White Paper

Noise Mitigation for Control Panels

Managing Electromagnetic Interference Risks

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Introduction

Electrical noise or Electromagnetic Interference (EMI) takes the form of an external electromagnetic signal from a noise emitting source (drive, power supply, or motion control component) and a victim cable/component, interfering with the normal, desired signal or control action that is expected to occur. EMI risks increase as a result of competing needs to add more networked components and power devices while attempting to minimize the control panel footprint to reduce panel costs.

Increased EMI and radio frequency interference (RFI) can adversely affect system efficiency and uptime by interfering with analog signals and Industrial Ethernet transmissions. The impact of EMI is often overlooked during initial design stages, therefore as communication networks expand on the factory floor, adequate design and deployment objectives need to be achieved. Detecting EMI as the source of a problem is more difficult and time consuming after your factory automation project is complete, therefore, to reduce the effects of EMI, it is critical to integrate noise mitigation solutions into your design process.

Electromagnetic compatibility (EMC) is the ability of a machine to operate in an electromagnetic environment, often using the technology of shielding or preventing EMI. The appropriate enclosure solution can control ingress and egress of EMI and the appropriate physical infrastructure solution can manage EMI issues between devices inside the enclosure. Regulatory compliance is another EMI consideration and involves taking measures to control noise in and out of a panel to achieve CE certification, which is critical for exports to Europe.

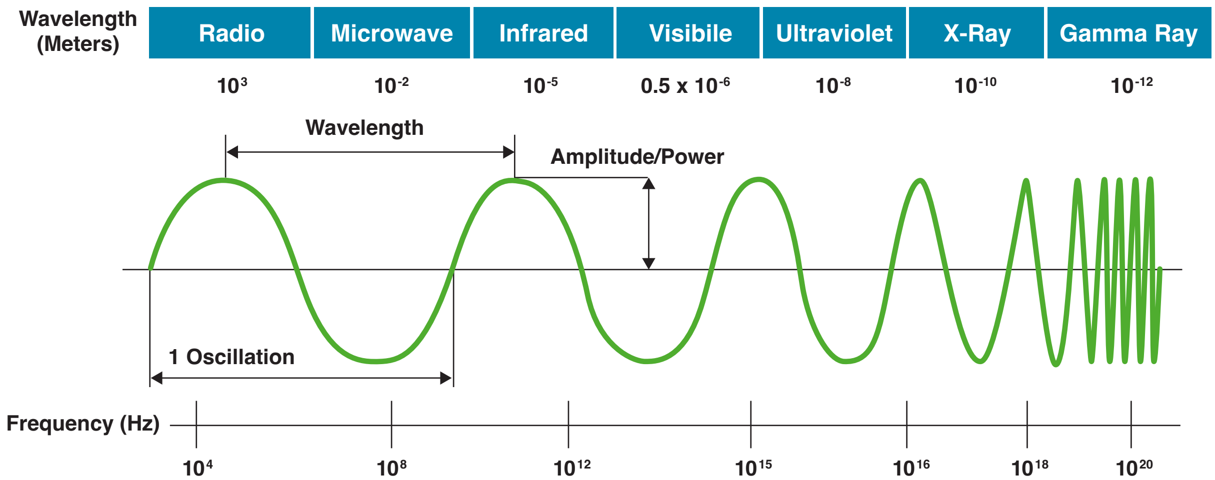
Too often, Ethernet switches placed into existing control panel designs can disrupt communications and control functions of the entire automation system and cause the failure of Industrial Ethernet installations to deliver on their promise of a robust, reliable and maintainable infrastructure.

This white paper examines best practices and solutions that will enable system integrators, panel designers and builders to mitigate electrical noise while optimizing the footprint space of the control panel as well as the space within the control panel. The intent of this paper is to provide a brief background in EMC theory and offer actionable guidance and products that deliver innovative solutions to reduce costs and space, improving system performance.

Noise Mitigation Theory

EMI is uncontrolled energy that is either radiated or conducted and has a unique set of frequencies, (Hertz, Hz) and amplitude, (decibels, dB) characteristics. The Electromagnetic Spectrum gives reference points for wavelength frequencies and their relative size (see Figure 1).

Figure 1. Frequency=the number of oscillations per second.
This figure shows the electromagnetic wavelength frequencies and their relative size.



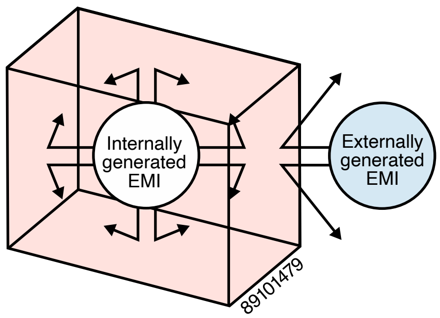
To protect against EMI ingress and egress, a metal enclosure creates a Faraday cage around the electrical components, as shown in Figure 2. The ideal Faraday cage is a continuously conductive shell around the internal components. This essentially "seals" internally generated EMI in and keeps externally sourced EMI out of the enclosure.

Attenuation

Attenuation is the reduction of electromagnetic energy and is caused by distance or an obstruction. For example, if a standard metal enclosure has an internal device generating EMI at a frequency of 1GHz (10^9 Hz) on the inside, and no EMC provisions are added, that enclosure will attenuate the signal by approximately 20dB.

Figure 2. Effective enclosure design provides necessary user access while maximizing the Faraday cage effect when closed, controlling noise inside and outside of a control panel.

Control Panel enclosure functioning as a Faraday Cage



Ingress and Egress of EMI and the Control Panel

Enclosures provide EMI protection through a Faraday cage; however enclosures need to allow access to the equipment inside through doors and cable entry points. These access points, while necessary, can create "leaks" in the Faraday cage and become pass-through points for unwanted EMI. If the frequency falls into a range in the spectrum that is able to penetrate or escape the enclosure, additional considerations need to be made to seal the enclosure tighter. There are several design elements that can be used to seal the access points from unwanted EMI ingress or egress. For 80% of control panel ingress/egress EMI problems, a standard steel enclosure, will be an adequate solution.

An enclosure usually has at least one door or access point. Higher frequency EMI can penetrate through the standard environmental gasket, creating leaks of EMI into or out of an enclosure. While the EMC gasket raises the shielding effectiveness, it lowers the environmental type rating of the enclosure.

EMI Management Best Practices within the Control Panel

The enclosure is an EMI barrier protecting internal circuitry from outside sources, however EMI is also generated by the internal circuitry. The devices within the enclosures can be more at risk because of their sensitivity and close proximity to these internal EMI generating sources. The controls of industrial processes reside within the enclosures, therefore additional protection is required, even though the devices are already protected from outside EMI (see Table 1).

Table 1. RIM to Industrial Automation Systems Due to EMI Noise within an Enclosure

Noise Sources +	Noise Victims =	?
• Servo drives • VFD drives • Switching power supplies • Contact switching of inductive loads *(Example: contact or coils)* • ESD • Lightning	• Communications/network wiring • Analog signal wiring • High speed counting signals • Controllers • Microprocessor based devices, drives,computers, sensors • Electronic equipment • Protective devices	• Productivity Loss • Downtime • Maintenance/repair costs • Troubleshooting costs • Device replacement costs • Inability to respond to market demands

Due to the close proximity of sensitive devices to noisy sources, the leading modes of EMI within an enclosure are capacitive and inductive coupling. Understanding both sources helps to examine how best practices and specifying noise mitigating products improve equipment reliability.

Both modes of coupling are unintentional and occur when current flowing through one wire induces a voltage on a parallel wire that lies within its magnetic field. Capacitive coupling is more of a concern in high frequency circuits, while inductive coupling is more of a concern in high current circuits. The magnitude of the noise generated can be measured with an oscilloscope with a victim wire attached (see Table 2). A multi-layered approach to mitigate EMI is recommended to maintain operations of critical communications and controls infrastructure.

Table 2. EMI Types, Sources and Mitigation Practices

	Cause	Mitigation
Capacitive or electrostatic coupling *(Voltage spike in the noise source causes voltage to develop in the victim conductor)*	• Voltage amplitude, source change rate • Victim impedance • Conductor spacing • Geometry, orientation	• Separation • Electrostatic shielding (conductive material) with at least one end bonded
Inductive or magnetic coupling *(Current in the noise source produces a field that causes a corresponding current in the victim conductor)*	• Loop size • Orientation • Distance • Rate of change • Current amplitude	• Route DC supply and return together rather than in separate runs • Separate noise sources from noise victims by 8” or more • Cross noise sources and victims at right angles • Magnetic shielding (highly conductive materiel) with both ends of cable terminated • Implement a conductive partition to shield EMI
Common mode conductor *(Victim circuit shares common con-ductor such as a current return path with a noise source current return)*	• Wiring layout • Daisy chaining • Bonding design	• Separate return path from noise • Star bonding to ground • Separate commons back to source

Grounding and Bonding Best Practices

Properly grounding noisy devices is a critical step that will greatly reduce EMI emissions. The following grounding best practices should be considered in the design of all control panels.

- Establish a ground plane and route wiring close to the ground plane.
- Avoid using a design with multiple grounds.
- Wires that form a loop make an efficient antenna. The efficiency of any antenna can be optimized by the length and/or the shape of the antenna for any given frequency. A good practice for minimizing the ability of an antenna to send or receive is to minimize the “loop”. Run feed and return wires together rather than allowing a loop to form. Twisting the pair together further reduces the antenna effects. This also applies to potential victim wiring. Antennas work equally well in both receive and transmit modes.
- Use an electro-galvanized sub-panel instead of the more common painted panel. A galvanized sub-panel avoids the need to remove paint for bonding with resultant long-term corrosion potential, risking poor performance.
- Bond the incoming ground conductors to the sub-panel where they enter the panel using a universal ground bar (see Appendix Item #1).
  - Bond the equipment grounds from the components in the cabinets directly to the sub-panel using equipment manufacturer recommended conductors or short flat braided bonding straps (see Appendix Item #2).
  - Bond the enclosure door(s).
  - Bond incoming cable shields, conduits, and cable trays to the enclosure grounding stud.

Separation and Segregation

The coupling of circuits and associated cabling is caused when the victim cabling lies within the magnetic field of the source cabling. Wire layout is a key consideration in controlling noise and the distance between the two is a critical factor along with the layout of wire pathways.

The following tips should be considered when routing wires:

- Cross conductors at right angles when proximity is unavoidable. Perpendicular conductors have much less common length than parallel conductors, therefore reducing noise coupling.
- When placing components on the panel door, ensure that closing the door does not bring the component close to a part of the panel that will cause problems, such as placing a video terminal too close to a transformer or servo drive.
- Avoid running DC next to AC.
- Keep wiring close to the back panel/ground plane as much as possible.
- Avoid running inputs next to outputs.
- Avoid loops in wiring design.
- Keep the unshielded PWM drive to motor power cables as short as possible.
- Avoid deforming the Ethernet cable by cinching too tight with cable ties. Deforming the cable can cause increased return loss and unbalance in the cable, resulting in more noise pick up.
- If possible, do not add terminal blocks between the servo drive and motor.

To reduce EMI, IEEE 518 recommends a distance of three to six inches between high voltage and low voltage conductors in parallel runs. Conductors in perpendicular runs are not subjected to the same levels of EMI. Twelve inches is the recommendation between encoder or resolver feedback cables and motor or any AC power cables.

Internal Shielding Barriers

When physical separation is not possible, a conductive partition can provide shielding with up to 20 dB in noise reduction, which is equivalent to six inches of air. These partitions are low resistance, grounded metal barriers to prevent EMI from emitting outward or EMI from coming inside. Figure 7 illustrates reference layouts specific to circuit separation for noise mitigation in control panels. See Figure 10-11 in the IEEE 1100 Emerald Book for more information.

The barriers can be incorporated into the wire pathway to segregate power, signal and Ethernet as seen in Figure 8. Use of shielded cable is another common practice providing EMI protection against noise coupling in the cable run.

Proper functioning of an Ethernet shielded cable requires understanding the ground system and bonding scheme to avoid inducing ground loops on the shielded cable. Ground loops occur if two or more ground points are at different potential, which causes high currents and can induce more noise in the Ethernet signal conductors than if unshielded cabling is used.

Figure 3. Typically, sources of EMI are placed on the right side of an enclosure, while victims of EMI are placed on the left side of an enclosure. To visually Identify EM/ sources and victims, black, white, and gray wiring duct is installed.

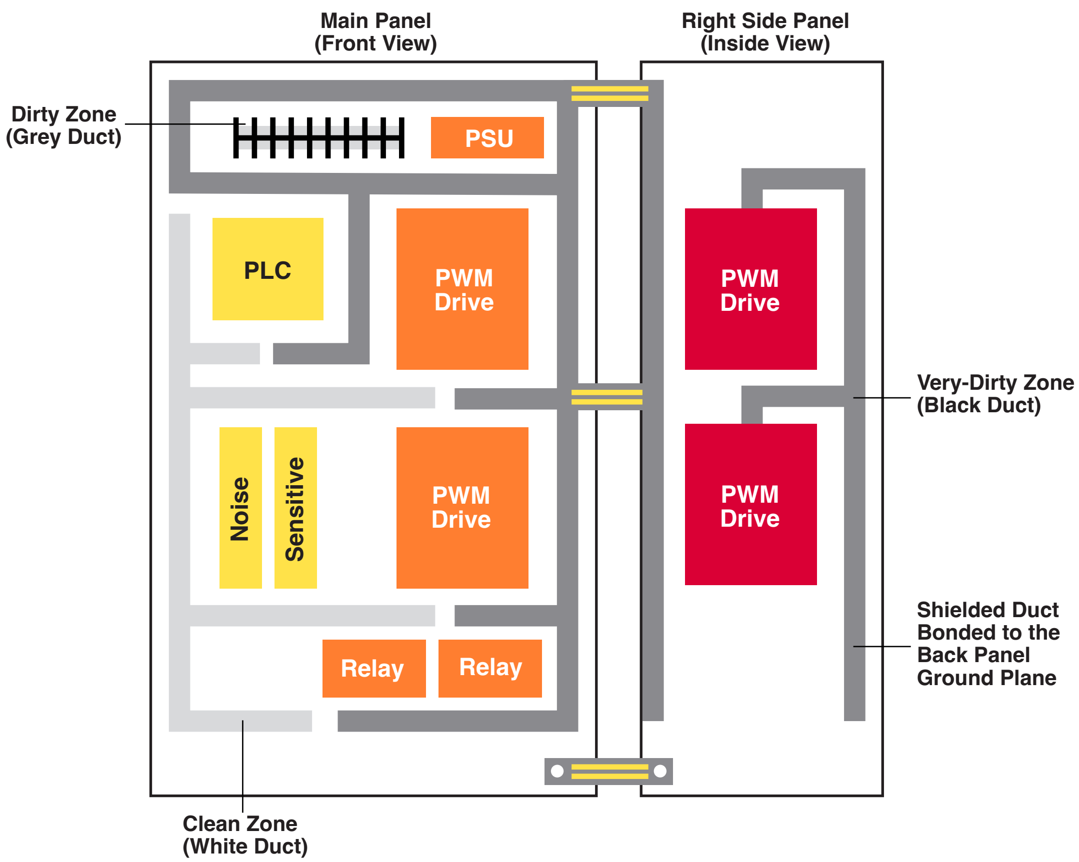


Figure 4. Noise shielding solutions can reduce the effects of EMI/RFI {electromagnetic interference, radio frequency Interference) and provide space optimization within Industrial control panels.

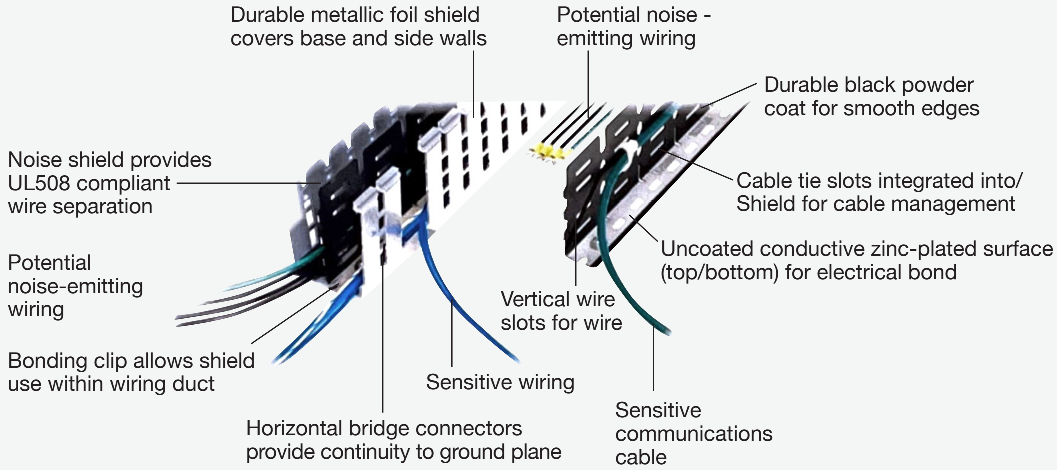


Table 3. Considerations for Installing Shielded Cable

360° shield termination	Use shield clamps that encircle the circumference of the shielded cable to avoid the high impedance caused by long pigtail drain wires.
Ground loop avoidance	Proper system bonding between machine and control cabinets can allow bonding both ends of shield without concern of ground loop for maximum shield benefit for controlling noise. Otherwise, consider hybrid bonding through the RC circuit or bonding only one end of shielded cable. Isolated ground.
Motor cable shielding	Shielding motor cables can reduce this noise source risk but requires termination at the motor and at the drive only. To avoid noise problems, do not terminate the motor cable to the sub-panel.
Ethernet cable shielding	Use shielded Ethernet cables for high noise environments if potential problems due to ground differences in the system are mitigated. Supplemental bonding to equalize ground noise voltages between panels or devices are one method to mitigate. Hybrid bonding schemes such as those built into many Ethernet/IP devices are another method. For facilities with poor grounding/ bonding systems and high noise, fiber optic links are recommended rather than shielded cables.

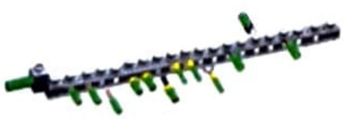
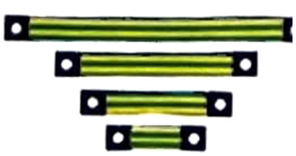
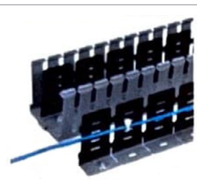
Conclusion

EMI is one of the core issues affecting the performance and reliability of industrial control systems and the real-time information they provide. The noise emitted from sources such as PWM drives, power supplies, and inductive load switching can adversely affect system efficiency and uptime by interfering with analog signals, industrial network transmissions, and PLC programs. To effectively mitigate noise in control panel environments, enterprises should:

- Control ingress and egress of EMI by choosing effective enclosure design including EMC enclosures, EMC gasketing and EMC cable strain relief.
- Provide EMI management within the control panel, including a multi-layered approach for grounding and bonding, segregation, shielding and filtering.

Design engineers have a tremendous amount of complexity to manage when applying control panels in today's industrial environments.

Appendix – Noise Mitigation Solutions

1 	**StructuredGround™ Universal Ground Bar System** Panduit offers a variety of UL listed universal ground bars for multiple termination methods (bare wire, ferrule, ring terminal and compression connector). 1 - Bare Wire #14 to 4 AWG 2 - Ferrules to 6 AWG 3 - Ring Terminals 4 - Compression Connectors
2 	**Panduit® StructuredGround™ Flat Braided Bonding Straps** Bonding straps, such as Panduit® StructuredGround™ Flat Braided Bonding Straps, help reduce the effects of EMI by passing high frequency noise more effectively than round stranded type cables
3 	**Panduit® PanelMax™ Corner Duct** Use Panduit®, PanelMax™ Comer Duct to bridge side panels to back panels and provide the greatest separation distance between clean and noisy circuits.
4 	**Panduit® PanelMax™ Shielded Wiring Duct and Noise Shield** The PanelMax™ Shielded Wiring Duct and Noise Shield solution provides up to 20dB reduction in noise, or 90% noise voltage reduction (NVR), which is equivalent to six inches of air spacing, generating valuable panel space savings of 40% or more.

Referenced Resources

- 518-1982 - IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources
- 1100-2005 - IEEE Recommended Practice for Powering and Grounding Electronic Equipment

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