RS-485 Design Guide

The purpose of this application note is to provide comprehensive information and guidelines for designing reliable, high-performance communication systems using the RS-485 interface.

Contents

1.   Standard Designation, Purpose & Features

RS-485 is a communication standard for transmitting and receiving data over long distances between devices. It uses a balanced pair of wires to send signals and can communicate at high speeds over distances up to 1200 meters. The purpose of RS-485 is to provide a reliable and robust communication protocol for industrial and commercial environments where noise and interference may be present. RS-485 supports multiple devices connected to a single pair of wires and provides options for data transmission, such as full-duplex, half-duplex, and multi-drop. It features low-power consumption, simple wiring, and the ability to communicate at high speeds over long distances, making it a popular choice for applications such as factory automation, building automation, and HVAC control systems.

2.   Suggested Network Topology

RS-485 is a communication standard that defines how devices can communicate over a serial network using a balanced pair of wires. Topology refers to how the devices are connected on the network. RS-485 supports several topologies, including point-to-point, multidrop, and daisy chain. In a point-to-point topology, two devices connect directly using a single pair of wires. In a multidrop topology, multiple devices connect to the same pair of wires, each with a unique address. In a daisy chain topology, devices connect linearly, each connected to the next number of devices, the distance between devices, and the required data rate in sequence. The choice of topology depends on the specific requirements of the application, such as the number of devices, the distance between devices, and the required data rate.
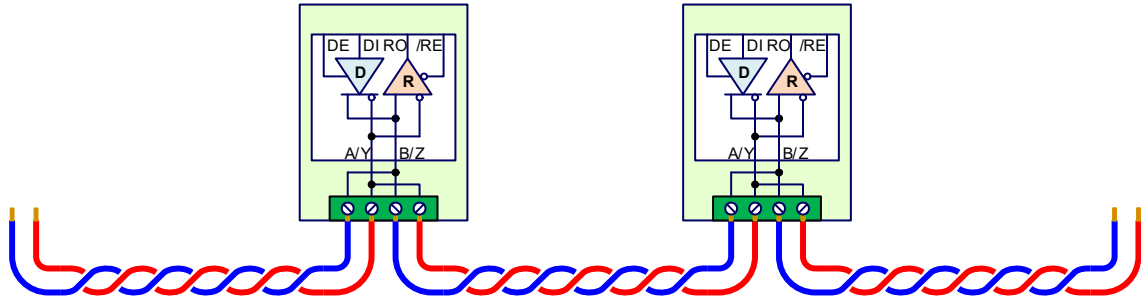
Figure 1. Daisy Chain Network Topology

3. Half-Duplex & Full-Duplex

In RS-485 communication, the difference between half-duplex and full-duplex transmission is how the data transmits over the communication channel. In half-duplex transmission, data can be sent and received over the same pair of wires, but not simultaneously. This means that devices on the network take turns transmitting and receiving data. In other words, when one device is transmitting, the other is listening, and when the other is transmitting, the first is listening. Half-duplex transmission is proper when only one device is required to communicate at a time.

In contrast, full-duplex transmission allows data to be transmitted and received simultaneously over two pairs of wires. This means that devices can send and receive data at the same time without having to take turns. Full-duplex transmission is useful when multiple devices are required to communicate with each other simultaneously. It provides faster communication and greater throughput than half-duplex transmission, but it requires additional wires for data transmission.
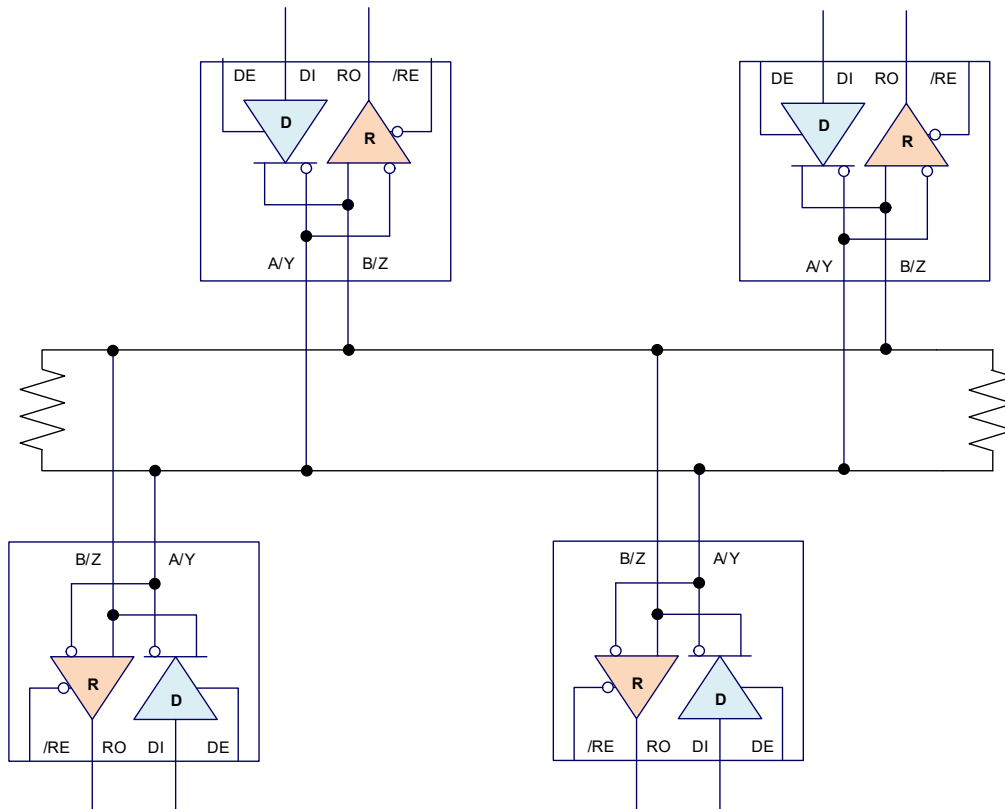

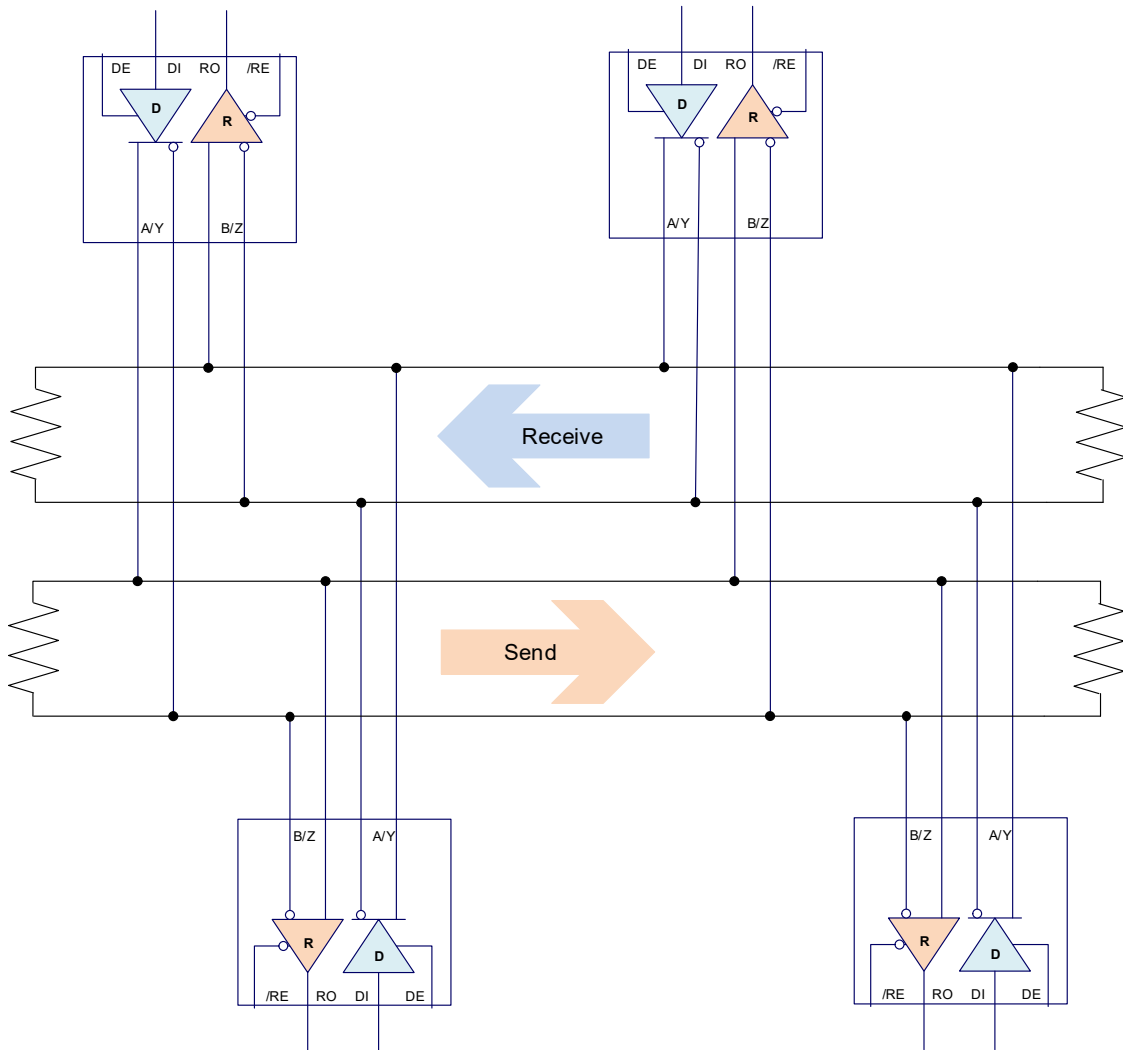**Figure 2. Half-Duplex Transmission**

Figure 3. Full-Duplex Transmission

4.   Signal Levels

The signal level standard in RS-485 refers to the specification for the electrical characteristics of the signals that are sent over the communication channel. RS-485 uses a balanced pair of wires to send signals, with each wire carrying a signal of the opposite polarity. The signal levels are specified in terms of voltage, with the standard specifying a differential voltage of at least 1.5 volts between the two wires. The voltage levels are referenced to a common ground, which is usually connected to the earth. The signal levels are designed to be robust and resistant to interference, so RS-485 is often used in industrial and commercial environments where there might be a lot of noise and other electrical disturbances. By adhering to the signal level standard, devices that use RS-485 can communicate with each other reliably over long distances.
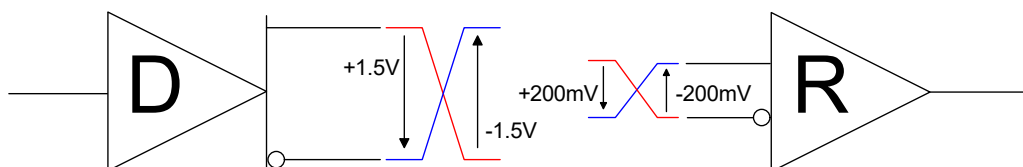

Figure 4. Signal Levels

5. Cabling

The choice of cable type for RS-485 communication depends on the specific requirements of the installation. However, in general, the best cable type for RS-485 transmission is a twisted pair cable with a characteristic impedance of 120Ω.

Twisted pair cables consist of two insulated wires that are twisted together, which helps to reduce electromagnetic interference and crosstalk between wires. The characteristic impedance of the cable refers to the resistance to the flow of electrical signals and matching the impedance of the cable with the impedance of the devices on the network can help to prevent signal reflections and improve signal integrity.

A cable with a characteristic impedance of 120Ω is recommended for RS-485 communication because it is the most used impedance value for RS-485 communication, and many RS-485 devices are designed to work with this value. Using a cable with a different impedance value might cause signal reflections and other issues that can affect the performance and reliability of the communication. Additionally, the cable should be shielded to reduce the effects of electromagnetic interference and other electrical noise.

6. Bus Termination

To prevent signal reflections in RS485 communication, data transmission lines should be terminated and any branch lines or stubs should be kept as short as possible. Proper termination involves matching the terminating resistors to the characteristic impedance of the transmission cable. Since RS-485 cables typically have a characteristic impedance of 120Ω, the cable trunk is usually terminated with 120Ω resistors, one at each end of the cable. In noisy environments, the 120Ω resistors might be replaced by two 60Ω low-pass filters, which provide additional filtering of common-mode noise. To ensure proper filtering, the resistor values should be matched as closely as possible, preferably with 1% precision resistors. Using resistors with larger tolerances, such as 20%, can cause the filter corner frequencies to differ and can compromise the ability of the receiver to filter out common-mode noise, which can affect the reliability of the communication.
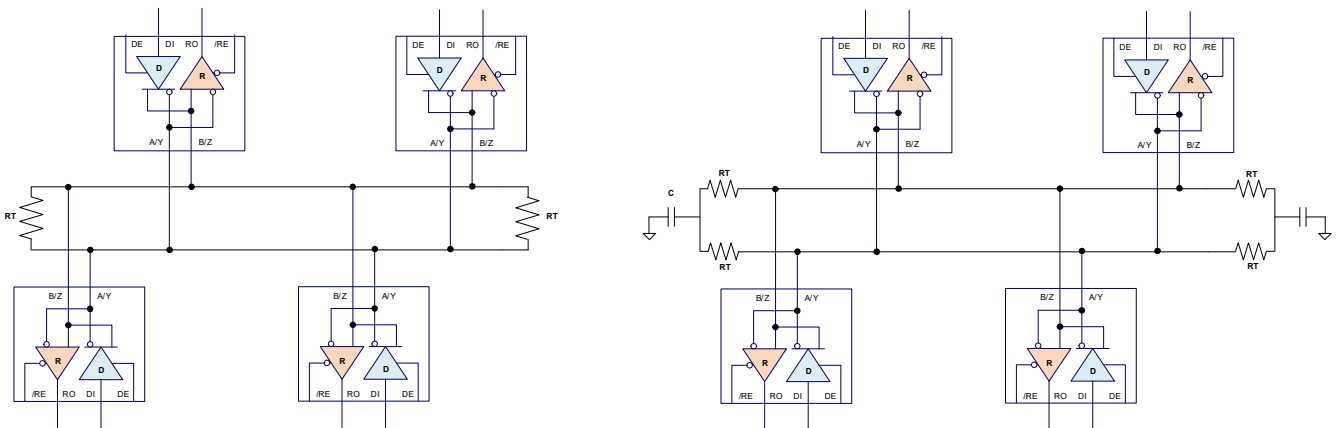

Figure 5. Bus Terminations

7. Stub Length

In RS-485 communication, a stub is a branch off of the main communication line that connects to a device or group of devices. The length of a stub is defined as the distance between the main communication line and the point at which the stub branches off. Stubs can cause signal reflections on the main communication line, which can lead to errors or even complete signal loss. The longer the stub, the greater the risk of signal reflections, which is why it is recommended to keep the stubs as short as possible. To avoid signal reflections, the stubs can be terminated with resistors to match the characteristic impedance of the main communication line. Additionally, the use of multi-drop repeaters can help to reduce the effects of signal reflections caused by long stubs.
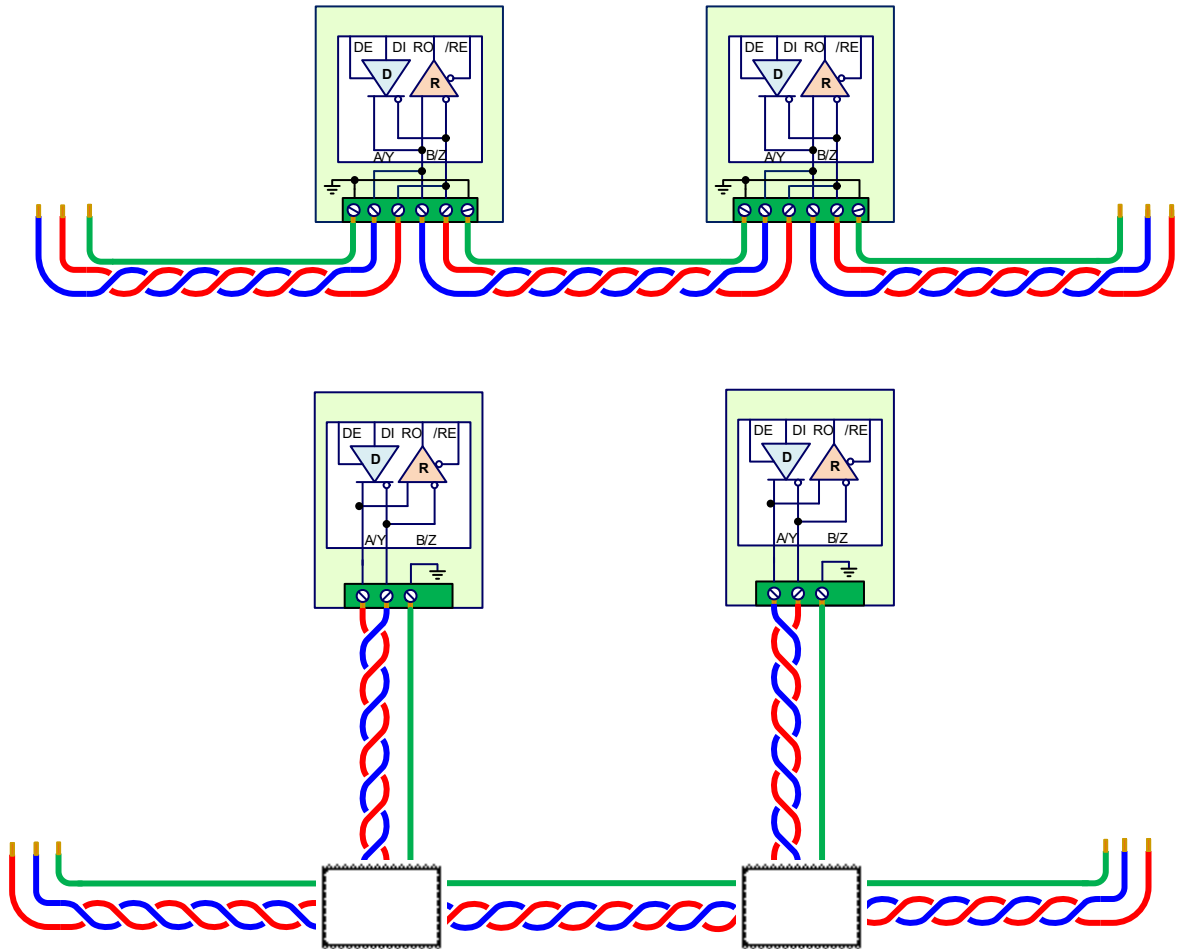
Figure 6. Stub Length

8.   Failsafe Biasing

Failsafe biasing is an important aspect of the RS-485 standard. It ensures that the receiver output of a transceiver is in a determined state when no signal is present on the transmission line, which can happen for reasons such as an open-circuit or idle-bus condition.

Without failsafe biasing, the receiver output of a transceiver would be in a random state, which could cause errors in data transmission. Modern transceivers have built-in biasing circuits to ensure failsafe operation, but external failsafe circuitry might be needed for applications in noisy environments. The external circuit consists of a resistive voltage divider that generates sufficient differential bus voltage to drive the receiver output into a determined state. The values for the failsafe bias resistors are calculated for worst-case conditions.
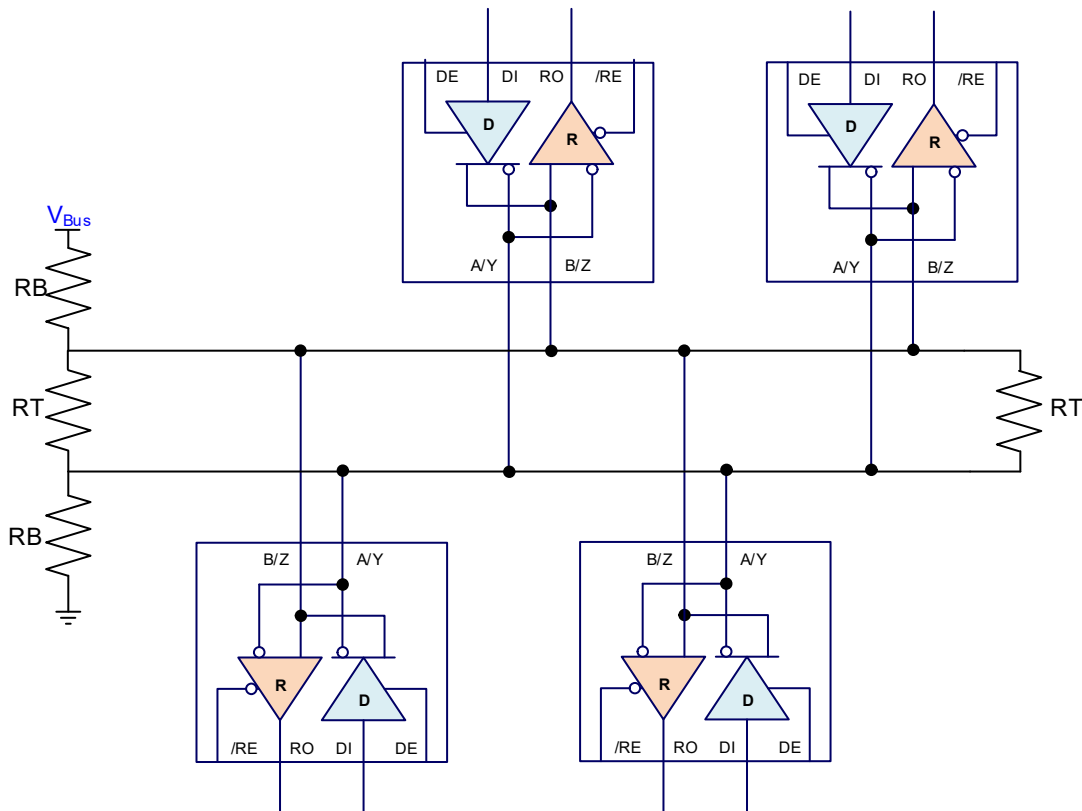
Figure 7. Failsafe Biasing

9.   Bus Loading

Adding transceivers and failsafe circuits to an RS-485 bus increases the total load current required because the output of a driver depends on the current it must supply into a load. To estimate the maximum number of bus loads possible, RS-485 defines a unit load (UL), which represents a load impedance of approximately 12kΩ. Standard compliant drivers can drive up to 32 of these unit loads. Some modern transceivers provide reduced unit loading, such as 1/8 UL, which allows the connection of up to 256 transceivers on the bus.

However, failsafe biasing adds up to 20 unit loads of bus loading, so the maximum number (N) of transceivers connected to the bus is reduced to:

(EQ. 1)
$$N = \frac{32\,ULStandard - 20\,ULFailsafe}{ULperTranceiver}$$

$$UL = unitload$$

10. Bus Length vs. Data Rate

In RS-485, the maximum bus length and data rate are related. As the bus length increases, the maximum data rate that can be supported decreases, and vice versa.

The maximum recommended data rate for a given bus length is determined by the signal propagation delay on the bus. This is the time it takes for a signal to travel from one end of the bus to the other. If the data rate is too high, the signal edges overlaps and distorts, which makes it difficult for the receiver to distinguish between ones and zeroes.

To determine the maximum data rate for a given bus length, the signal propagation delay is compared to the bit time, which is the time it takes to transmit one bit of data. The maximum data rate is then calculated as the reciprocal of the bit time. As the bus length increases, the signal propagation delay increases, which reduces the maximum data rate that can be supported.

In general, longer bus lengths require lower data rates, and shorter bus lengths allow for higher data rates. However, the maximum length of the bus also depends on factors such as the cable type and quality, noise levels, and termination. Therefore, it is important to follow the recommended guidelines for bus length and data rate for a given application.
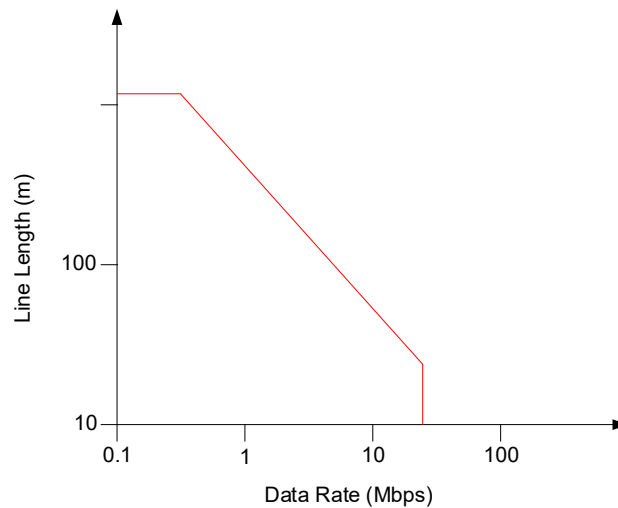

Figure 8. Bus Length vs. Data Rate

11. Minimum Node Distance

In RS-485 communication, it is important to maintain a minimum spacing between nodes (devices) on the bus to prevent signal reflections and ensure reliable data transmission. This is because the electrical characteristics of the physical media, including the interconnecting cables and printed circuit board traces, create distributed inductance and capacitance along the bus, which can cause impedance mismatches when devices are connected to it.

To ensure a valid receiver input voltage level during the first signal transition from an output driver anywhere on the bus, a minimum loaded bus impedance of Z' > 0.4 × Z0 is required. Use Equation 2 to calculate the minimum distance (d) between bus nodes, where CL is the total lumped load capacitance and C is the media capacitance (cable or PCB trace) per unit length:

(EQ. 2) $$D > \frac{CL}{5.25 \times C}$$

The 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.

The specific values for CL and C depends on the characteristics of the devices and media being used. For example, 5V transceivers typically have a capacitance of 7pF, while 3V transceivers have about twice that capacitance at 16pF. Board traces can add about 0.5 to 0.8pF/cm depending upon their construction, and connector and suppression device capacitance can vary widely. Media distributed capacitance ranges from 40pF/m for low-capacitance, unshielded twisted-pair cable to 70pF/m for backplanes. By using these values in the Equation 2, you can determine the minimum node spacing required for your RS-485 communication system.

12. Ground Potential Difference (GPD)

In an RS-485 network, ground potential difference (GPD) can occur when different parts of the network have different electrical ground potentials. GPD can cause communication errors or even damage to equipment, as it can create a voltage potential between two nodes that is not accounted for in the system design.

Ground potential difference can occur when a device in one part of the network is connected to a different power source or ground than a device in another part of the network. If these devices share a signal reference, such as the signal ground in an RS-485 network, the voltage potential between them can create current flow through the signal ground. This current flow can cause voltage drops in the signal ground and can interfere with signal transmission, potentially leading to data errors.

To prevent ground potential difference, it is important to ensure that all devices in an RS-485 network share a common ground reference. This can be achieved by connecting all signal grounds to a common point, typically at the point where the network enters or exits the system. Additionally, any devices with isolated power supplies should use isolated RS-485 transceivers to avoid creating a ground loop. Proper grounding and isolation are important aspects of designing a reliable and robust RS-485 network.
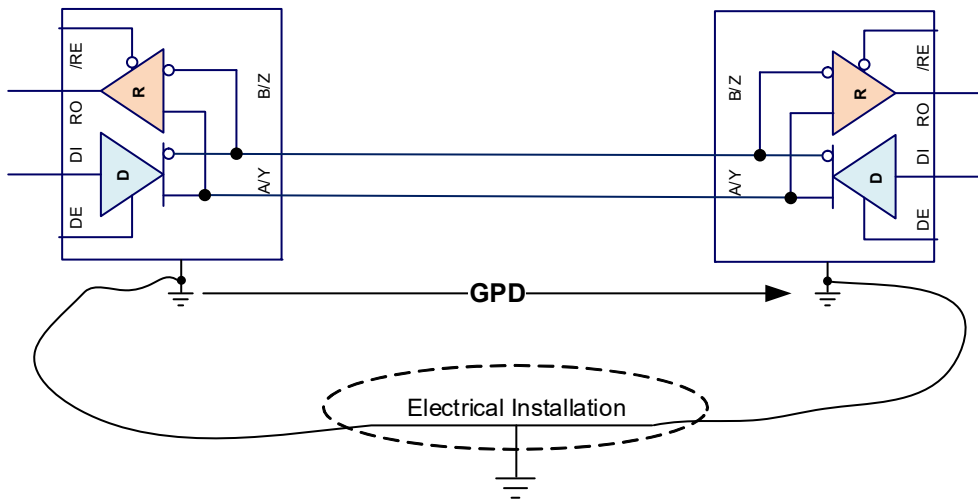

Figure 9. Ground Potential Difference

13. Revision History

Revision	Date	Description
1.00	Sep 12, 2023	Initial release.

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