Technical Note 121

RS-485 Design and install best practices

Guidelines for successful communication

Variable Frequency Drives (VFDs) commonly include embedded fieldbus communications for network control and monitoring using a serial communication protocol based on the RS-485 standard. This technical note covers some of the design requirements for creating a successful network including wiring, shielding, polarity, terminations (End of Line), biasing, unit load (UL), data rates, network lengths and topology. In the early 1980s, the RS-485 electrical standard for serial communication was defined by the Electronic Industries Association (EIA). Eventually the Telecommunications Industry Association (TIA) took ownership to maintain the standard. Although the naming convention technically changed to EIA-485 or TIA-485 and has begun to be used interchangeably, the industry still commonly refers to this standard as RS-485 so for this paper we will stick to that name as well.

Technically, RS-485 is not a communications standard for protocols such as BACnet MS/TP but the requirements for electrical signal transmission across a medium, in our case copper wire. Because of this, RS-485 is used with multiple communication protocols such as BACnet MS/TP, Modbus RTU, LONtalk, and Profibus available on the ACH580, ACS580, ACQ580 and their communication option modules.

Wiring, how many conductors and why twisted

To understand how many wires should be used when communicating with a serial protocol lets first understand how the communication occurs. Each device will have a driver to generate signals and a receiver to detect signals, named a transceiver. The signal will be a change in voltage across a load as low as 1.5 volts differential from a driver. While a receiver should be able to detect a differential voltage as small as 200 millivolts. Since this is a relatively small voltage there are several possible influences on the wire that could affect receivers from missing a signal or misinterpreting a voltage change as a signal. The max range of voltage per RS-485 is -7 to +12 volts when measured between the terminals of A(-) or B(+) to the reference wire REF.

One possible influence will be a floating reference voltage for isolated devices. Two wire devices will likely have non-isolated transceiver which share a reference to chassis ground internally. While three wire devices will have isolated transceiver, disconnected from the rest of the internal electronics. The benefit is the signal circuit will be isolated from noise generated on a device, such as VFDs. A reference between transceivers or a common electrical connection like chassis ground is required, otherwise the signal voltage will be floating. What should be a 5 V signal from one device could be 15 V at another if its reference to 0 V was actually floating at 10 V.

If your RS-485 communication link includes only isolated devices, with a third connection for reference, the ideal cabling will be a twisted pair for +(B), –(A) and a third wire terminating on REF, DGND, or COM. Sometimes these will need to be 4 conductor, twisted pair cables or maybe called 1.5 conductor twisted pair. If your comm link is a mix of two wire and three wire devices, you will still be able to provide a reference for the isolated devices by using the third wire connection and by tying them together but through small (100 ohm) pull-down resistor to chassis ground.

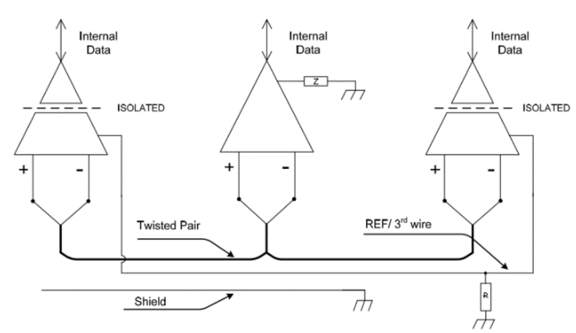


Figure 1: Mixed devices on 3-conductor cable with shield

So why are the wires twisted? This is where the signal differential voltage is an important distinction. If at any point along the cable, there is electromagnetic interference (EMI) event that induces a current on the cable it will affect both wires since they are twisted. The total voltage on each wire may then change but equally so the differential voltage will remain the same.

Figure 2: RS-485 cable, 1 pair twisted, 1 conductor

Shielding, where it terminates

The communication cable shield is another layer of protection from interference. It works to block EMI from inducing current along long stretches of cable run that may come within the magnetic field of other cables that produce EMI. For the shield to properly mitigate that interference it needs to provide a path for the current to flow that doesn't then affect the comm wires. The shield needs be to be a continuous connection from each device, and only terminating to ground at one location. Preferably the ground connection is at the main supervisor controller of your network. This prevents ground current loops which could produce noise or interference in the comm wires that the shield was intended to block. It is best to remove the least amount of shield possible to terminate your wires and cover the exposed shield connection between devices with tape.

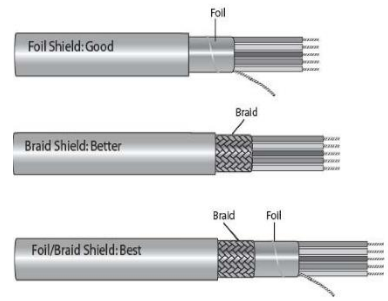
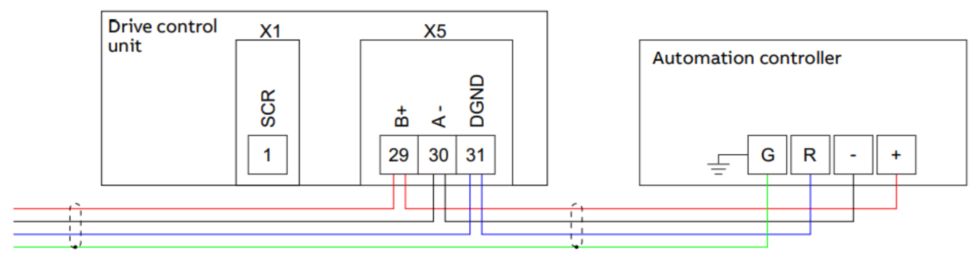


Figure 3: Typical shielding configurations

Polarity, positive and negative signals

RS-485 works as a communication method by defining the transfer of '0's and '1's. This occurs when the transceiver terminals, A and B, are positive or negative relative to each other. When A is positive to B, that is a 0. Then when A is negative to B, that is a 1. All devices on the comm link will need to generate and detect signals of the same polarity to read the same logical state. If any one device is reversed, it will read the wrong signals and generate the wrong signals to other devices causing a communication failure. With any two conductor or three conductor wiring, ensure the same color wire is used for the B(+), A(-) and reference terminals.



Connect the cable shields together at each drive, but do not connect them to the drive.
Connect the shield only to terminal "G" (ground) in the automation controller.
Connect the DGND conductor to terminal "R" (reference) in the automation controller.

Figure 4: Wiring polarity, reference and shield

Terminations (End of Line), signal reflection

As the signals of 1s and 0s travel on the RS-485 communication link as a differential voltage, slight variations in the wiring may cause what is known as a reflection to occur. Similar to a wave in a pool hitting the pool edge and returning to you, reflections will cause unintended signals on the comm link. To eliminate the signal reflection, a terminating resistor on each end of the link should be installed that match the characteristics of the wire. Since most RS-485 wiring recommendations use similar wiring characteristics this is why the suggested resistor range is between 100 – 120 ohms depending on the communications protocol.

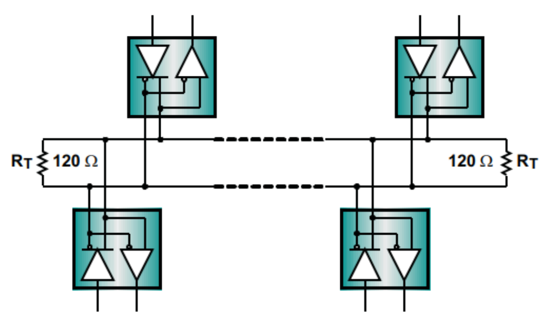


Figure 5: Bus Termination, End of Line

Biasing, high and low

During periods of no signals, drivers are not actively sending the 1s and 0s along the communication link for receivers to detect. However, they are still active and listening for the next signal. Even with the mitigation of shielding and grounding, interference and noise are able to affect the comm wiring. Receivers only need to detect a minimum differential voltage of 200 mV to interpret this as a signal from a driver. To eliminate this condition and place the link into a “failsafe” state, a bias network is used to hold wire B(+) positive with respect to wire A(-). This bias can be overcome by normal network operation.

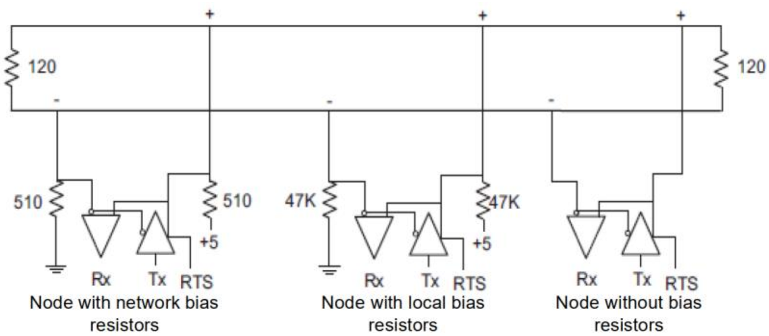


Figure 6: Biasing circuits

Some controller manufactures provide devices that include these biasing circuits (Trane’s BACnet Terminator) and will be installed as part of their system. While others might exclude biasing and place this responsibility on the control installer to provide some bias device on the comm link. For this purpose, the ACH580 has bias circuit that can be enabled if necessary. Unlike the end of line terminator for each end of the link, only one bias circuit should be enabled on a RS-485 truck.

Unit Load (UL), determines number of devices

RS-485 signals are a differential voltage across the communication link. All devices on the link, or units, create an electrical load to generate or detect this voltage. As more devices, units, are added to the link the load increases. Unit Load is the measure of how much load a device can place on the comm link. If wire Unit Load is too high, voltage drop across all devices will be too great and there will be signal degradation. Transceivers are available in varying Unit Loads which allows for a greater number of devices on a network. These can be full, half, quarter or eighth unit load circuits, see Table 1.

Table 1: Theoretical devices count per RS-485 link

Unit Load	Device count	ABB products
Full (1)	32	ACH550, ACS320
Half (1/2)	64	ACH580, ACH480, ACH180
Quarter (1/4)	128	
Eighth (1/8)	256	E-Clipse Bypass

However, not only do the transceivers place a load on the comm link but the terminators and bias circuit resistors do as well. Since it is likely that not all devices on a comm link will be the same, the max number of devices will be dependent on the total unit load and will have to be determined on a case by case basis.

Addressing, unique identification

RS-485 signals are transmitted are on a serial bus meaning all devices able to send commands (masters, or managers) will be detected by all receivers. Who then should respond to any given command? Part of the signal generated will include an identification or address for which device should follow that command while all others should ignore it. Each device then is required to have a unique address so no two devices react to unintended commands. The protocol used will then determine how to manage duplicate or out of range address.

Data rates, how fast can you talk

RS-485 data rates, or baud, can be as fast as 10 Mbps (megabits per second) or commonly as slow as 9.6 kbps (kilobits per second). Why not send your signals as fast as possible so your network updates can happen more quickly? Transmission losses on the cable will start to degrade the communication signals if comm trunk length multiplied by baud rate are greater than a suggested limit; rule of thumb is less than 10^8.

$$\text{Cable length (meters)} * \text{Baud rate (bps)} \leq 10^8$$

$$1200 \text{ m} * 76{,}800 \text{ bps} = 92{,}160{,}000 < 100{,}000{,}000$$

For our typical communications protocols (BACnet MS/TP, Modbus, etc.) you will see recommended baud rates of 9.6 – 115.2 kbps because these rates will not see diminished quality of signal on network cable maximum length of 1200 m (4000 ft).

Another important factor is all devices on a single RS-485 link must communicate at the same baud rate. If your network is set to have all devices communicating at 76.8 kbps, but one device is at 38.4 kbps you will have no communications on the link because there is a mismatch of signal timing preventing any device from understanding who is talking at the proper rate of signal change.

Network length, well that depends

So, you have the baud rate set at or below 115 kbps, why might you not be able to run 4000 ft of communication cable? What gauge wire should you use to reduce voltage drop depending on unit load? Does it match the impedance or capacitance characteristics of the biasing circuit? Does your networking wiring include any stubs from the main trunk, do the devices themselves have stubs between terminations and transceivers? Does your network cable run along the ceiling and drop down to devices before returning to the cable tray at the ceiling? While taking all these considerations into account a margin of error may be needed to be below the recommended limit of total max network cable length.

Topology, daisy chain and trunks

Due to driver technology used for the RS-485 standard, daisy-chain wiring topology is the required method for device connection. This series linking between devices is easiest to apply by terminating two wires to the B(+), A(-) and REF terminals when connecting multiple devices along one communication link as seen in Figure 7. Only the end devices will have a single set of wires terminated into the comm connector unless you require EOL terminators or bias circuits. While the RS-485 standard does allow for small stubs from the main link, too many or long lengths will generate signal reflections or degradation.

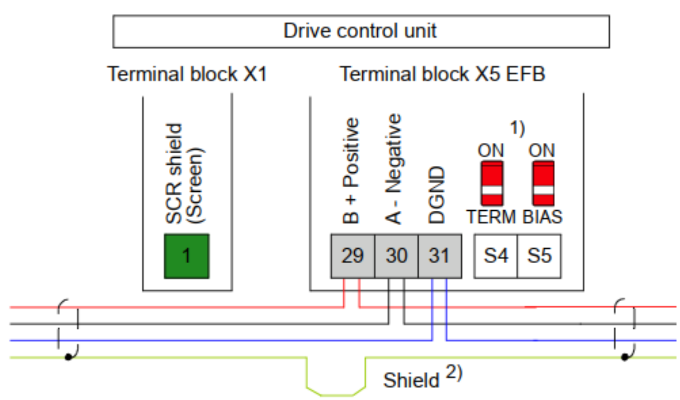


Figure 7: Daisy-chain topology

Summary

Unlike ethernet standards for communication protocols such as TCP which include redundant, repeated transmissions of packets until received or acknowledged (error correction), RS-485 signals will be sent without requiring a confirmation. When interruptions or interference occur in the differential signal, the data is corrupted without being repeated or received; “fire-and-forget”. To ensure the reliability of the signals transmitted on your RS-485 communication link be sure to maintain the wiring best practices described.

References

Figure 1: ANSI/ASHRAE Standard 135-2008 addendum Y, Figure 9-1.4 Mixed Devices on 3-Conductor Cable with Shield.

Figure 2: Belden RS-485 Multi-Pair Cable - 3106A (belden.com)

Figure 3: Alpha Wire technical paper: Understanding Shielded Cable

Figure 4: ABB ACH580-01 Quick Install Guide: 3AXD50000788286 Rev C, EIA-485 embedded fieldbus connection

Figure 5: Texas Instruments RS-485 Design Guide: SLLA272D, Bus Termination: Proper RS-485 Terminations

Figure 6: ABB ACH580-01 HVAC Firmware Manual: 3AXD50000027537 Rev G, Chapter 13 BACnet MS/TP EFB

Figure 7: ABB ACH580-01 HVAC Firmware Manual: 3AXD50000027537 Rev G, Chapter 12 Modbus EFB