technical update

Shield-Grounding Practices and Surge Implications

Power Quality Tools

Introduction

Proper grounding of equipment can serve purposes such as fault clearing, establishing equipotentials, dissipating static charge, and preventing radiated noise from being coupled into equipment. Shielded cables are applied to signal wires of industrial controls to reduce capacitively coupled (electrostatic) noise onto signal lines, especially where cable-perhaps scores of feet of cable-is used between drive cabinets, remote input/output devices, sensors, and programmable logic controllers (PLCs). However, shield-grounding practices may invite destructive surge-related currents into the very equipment that the shielding is intended to protect.

The industrial community is replete with advice on grounding techniques for shielded cables. For example, one published grounding scheme is to ground the shield at both ends. However, if a surge enters the building, is equipment that is grounded in this configuration more likely to be damaged? This document describes surge testing to communication ports where a variety of shield-grounding schemes were compared for vulnerability to surge damage. It also reviews existing advice on shielding of communication lines used in industrial automation equipment.

The equipment under consideration is a simple industrial control system comprised of a PLC, adjustable-speed drive (ASD), and motor. The PLC and ASD were interconnected by multiple communication schemes, both analog and digital. Figure 1 is a wiring diagram of the subject equipment.

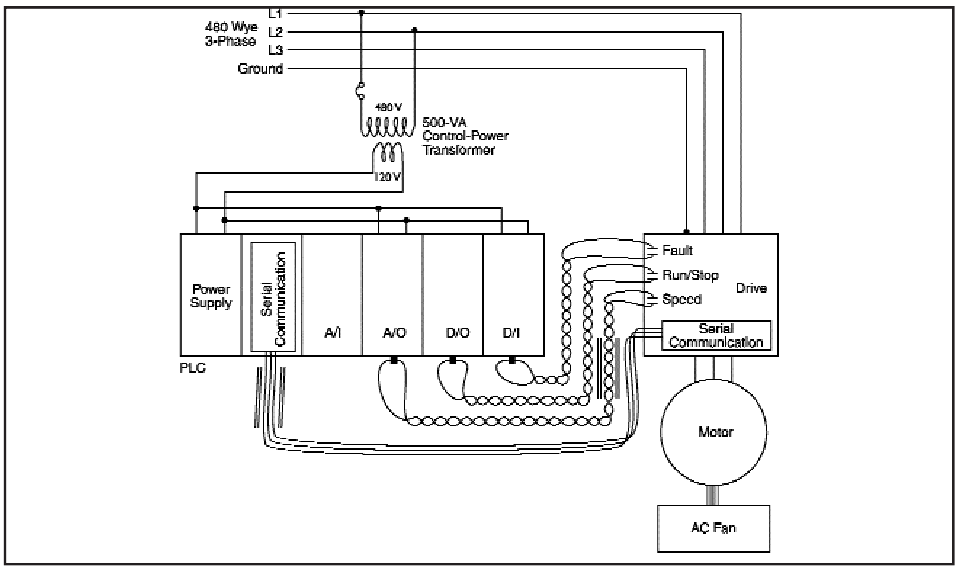


Figure 1. System Under Test

Shield-Grounding Practices

Existing information on shield grounding addresses only noise immunity without concern for surges. Little is known about the surge implications of shield grounding. It is a goal of this research to shed some light on this area.

Many installers follow conventional wisdom or rules of thumb. Other credible sources for information on how to ground shields are user manuals provided by manufacturers of the equipment, IEEE standards such as Std 1100 on wiring and grounding (Emerald Book), industrial trade magazines, and reference materials on EMI.

Not all sources of information are in agreement. To illustrate the inconsistency in shield-grounding recommendations even among manufacturers, the following are excerpts from user manuals of a few well-known brands of ASD and PLC equipment:

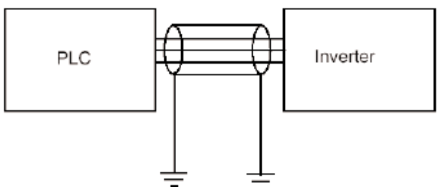
ASD
Source:
User's Manual Omron SYSDRIVE 3G3MV, page 2-40

Note:
"Ground the shield on the Inverter side only."

ASD
Source:
Siemens Standard Drives Application Handbook, page 39

Note:
"Therefore short, thick braided leads will be most effective in grounding, and high quality screened cable, grounded at both ends, will be needed to limit effects on signal leads."

The diagram illustrated below was found on page 40:



Screening of Control Cables

2. Use screened leads for connections to the control circuitry. Ground the screen at both ends.

ASD
Source:
Schneider Electric Altivar 28 Adjustable Speed Drive Controllers User's Guide, page 20

Note:
"Use shielded cables with the shields connected to ground at both ends of the motor cable, control cables, and the braking resistor (if used). Conduit or metal ducting can be used for part of the shielding length, provided that there is no break in continuity."

PLC
Source:
Siemens Simatic S7-200 Programmable Controller System Manual, page19

Note:
"Use shielded wires for optimum protection against electrical noise. Typically, grounding the shield at the S7-200 gives the best results."

PLC
Source:
Schneider Electric TSX Micro PLCs TSX 3705/3708/3710/3720 Implementation Manual Volume 3, page 23

WARNING

Cable shielding

It is advisable to reconnect the cable shielding, at each end, to the shielded restart terminal blocks (ground terminal blocks).

Failure to follow this precaution can result in death, serious injury, or equipment damage.

Note:
The warning caption illustrated above is located in the document.

For comparison, the IEEE 1100-1999 (Emerald Book) page 167 states, that for effective electrostatic shielding, "Long shields need to be grounded at multiple locations along their length. Cable shields must be either grounded at both ends or grounded at one end and grounded via an SPD [surge protective device] at the opposite end."

The Surge-Coupling Mechanism

Usually, lightning-induced surges affect every mode of coupling on every conductor of the mains, including the grounding conductors. Voltage disturbances that result from such surges stress both power and communication circuits.

In fact, communication circuits have been shown to be more susceptible to surges than power circuits, even when the surge impinges upon the input power lines, ground line, or both.

For example, consider the following scenario: A PLC and ASD are part of the same industrial process but are located in different control cabinets and are separated by a distance of 25 feet (7.6 m). Their power wires and communication wires are run through conduits and cable trays. Lightning strikes the building or the ground nearby. This elevates the ground potential in the area of the strike, but at increasing distance from that point, the ground potential is lower. The difference will cause current to flow in all building ground paths, as shown in Figure 2. This scenario is described in ANSI/IEEE C62.45-1992, Annex C and IEC 61000-4-5 p.15. If current flows in a ground wire that is connected between two pieces of equipment and if that ground wire is bundled with or near the communication cables, the surge can be induced into the communication cables by magnetic coupling.

For reference, this coupling scenario is described in IEEE 1100-1999 pp. 118-119. Additionally, if a shield is grounded at both ends, it will carry surge current itself.

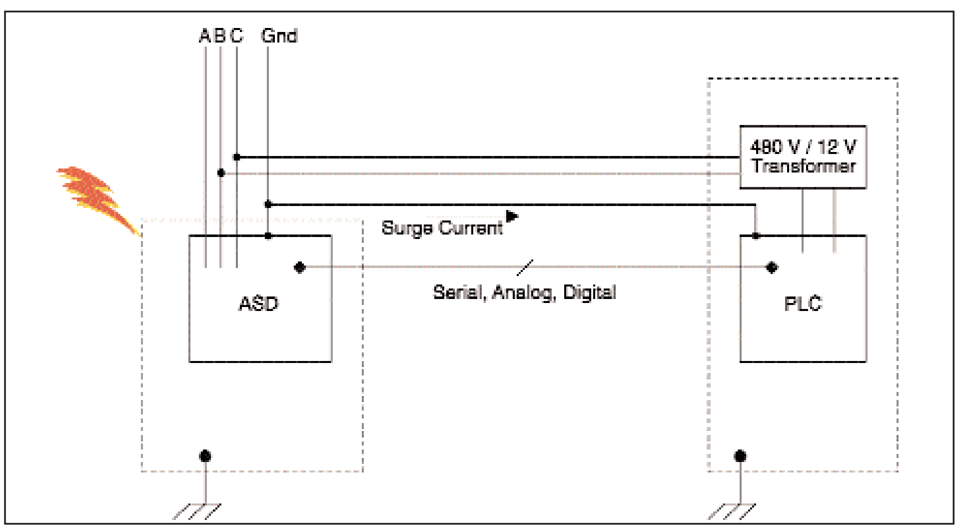


Figure 2. Typical Surge Scenario at an Industrial Facility

The amount of the surge coupled onto the communication wires is related to the magnitude of the surge current, the proximity of the communication wires to the surge-carrying conductor, the length of wire, and any terminating resistance in the communication scheme. Input impedance of the ASD and PLC also play a role in the induced voltage.

Test Approach

Several ASD/PLC systems were purchased from a local distributor for the purpose of potentially destroying them with exploratory surge tests. Each system had identical components, including a PLC, ASD, and control-power transformer. The equipment distributor was given instructions on how to assemble and configure the equipment. Some of the instructions include:

1. Mount the equipment on a 2-foot (0.61-m) square metal backplate.
2. Interconnect the ASD and PLC with as many ports as available.
3. Ground the shields as they would be grounded in an actual installation.
4. Program the PLC to communicate a specific pattern of set speeds to the ASD.

When the test samples arrived at the test lab, they were inspected, and information about their shield-grounding configurations was recorded. This document reports the results of testing one of those sample systems. Table 1 documents the shielding configurations of its communication lines "as shipped." The labeling of ports is from the point of view of the PLC.

Each system was connected to a motor/fan assembly, which was part of the test stand. All interconnecting wires (including power wiring, a ground wire, and communication lines) were replaced with 25-foot (7.6-m) lengths of similar wire.

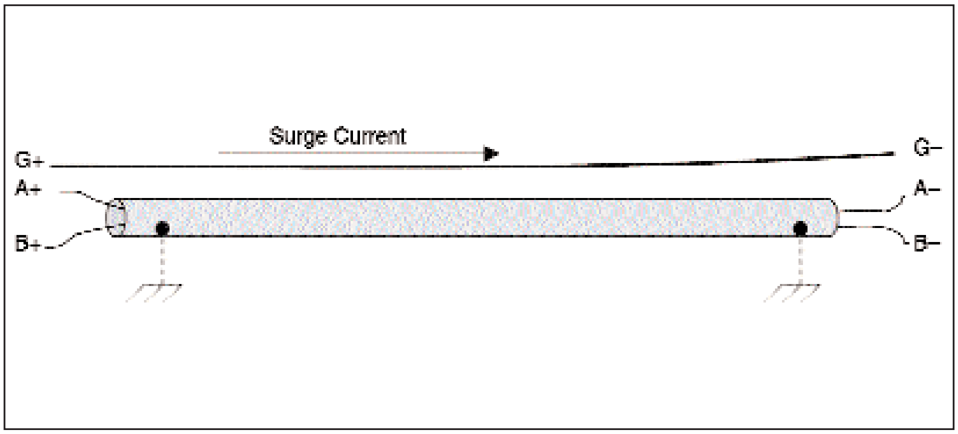


Figure 3. Surge Coupling Scenario

The long wires were then bundled together. The objective of the tests was to induce a surge into the communication wires by bundling them with a ground wire and applying a surge to the ground wire. Surge current traveling through the ground wire will induce a surge onto the communication wires, as shown in Figure 3. The coupling would then be measured in four grounding modes: positive end grounded, negative end grounded, both ends grounded, neither end grounded.

The coupling mechanism was verified by initial experiment using 25-foot (7.6-m) lengths of cable and no EUT connected. Each surge was applied across the ground wire (generator connected G+ to G-), forcing a current (approximately 50 A peak) through the wire. A corresponding surge voltage was measured across a single conductor in the shielded cable as shown in Figure 3. The voltage measured from A+ to A- was approximately 80% of the voltage produced by the surge generator. If A+ and A- are shorted together with a short piece of wire, then the current in A is approximately 80% of the current in G.

The surge waveform used for these tests was the 100-kHz ring wave with a waveform specified in ANSI/IEEE C62.41, which also states that most field-measured surge voltages will have an oscillatory waveshape as they propagate through indoor power systems. The fast rate of change of current will produce strong coupling into nearby wires. This waveshape has less capacity for energy deposition than longer waves, but high energy deposition is not a requirement for these tests.

The purpose of the described testing approach was not to damage the specimen but rather to enable repeated "harmless" surges under different grounding conditions so that measurements could be compared to see which configurations appeared to put the equipment at risk. The surge generator was therefore set to 1000 V and maximum surge current of 83 A peak.

Table 1. Shielding of a Sample ASD/PLC System

Serial Communications	Digital Input	Digital Output	Analog Input	Analog Output
Shield present but not grounded	No shield	No Shield	Shield present but not grounded	N/A

Table 2. Channel Scheme for Result Graphs

Channel	Connection	Scale
4	Surge current induced in a + wire of serial port	5 A/div
6	Surge current induced in a – wire of serial port	5 A/div
7	Voltage induced across the two serial communication conductors measured at the ASD end	5 A/div
8	Voltage induced across the two serial communication conductors measured at the PLC end	5 A/div

Test Procedure

Investigators created a test procedure that would maximize the results for a limited number of test samples. The conservative surge level enabled repeated surges and therefore more test data. Because all communication wires were bundled with the ground wire, each surge was coupled to all ports simultaneously. With repeated conservative-level surges, each port could be measured under identical test conditions. Probes were simply moved from one port to the next for a subsequent set of surge tests. In this way, investigators were able to compare measurements to determine which ports were experiencing the most stress during a surge.

The following test procedure was carried out for each specimen of ASD/PLC system:

1. Starting with the serial port, connect transducers at the following monitoring points (referring again to Figure 3):

- Surge voltage across the surged (ground) conductor (G+ to G-)
- Surge current through ground conductor
- Voltage across one conductor in the shielded pair (A+ to A-)
- Current through that conductor
- Voltage across the other conductor in the shielded pair (B+ to B-)
- Current through that conductor
- Voltage across the shielded pair at the ASD (A+ to B+)
- Voltage across the shielded pair at the PLC (A- to B-)

2. With equipment connected to the power source and running normally, apply one surge in each of the following grounding configurations:

Test Number	Grounding Configurations
1	No shields
2	Shields grounded at ASD
3	Shields grounded at PLC
4	Shields grounded at both ends

3. After each surge, record the waveform and peak voltages and currents.

4. Move the probes to the next port and repeat the four surges. Test all available ports, such as serial, analog in, analog out, digital in, and digital out.

Test Results

The following test results are from testing a single sample of an ASD/PLC system. Some analysis of the serial port was done before testing began. The scheme used in the sample ASD/PLC system reported here was determined to be a balanced (differential) pair with a terminating resistor. Nominal signal level during normal operation was measured at 5 V. Because a differential pair is more immune to noise, it is the preferred scheme for industrial applications (compared to RS-232, which is ground-referenced).

Results of Testing the Serial Port

The four graphs shown in Figures 4 through 7 use the channel scheme shown in Table 2. For clarity, only the four channels that reveal the most information are shown. Note that Figures 6 and 7 show significantly more voltage across the differential pair of signal-carrying conductors. Additionally, Figure 6 is the only test result with a measurable current into the port (Channels 4 and 6). The system was upset (tripped) in response to the surge applied when the shield was grounded at the PLC end. All graphs are results from testing the serial port.

Serial ports are typically constructed of sensitive electronics having a low tolerance to surges. We did not expect any failures at the levels used during the surge tests, and the test results confirmed that expectation. No systems were damaged during the surge tests.

Results of Testing the Analog Port

Tests were repeated in each of the four grounding modes while monitoring the surge activity on the analog port of the PLC.

This port connects the PLC's analog input to the ASD's analog output. For brevity, we show only the peak voltages and currents in Table 3. Again, there is significant difference in coupling of the surge voltage when comparing the "Grounded at PLC" configuration and the other configurations.

Results of Testing the Digital Input Port of the PLC

Tests were again repeated in each of the four grounding modes while monitoring the surge propagation at the digital input port to the PLC, which is connected to the digital output of the ASD. In summary, the results compare favorably with results of the first two rounds. More surge coupling was observed when the shields were grounded at both ends and at the PLC end.

Discussion

Preliminary tests showed that grounding of shields did play a role in the operation of the control system under test. With moderate surges, the equipment would consistently trip when the serial cable shield was grounded at the PLC only. We might speculate that if the relatively small surge can cause upset, then a larger surge could cause permanent damage. According to IEEE 1100, actual lightning currents can range from a few hundred amperes to more than 500 kA. In much of North America, 20-40 kA is the value that is often used to estimate typical lightning current conditions. Compare this to the roughly 50 amps that were produced in the ground wire during the surge tests.

What is different between "Grounded at PLC" and "Grounded at ASD" that would make such a significant difference in the results? This question might be answered by the position of the equipment relative to the surge application. The PLC in the test configuration is at the "far" end of the cables relative to the incoming power system (see Figure 2). It is expected that by swapping the positions of the ASD and PLC in the test setup, that the results will cause higher surge magnitudes to appear at the ASD.

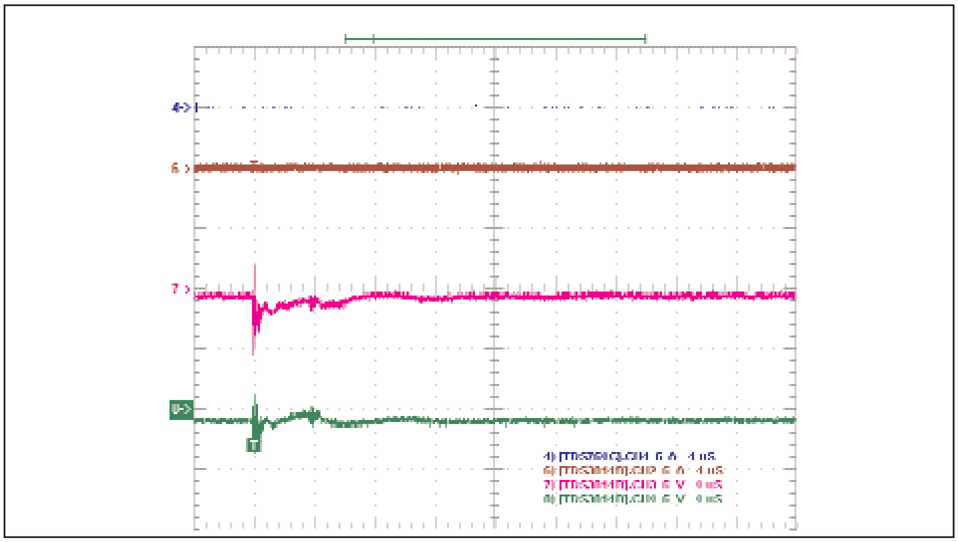


Figure 4. Results for No Grounds: Fast Ringing Transient of Very Low Magnitude (≤5V)

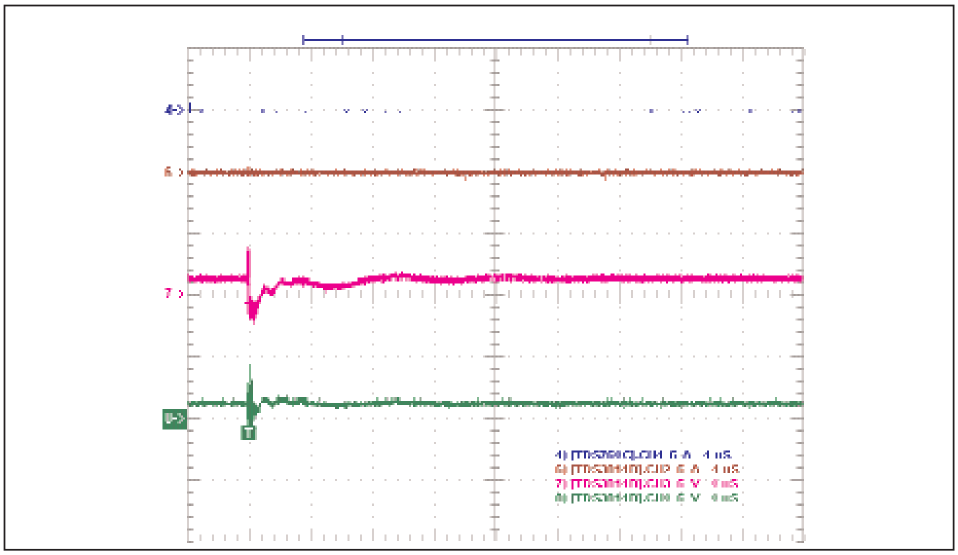


Figure 5. Results for Shields Grounded at ASD: Fast Ringing Transient of Very Low Magnitude (≤5V)

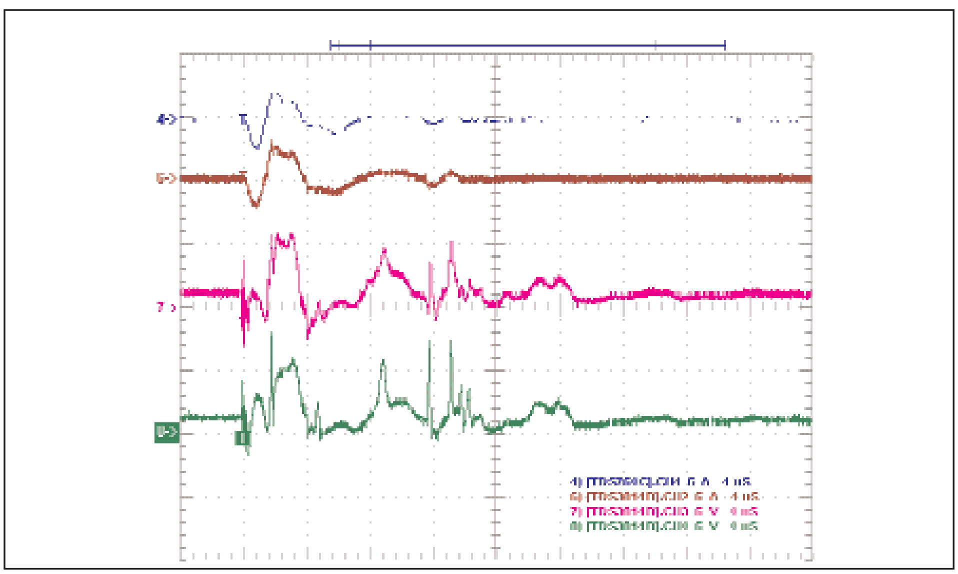


Figure 6. Results for Shields Grounded at PLC: Voltage Peaks ~7V, Current Peaks ~3A

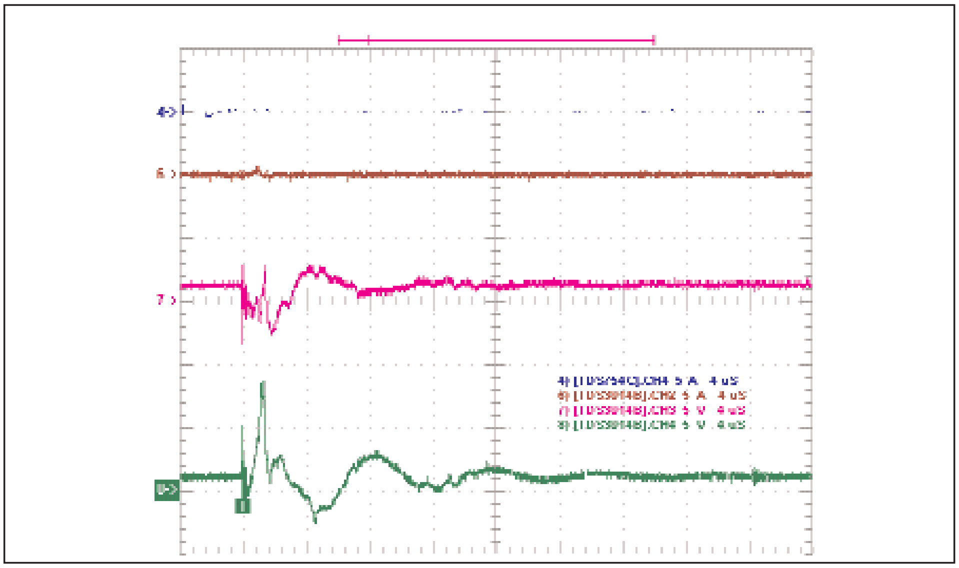


Figure 7. Results for Shields Grounded at Both Ends: Voltage Peaks ~7V, No Current

Conclusions

Surges can be coupled into a system of interconnected equipment in a variety of ways. Consequently, equipment can be upset or damaged. The results of tests reported in this document demonstrate a difference in surge vulnerability based only on the chosen grounding configuration of shielded conductors.

This document reports the results of ongoing research. As the project progresses, more results will be analyzed and released. Because this document reports the results from only one test sample, the results should not be construed as definitive but should be viewed as a springboard for discussion and further study.

Acknowledgments

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Table 3. Results of Testing the Analog Port

Shield Grounds	Peak Current in Analog + (Ch 4) (A)	Peak Current in Analog – (Ch 6) (A)	Peak Voltage Across Analog Input at ASD (Ch 7) (V)	Peak Voltage Across Analog Input at PLC (Ch 7) (V)
No grounds	0.2	0.6	2.1	2.6
Grounded at PLC	0.9	0.6	25.4	25.4
Grounded at ASD	0.2	0.5	2.0	1.8
Grounded at both ends	0.2	0.6	1.9	2.0

Table 4. Results of Testing the Digital Port of the PLC

Shield Grounds	Peak Current in Digital Signal Wire (Ch 4) (A)	Peak Current in Digital Ref Wire (Ch 6) (A)	Peak Voltage Across Digital Input at ASD (Ch 7) (V)	Peak Voltage Across Digital Input at PLC (Ch 7) (V)
No grounds	0.2	0.5	37.4	39.6
Grounded at PLC	0.2	5.9	72.3	45.4
Grounded at ASD	0.2	0.6	43.6	34.6
Grounded at both ends	0.2	3.9	72.1	45.3

For More Information

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