22** has controlled driver output slew rate for low radiated noise in emission-sensitive applications and for improved signal quality with long stubs. Up to 256 **HVD22** nodes can be connected at signaling rates up to 500 kbps.

The **HVD23** implements receiver equalization technology for improved jitter performance with data rates up to 25 Mbps at cable lengths up to 160 meters.

The **HVD24** implements receiver equalization technology for improved jitter performance with data rates in the range of 1 Mbps to 10 Mbps at cable lengths up to 1000 meters.

Isolation



For very high common-mode voltages in the hundreds and even thousands of volts, galvanically isolate the bus transceivers from their local node circuits.

This includes the isolation of data lines and power supply lines.

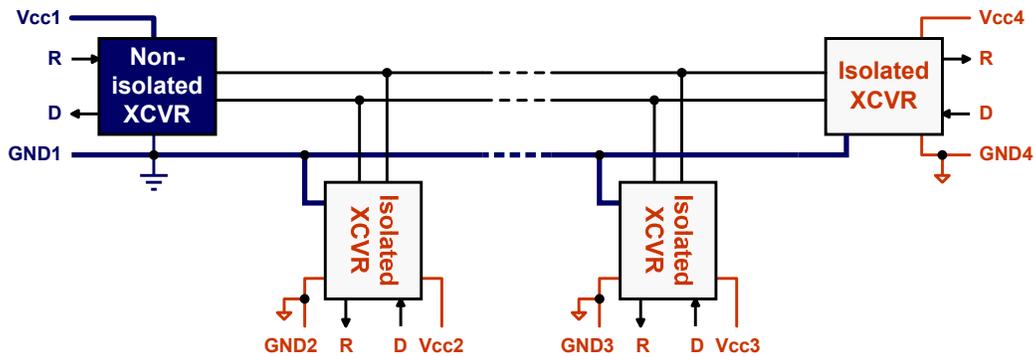
The approach to tolerate GPDs up to several kilovolts across a robust RS-485 data link and over long distance is the galvanic isolation of the signal- and supply lines of a bus transceiver from its local signal- and supply sources.

Here 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.

*Isolated DC/DC converters typically used: **DCR010505, or DCR010503***

*Digital Isolators typically used: **ISO7241***

Single Ground Reference: Theory



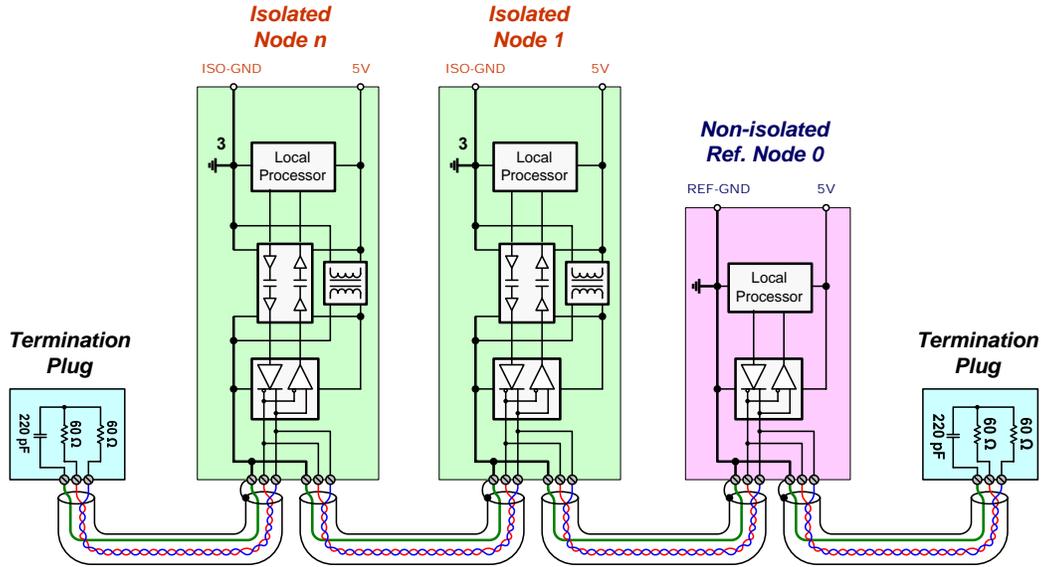
Single Ground Reference: All but one transceivers are isolated.

For data lines use: Digital, capacitive isolators of the ISO72x family

For power lines use: Isolated DC/DC converters from the DCR01050x family.

While Slide 18 shows the detailed connection of only two transceiver nodes, Slide 19 gives an example for multiple, isolated transceivers. Here all but one transceiver connect to the bus via isolation. The non-isolated transceiver on the left provides the single-ground reference for the entire bus.

Single Ground Reference: Practice



Go to [www.TI.com](http://www.ti.com) and enter the bold literature numbers into the Keyword Search field.

- Removing Ground Noise in Data Transmission Systems (**slla268**)
- Interface Circuits for TIA/EIA-485 (RS-485) (Rev. C) (**slla036c**)
- Detection of RS-485 signal loss (**slyt257**)
- Overtemperature Protection in RS-485 Line Circuits (**slla200**)
- Device spacing on RS-485 buses (**slyt241**)
- PROFIBUS Electrical-Layer Solutions (Rev. A) (**slla177a**)
- A statistical survey of common-mode noise (**slyt153**)
- Failsafe in RS-485 data buses (**slyt080**)
- The RS-485 unit load and maximum number of bus connections (**slyt086**)
- Using Signaling Rate and Transfer Rate (Rev. A) (**slla098a**)
- Operating RS-485 Transceivers at Fast Signaling Rates (**slla173**)
- RS-485 for E-Meter Applications (Rev. A) (**slla112a**)
- Failsafe in RS-485 Data Buses (**slyt064**)
- Use Receiver Equalization to Extend RS-485 Data Communications* (**slla169**)
- The RS-485 Unit Load and Maximum Number of Bus Connections (**slla166**)
- Comparing Bus Solutions (Rev. A) (**slla067a**)
- RS-485 for Digital Motor Control Applications (**slla143**)
- 422 and 485 Standards Overview and System Configurations (Rev. C) (**slla070c**)
- TIA/EIA-485 and M-LVDS, Power and Speed Comparison (**slla106**)
- Live Insertion with Differential Interface Products (**slla107**)
- The ISO72x Family of High-Speed Digital Isolators (**slla198**)

Conclusion

Without claiming to be complete, the objective of this session 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 here and consulting the detailed application reports referenced above will 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 3V and 5V regulated outputs), to provide the power supply across the isolation barrier.