Grounding and RS-422/485 (No Free Lunch!)

RobustDC Application Note #5

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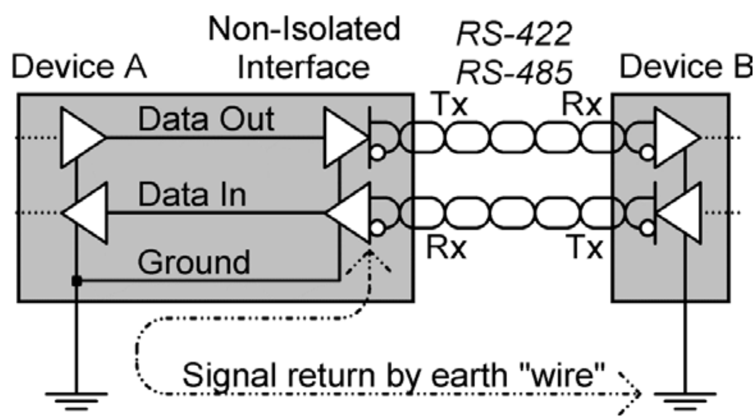
RS-422 and the more robust RS-485 are the most common standard data communication interfaces found in industrial equipment today. Yet it is common to hear users complain that these products communicate unreliably -- sometimes they work, sometimes they do not. But rather than the product being at fault, it is often a poor understanding of the basic principles behind these standards which causes this. Poor ground design is one of the most common reasons users have trouble with RS-422 and RS-485. This application note attempts to explain the design options available for grounding RS-422 and RS-485 data communication systems. It starts with the older non-isolated designs and progresses to the more modern designs which require complete galvanic isolation between devices.

• Grounding non-isolated RS-422/485



The primary source of confusion over RS-422/485 grounding is the "magic" nature of the ground in the common non-isolated RS-422/485 system. Most users incorrectly assume that the two wires within each twisted pair consist of a signal wire and a return wire. While this may be true for current loop systems, this is completely incorrect for RS-422/485. Both transmit wires at each device are supplying current to maintain a voltage level relative to an external reference. Quoting the EIA/RS-485 standard:

> *"Proper operation of the generator and receiver circuits requires the presence of a signal return path between the circuit grounds of the equipment at each end of the interconnection. The circuit reference may be established by a third conductor connecting the common leads of devices, **or** it may be established by connections in each using equipment to an earth reference."*

Even without turning a screw or pulling a wire, you still have a magic ground "wire" through the device's normal earth reference or physical earth (PE). So a non-isolated RS-422/485 connection works as expected without a specific ground wire. In fact, adding such a wire just leads to destructive ground loop problems such as suffered by RS-232.

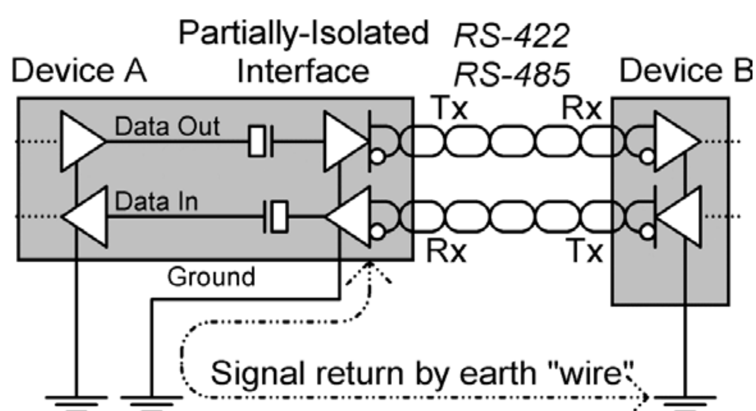
While using the "earth wire" is free and easy, it is one of the noisiest "wires" known. Every surge, system fault, and lightning strike on the planet dumps current into this "wire", plus earth materials with variable resistance's causes unpredictable movements of charges around plant sites. Besides minor back-ground noise, a more serious problem exists with this simple earth return. *Common mode surges* will be caused by momentary shifts in the ground potential between device A and device B. For minor day-to-day fluctuations of ground potential this is not a problem -- RS-485 was specifically designed to both function normally with a ±7v ground potential difference and survive ±25v surges.

However ±25v is not a big voltage when compared to the potentials in the surrounding industrial environment. Power system faults or equipment malfunctions can easily cause brief but powerful ground potential differences as large as the voltage of the power system -- for example 110, 230, or 480 volts. What about lightning discharges? These can cause momentary ground potential difference of hundreds or even thousands of volts. This refers not to direct strikes -- even the best "surge protection" device in world will not save a CMOS device struck by lightning. This refers to the common discharges on a local site which are caught and safely directed to earth by regulation lightning protection equipment. Even these good discharges elevate local ground potentials until they can dissipate into earth.

Of all the fatal surge damage suffered by data communications equipment, this is the most common culprit. Non-isolated devices often completely fail when damaged by surges due to an unpredictable number of failures and/or protection diodes shorting power rails to ground. For example, a surge may burn out both the serial port and a hard disk or even a video display. The actual damage is somewhat unpredictable. A common fix to this problem is to install external surge protection devices which offer a lower impedance path for surges to ground. These attempt to keep the surge energy out of the protected device. Another solution is the current trend for galvanic isolation of data communication in systems.

In Summary: A ***non-isolated RS-422/485*** link must never have a direct ground wire between the two ends. It must rely on each device having a good physical earth connection, plus have external surge protection to divert the inevitable common mode surges to ground.

• Grounding & Partially isolated RS-422/485



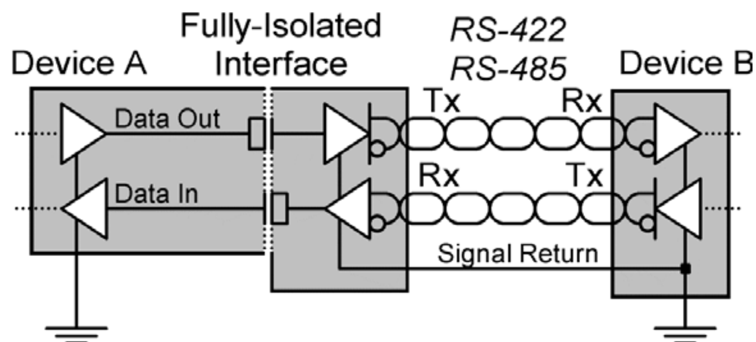
Robustness can be greatly improved at low cost by partial isolation of the RS-422/485 system. The interface is isolated from the local device, but often grounded with an external power supply to the same earth ground as the device. This can also be referred to as 2-port galvanic isolation. Partial isolation is more robust than no isolation because it virtually guarantees that surges will by-pass the delicate, high-speed CMOS circuits used in most intelligent devices today. From a surge stand-point, RS-422/485 interface chips are an order of magnitude more robust than - for example - a Pentium CPU or ultra low-power hard disk controller.

Yet partial isolation is still susceptible to the large common mode surges that affect non-isolated systems. The main advantage over no isolation is that surge damage in partially isolated systems is predictably limited to the interface circuit alone. Many PLC devices use partial isolation for their communications ports and isolated field I/O. It is a good compromise between keeping costs low while increasing system robustness. As testimony to it's effectiveness, I remember a site where a low-cost PLC was connected by non-isolated modems to a DCS 2Km away. A lightning discharge caused a common mode surge which destroyed both modems and the PLC's partially isolated communication port -- destroyed meaning black, charred components. Yet the PLC itself was unaffected and continued it's control without interruption.

In Summary: A ***partially isolated RS-422/485*** link generally is locally grounded and would not have a direct ground wire between the two ends. It still relies on external surge protection to divert the inevitable common mode surges to ground.

• Grounding & Fully isolated RS-422/485

The ultimate form of isolation with metal wires is full galvanic isolation. The interface is both isolated from the device and the local ground. This can also be referred to as 3-port galvanic isolation. Returning to the EIA/RS-485 standard:



*"Proper operation of the generator and receiver circuits requires the presence of a signal return path between the circuit grounds of the equipment at each end of the interconnection. The circuit reference may be established by a third conductor connecting the common leads of devices, **or** it may be established by connections in each using equipment to an earth reference."*

Since we no longer have a signal return path through the earth "wire", full galvanic isolation requires a physical wire to act as a circuit ground. While from an installation stand-point this can be an unexpected cost and even a nuisance, one must consider the trade-offs involved. A properly isolated RS-422/485 system will be almost as effective as fiber optics with none of the technical difficulties of managing fiber cables and connectors.

One great characteristic of full galvanic isolation is that to a common mode surge the data communication link now looks like an electrical dead-end. Ground potential differences up to the rated voltage of the isolation barrier will cause no common mode surge. Ratings of fully isolated RS-422/485 interfaces are often in the range of 250-500 or 1500-2500 volts.

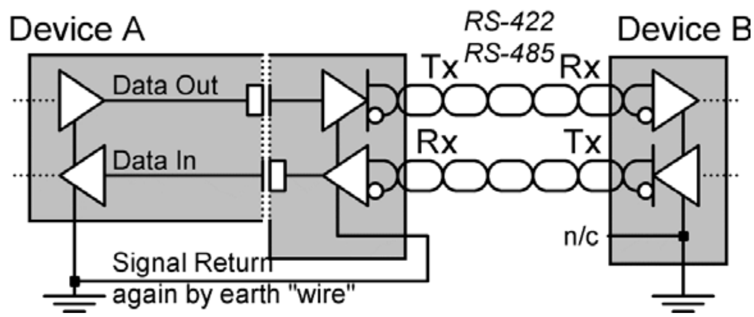
Virtually all modern, system-oriented data communications standards require full galvanic isolation. For example, thick Ethernet requires at least 1500v isolation, while even the thin Ethernet requires 500v. The new

Fieldbus standard requires full galvanic isolation between each device and the bus. All successful, big-name proprietary control bus systems include either optical or transformer isolation at each node. And of course, the current interest in fiber optics is due in part to the complete galvanic isolation it offers between all devices.

In Summary: A ***fully isolated RS-422/485*** link generally requires a direct ground wire between the two ends. External surge protection is only required if large lightning related surges to ground are expected.

• "I don't want (or can no longer afford) to run an extra wire ..."

If running the extra ground wire for full galvanic isolation is "too costly", there are three alternatives. The first is to connect the floating ground locally, converting the full galvanic isolation to partial isolation. It solves the ground problem without extra cost and still retains some advantages of isolation.



Fully Isolated Interface Converted to Partial Isolation

The second alternative is slightly controversial. You can run the floating ground through the cable shield. This practice is widely used and accepted for signals above 1MHz, such as for Ethernet and most other systems with coax cable. However, your signal is likely less than 1MHz -- for example 9600 baud is only about 0.01MHz. This will cause a current flow in your shield, which increases the noise in your data communication link. So we now have a design trade-off : running a reference ground through your shield increases noise, but so does grounding a circuit at both ends. Which solution is better or worse I have seen no good answer to yet. But it is clear that grounding the circuit at both ends (ie: partial isolation) causes the common mode surge problems mentioned above, while running ground through shield eliminates these surges.

The third alternative is to connect the floating earth of the isolated interface to the surge protection earth. The surge devices keep the signal voltages referenced to approximately the correct level.

• Specific recommendations

1) Both devices are in the same functional area and sharing the same power system.

Need for isolation:...Low
Need for common mode surge protection: ....Low

Examples: a computer and control device in the same room and both plugged into power points in the same circuit of the power distribution system.

Since both of these device share an almost identical ground, the probability of a significant ground potential developing between them is slight.

2) Devices are in the different functional areas but sharing the same power system

Need for isolation:..Medium
Need for common mode surge protection: ....Low

Examples: a computer in a control room and a control device on the plant floor. Each is on a different circuit of the same power distribution system.

The greater the electrical distance of the ground connection between the two devices, the greater the probability of a significant ground potential developing between them. While engineers like to quote the theorem "connected grounds are like grounds", *this only applies in normal, steady-state conditions*. Even if the two device are on very nearly the same power distribution circuit today, future changes to the power distribution panel may put them into completely different sub-systems. There is also another risk here. Since the functional areas are different, the person maintaining (or vendor supplying) each end of the link may be different. Adding isolation is a wise political move to prevent finger pointing after a system failure.

3) Devices are in the same building but having different power systems

Need for isolation:..**High**
Need for common mode surge protection: ....Medium

Examples: a computer powered by 230vac and a control device powered by a 110vac UPS or two control devices powered by different physical generators.

There is a very high probability of a significant ground potential developing between them during lightning storms or system faults. The small data communications wire may become a bridge or short circuit between two very large power systems. Even if two devices normally share the same UPS, if users can easily move the power plugs, someday they will not be sharing the same UPS. One will be connected to the USP and one to main supply.

4) Devices are in different buildings

Need for isolation:..**High**
Need for common mode surge protection: ....**High**

Examples: a computer connected to a control device in an outside building, or a computer connected to a terminal device in a detached guard house.

Since the two "sites" are not connected by a metal structural ground, there is a very high probability of a significant ground potential developing between them during lightning storms.

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