Allen-Bradley

System Design for Control of Electrical Noise

Reference Manual

Rockwell Automation

Important User Information

Because of the variety of uses for the products described in this publication, those responsible for the application and use of this control equipment must satisfy themselves that all necessary steps have been taken to assure that each application and use meets all performance and safety requirements, including any applicable laws, regulations, codes and standards.

The illustrations, charts, sample programs and layout examples shown in this guide are intended solely for purposes of example. Since there are many variables and requirements associated with any particular installation, Allen-Bradley® does not assume responsibility or liability (to include intellectual property liability) for actual use based upon the examples shown in this publication.

Allen-Bradley publication SGI-1.1, *Safety Guidelines for the Application, Installation and Maintenance of Solid-State Control* (available from your local Allen-Bradley office), describes some important differences between solid-state equipment and electromechanical devices that should be taken into consideration when applying products such as those described in this publication.

Throughout this manual we use notes to make you aware of safety considerations:

ATTENTION Identifies information about practices or circumstances that can lead to personal injury or death, property damage or economic loss.

Attention statements help you to:

- identify a hazard
- avoid a hazard
- recognize the consequences

IMPORTANT Identifies information that is critical for successful application and understanding of the product.

Noise Control Supplement

Appendix A

EMC Product Suppliers

Appendix B

Read this preface to familiarize yourself with the rest of the manual. The preface covers the following topics:

- Who should use this manual
- The purpose of this manual
- Contents of this manual
- Related documentation
- Conventions used in this manual
- Allen-Bradley support

Who Should Use this Manual

Use this manual if you are responsible for the circuit design and layout of wiring panels or the installation and mounting of Allen-Bradley products. Specifically, the following disciplines should be included:

- Circuit designers
- Panel layout designers
- Panel builders and electricians
- Electrical technicians

In addition, you should have an understanding of:

- Drive control and basic electronics
- Appropriate electrical codes

Purpose of this Manual

This manual outlines the practices which minimize the possibility of noise-related failures and that comply with noise regulations. It gives you an overview of how electrical noise is generated (sources), how the noise interferes with routine operation of drive equipment (victims), and examples of how to effectively control noise.

This manual applies in general to Allen-Bradley drives products. For information on specific Allen-Bradley motion products refer to *Noise Control Supplement - Motion Products Reference Manual* (publication GMC-RM002*x*-EN-P).

Contents of this Manual

The contents of this manual are described in the table below.

Chapter	Title	Contents
	Preface	Describes the purpose, background, and scope of this manual. Also specifies the audience for whom this manual is intended.
1	Electrical Noise Control Overview	Provides a brief understanding of the need for electrical noise control, how noise affects system performance, noise coupling methods, and solutions.
2	High Frequency (HF) Bonding	Describes the ground plane principle and provides techniques for bonding devices, panels, machines, floors, doors, and buildings.
3	Segregating Sources and Victims	Describes how establishing zones within your system for noise sensitive or noise generating components can reduce electrical noise coupling.
4	Shielding Wires, Cables, and Components	Describes how using shielded cable or steel shields can reduce electrical noise.
5	Filtering Noise	Describes how low-pass filters and ferrite sleeves can reduce electrical noise.
6	Contact Suppression	Describes how contact suppressors for relays and various other switches can reduce electrical noise.
7	Power Distribution	Describes bonding, segregating, shielding, and filtering techniques for use when routing AC and DC power.
8	Motor Wiring	Describes shielding, grounding, and splicing techniques for use with motor wiring.
9	High Speed Registration Inputs	Describes how wiring sensitive to electrical noise benefits from proper noise reduction strategies.
10	Encoders	Describes bonding, segregating, shielding, and filtering techniques for use with encoders.
11	Measuring Noise Reduction Effectiveness	Describes the equipment, methods, and various guidelines for measuring noise levels and noise reduction effectiveness.
Appendix A	Noise Control Supplement	Provides background information on specific topics related to electrical noise control.
Appendix B	EMC Product Suppliers	Provides a list of EMC product suppliers, the products they offer, and internet website.

Related Documentation

The following documents contain additional information related to electrical noise control. To obtain a copy, contact your local Allen-Bradley office or distributor.

For:	Read This Document:	Document Number:
Specific advice on motion products	*Noise Control Supplement - Motion Products*	GMC-RM002*x*-EN-P[1]
Advice specific to large systems	*Industrial Automation Wiring and Grounding Guidelines for Noise Immunity*	1770-4.1
Advice specific to large systems	*Installing, Operating and Maintaining Engineered Drive Systems* (Reliance Electric)	D2-3115-2
Safety advice	*Safety Guidelines for the Application, Installation, and Maintenance of Solid-State Control*	SGI-1.1
IEEE industry standards for electrical equipment installation	*IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources*	IEEE 518
A text book on noise reduction techniques	*Noise Reduction Techniques in Electronic Systems* Henry W. Ott Published by Wiley-Interscience	N/A
A text book on grounding techniques for the control of EMI	*Grounding for the Control of EMI* Hugh W. Denny Published by Don White Consultants	N/A
A text book on solving interference problems	*Solving Interference Problems in Electronics* Ralph Morrison Published by Wiley-Interscience	N/A
A technical paper on EMI emissions	*EMI Emissions of Modern PWM ac Drives* Gary L. Skibinski, Russel J. Kerkman, & Dave Schlegel IEEE Industry Applications Magazine, Nov./Dec. 1999	N/A
A text book on EMC	*EMC for Product Designers* Tim Williams Published by Newnes	N/A

[1] Available in future. Check with The Automation Bookstore.com or your Allen-Bradley sales representative for documentation availability.

Conventions Used in this Manual

The following conventions are used throughout this manual:

- Bulleted lists such as this one provide information, not procedural steps.
- Numbered lists provide sequential steps or hierarchical information.
- Words that you type or select appear in bold.
- When we refer you to another location, the section or chapter name appears in italics.

Electrical Noise Control Overview

Chapter Objectives

This chapter provides a brief understanding of the need for electrical noise control, how noise affects system performance, noise coupling methods and solutions. This chapter covers the following topics:

- What is electrical noise
- Understanding the need for electrical noise control
- Noise control basics
- Coupling mechanisms
- Solutions for reducing noise
- Implementation
- Measuring effectiveness

What is Electrical Noise?

Electrical noise is voltage spikes, generated by the routine operation of selected system components (sources), that interfere (due to a coupling mechanism) with the routine operation of other selected system components (victims).

Understanding the Need for Electrical Noise Control

In Europe, a system must satisfy EMC regulations. It must also work reliably without suffering from noise-induced failures.

CE Compliance

Most equipment is CE marked. This means it is certified to be compliant with European Directives which comprise two main requirements:

- Potential noise sources must be limited in noise output to a specified level.
- Potential victims of noise must be hardened to withstand a higher noise level.

In both cases, equipment must be installed to manufacturers recommendations to achieve compliance. The frequency range covered is 150kHz to 1GHz, though the upper limit is likely to be raised as operation frequencies increase.

Despite this, a CE compliant industrial drive system may still suffer functional failures due to electrical noise. Additional measures are often necessary to prevent noise from being coupled between source and victim. The frequency range involved in system failures is generally confined between 200kHz and 10MHz.

Best Practices

Most industrial control products do not utilize high frequencies directly, but they can generate them in the form of noise. Logic circuits are affected by this noise, so you need to be able to control it.

Because it is far less expensive to apply noise control measures during system installation than it is to redesign and fix a malfunctioning system, we recommend you implement the best-practice procedures described in this document.

If basic measures are implemented rigorously, a reliable system should result. However, if just one wire is routed incorrectly or a filter is missed, it may be enough to cause problems. Experience shows that it is very difficult to ensure that these measures are applied 100% of the time. If all possible measures are taken (incorporating redundancy), the system is likely to be more tolerant of minor mistakes in implementation.

Noise Control Basics

A typical industrial control system will contain a mixture of noise sources and potential victims. Problems are caused when a coupling mechanism is introduced.

Noise Sources

Typical noise sources include:

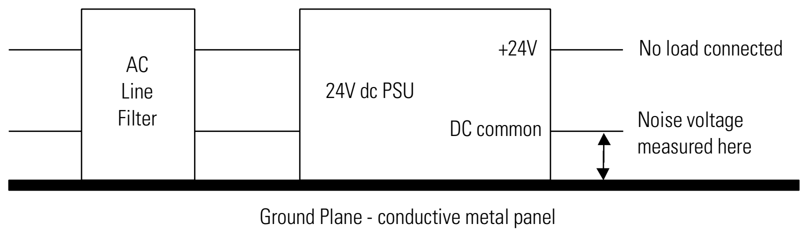
- Mechanically switched inductive loads create intense intermittent noise.
- PWM drive power outputs create intense continuous noise.
- Switch-mode DC power supplies can create continuous noise.

- Microprocessor clocks can generate high levels of noise at the clock frequency and its harmonics.
- Contact switching.

Of the noise sources listed above, only contact switching noise can be reduced at the source by the system builder.

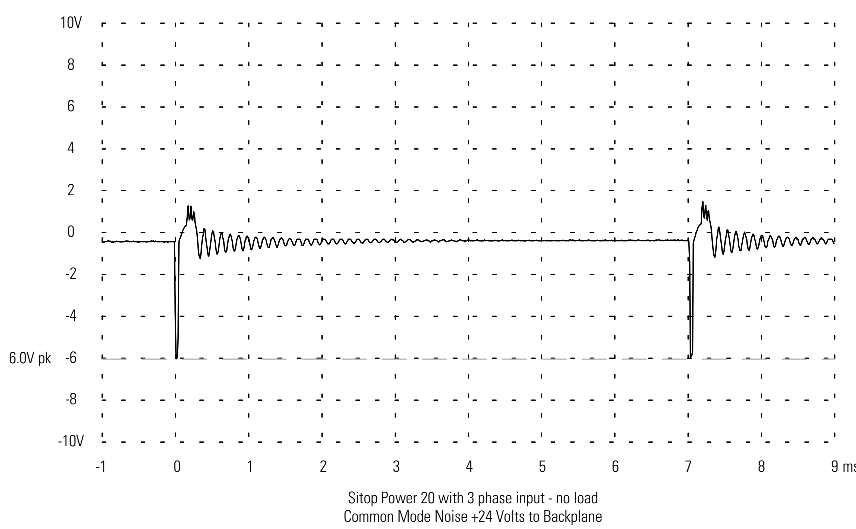
Refer to the figure below for an example of a typical noise source.

Figure 1.1
Switch-Mode Power Supply Noise Measurement



Refer to Figure 1.2 for an example of six volt noise spikes from a typical 24V dc power supply. The spikes usually contain frequencies above 10 MHz.

Figure 1.2
Switch-Mode Power Supply Noise



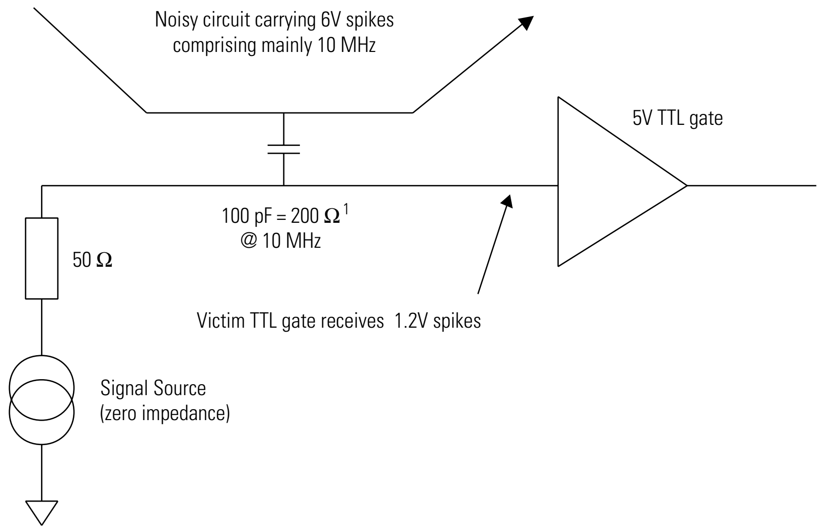
Noise Victims

Typical noise victims include the following:

- Microprocessor controlled devices
- Analog devices
- Encoder and registration interfaces

Refer to Figure 1.3 for an example of a typical victim.

Figure 1.3
A victim TTL gate is easily triggered



[1] Refer to the section *Capacitance* below for an explanation of the 200 ohm impedance. Generally, most potential victims are better protected than this.

The source noise level and the victim's sensitivity are normally outside the control of the system designer so that it is necessary to concentrate on the transmission of noise between them.

Coupling Mechanisms

The coupling mechanism is the means by which electrical noise interferes with the routine operation of equipment. This section describes the four common coupling mechanisms for electrical noise transmission.

Conducted Noise

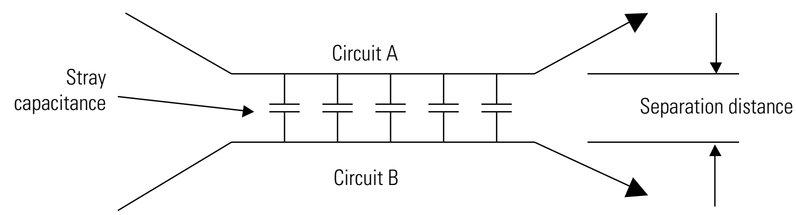
Noise is conducted directly by system power wiring. A common route for conducted noise is the 24V dc distribution wiring.

Capacitance

At radio frequencies (RF) the capacitance between two adjacent wires is significant. Two insulated wires touching each other and only 1.0 meter (39.0 in.) long form a capacitance of approximately 100 pF (Pico Farads). At 10 MHz the impedance is only 200 ohms.

Fortunately, the effect reduces as the square of the separation distance. Refer to Figure 1.4 for an example of capacitive coupling.

Figure 1.4
Capacitive Coupling

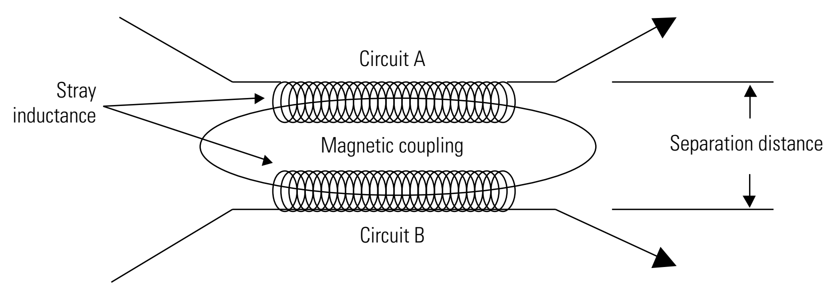


Mutual Inductance

At radio frequencies (RF) the inductance of a straight wire is significant. A length of wire 1.0 meter (39 in.) has an inductance of approximately 1.0 μH (Micro Henry). At 10 MHz the impedance is 60 ohms.

Two adjacent wires have mutual inductance forming a transformer. Fortunately, the effect reduces as the square of the separation distance. Refer to Figure 1.5 for an example of inductive coupling.

Figure 1.5
Inductive Coupling



Electromagnetic Radiation

An example of electromagnetic radiation is radio transmission. Industrial control wiring systems are large, wideband antenna which radiate noise signals to the world. These signals (together with conducted noise) are the primary target of the European regulations, but rarely cause system malfunctions.

Solutions for Reducing Noise

Noise reduction solutions are categorized as coupling reduction and source reduction. There are four main methods used to reduce the coupling of noise between source and victim. However, contact suppression is the only source reduction technique that can be directly applied by the system builder. Refer to the table below for a summary.

This method:	In this category:	Is defined as:	For more information refer to:
HF (high frequency) Bonding	Coupling Reduction	Maintaining all metalwork at the same electrical potential. This method is low cost and the basis for all other methods. It works by ensuring all equipment chassis are at the same potential at all frequencies. If different potentials exist the voltage difference is seen as common-mode noise on all interconnecting wiring.	The chapter *High Frequency (HF) Bonding*.
Segregation	Coupling Reduction	Separating sources and victims of electrical noise into zones. Noise coupling reduces with the square of separation distance. Zoning is zero cost (within limits).	The chapter *Segregating Sources and Victims*.
Shielding	Coupling Reduction	Using shielded cable and steel barriers (Faraday cage effect) to reduce electrical noise. Because of its relatively high cost, shielding is used with discretion.	The chapter *Shielding Wires, Cables, and Components*.
Filtering	Coupling Reduction	Using low-pass filters to attenuate RF noise. Relatively low cost but impractical for every wire.	The chapter *Filtering Noise*.
Contact Suppression	Source Reduction	Adding contact suppression to mechanical switches to reduce noise. Generally, the one noise source directly influenced by the system builder.	The chapter *Contact Suppression*.

Implementation

Implementation involves applying the methods summarized in the table on page 1-6 to the applications as shown in the table below.

This application:	Is defined as:	For more information refer to:
Routing AC and DC power	Applying bonding, segregating, shielding, and filtering techniques to AC and DC power supplies and the associated wiring.	The chapter *Power Distribution*.
Routing motor power cables	Applying shielding, grounding, and splicing techniques to motor power cable installation.	The chapter *Motor Wiring*.
Wiring high speed registration inputs	Applying all the noise reduction methods available to improve the performance of noise sensitive wiring.	The chapter *High Speed Registration Inputs*.
Routing encoder power cables	Applying bonding, segregating, shielding, and filtering techniques to encoder installation.	The chapter *Encoders*.

Measuring Effectiveness

Measuring noise reduction effectiveness involves using an oscilloscope to test for noise during implementation. It also involves monitoring for noise after implementation should updates to the system affect system performance.

This application:	Is defined as:	For more information refer to:
Measuring effectiveness	Testing for electrical noise during implementation, identifying the sources of noise, determining acceptable noise levels, and monitoring for noise on an on-going basis.	The chapter *Measuring Noise Reduction Effectiveness*.

High Frequency (HF) Bonding

Chapter Objectives

This chapter describes the ground plane principle and techniques to extend the ground plane to devices, panels, machines, floors, doors, and buildings. This chapter covers the following topics:

- Understanding the source of electrical noise
- Noise solutions using a ground plane
- Grounding (safety earth)

Understanding the Source of Electrical Noise

The most common source of electrical noise is due to switching of PWM output stages.

Two examples of how noise is generated by a drive system are given on the following pages.

Noise Example 1

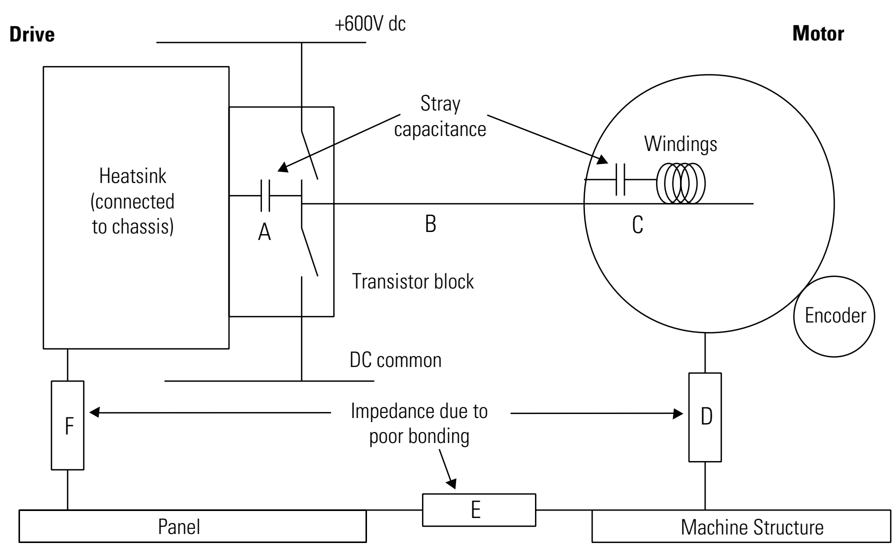
The transistors impose a 600V step change in the wire B (typically less than 200nS). Stray capacitance A charges very rapidly causing a current spike. This is the dominant noise source in PWM (Pulse Width Modulated) drive systems.

The current circulates through stray capacitance C, bonding impedance D, bonding impedance E, bonding impedance F, and back to stray capacitance A. A voltage spike will appear between motor frame and machine structure (Vd), between machine structure and the panel (Ve) and between the panel and drive chassis (Vf).

The circuit of an encoder mounted on the motor will then have a voltage spike of amplitude Vd + Ve relative to the panel and to any input circuit on the panel, potentially a noise victim.

The noise voltages are proportional to the impedance of the bonds (voltage = current x impedance). If these are reduced to zero, no voltage will appear between encoder and panel.

Figure 2.1
Switching noise affecting encoder signal



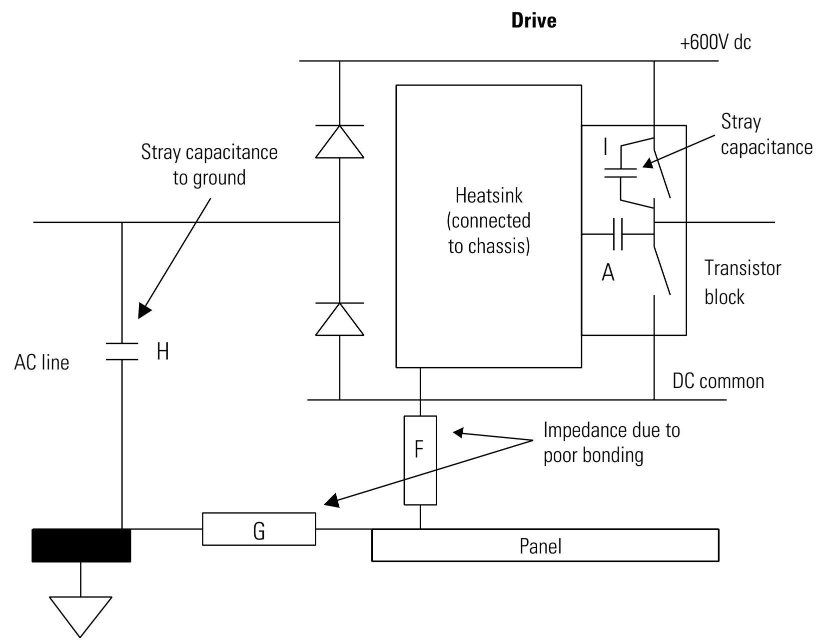
IMPORTANT The quality of bonding techniques applied during installation directly affects the noise voltages between system components.

Noise Example 2

Stray capacitance I charges very rapidly. Current circulates via stray capacitances H, bond G, bond F, and A. In this way, a voltage Vf + Vg is developed between the drive chassis and true-ground.

Any remote equipment grounded to this true-ground and wired to the drive will have this noise voltage imposed upon its incoming signal.

Figure 2.2
Switching noise affecting incoming power



Many other noise sources exist in a typical system and the advantage of good bonding holds true for all.

The Ground Plane Principle

The purpose of High Frequency (HF) bonding is to present a defined low impedance path for HF noise currents returning to their source.

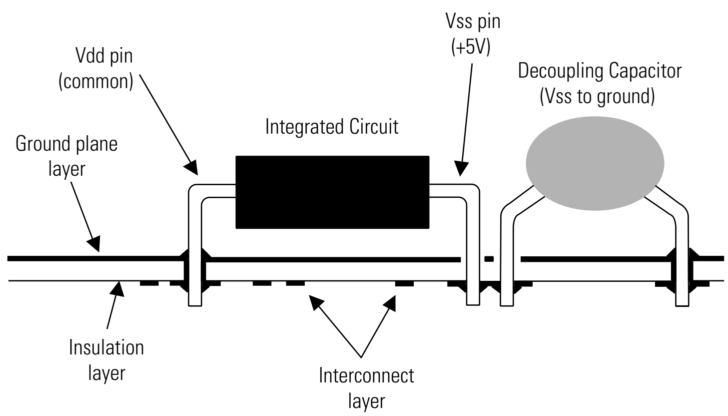
IMPORTANT Noise current must and will return to source. If a safe path is not provided, it may return via victim wiring and cause circuits to malfunction.

Most textbooks on radio frequency (RF) techniques describe the ground plane (GP) as the ultimate ground reference and an absolute requirement for controlling RF current paths.

The ground plane principle was originally developed by printed circuit board (PCB) designers for high frequency circuits. In multi-layer PCBs a minimum of two copper layers are used with one being designated the ground or common. This layer covers as large an area as possible and each IC common is tied directly to it. In addition, each IC Vss (+5V) pin is decoupled by a 0.1 μF capacitor to the ground plane as close as possible to the pin. The capacitor presents a very low impedance at RF hence any induced noise current generates minimal voltage.

The fundamental property of a ground plane is that every point on its surface is at the same potential (and zero impedance) at all frequencies. At high frequencies this is more effective than the use of single point grounding schemes. This is because wire has significant inductance at RF and just a few inches can create an unacceptable voltage drop. Refer to the section *Bonding Surfaces* in *Appendix A* for more information.

Figure 2.3
Ground plane layer in a double-sided printed circuit board



Ground plane construction has proved so successful that it is now universal in PCB design for all but the most price-sensitive and low frequency circuits. Single-sided PCBs are not generally used for RF or TTL circuits.

Extending the Ground Plane Principle

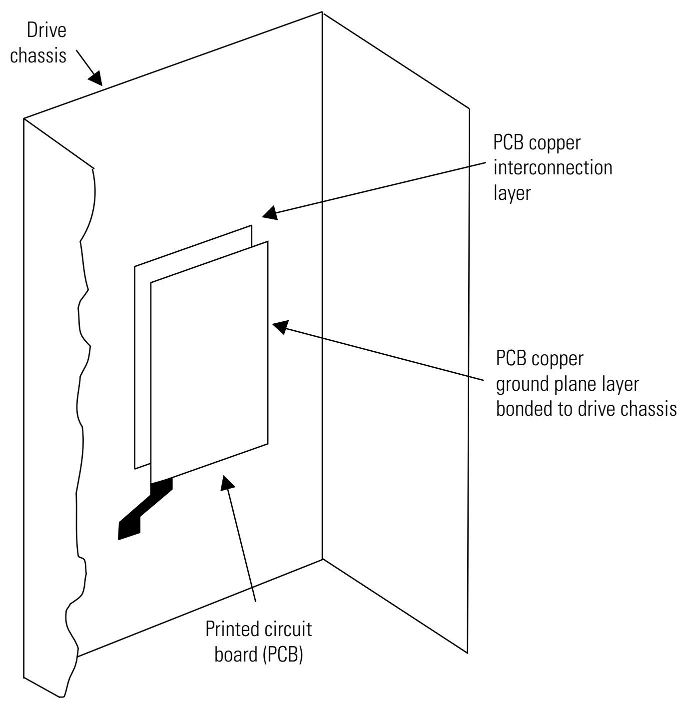
The same theory holds true regardless of scale, (the earth being the ultimate and literal ground plane) and can be used at control cabinet level or even building level, but requires rigorous implementation.

A ground plane does not have to be flat, but gentle curves prove more effective than sharp corners. Area is what matters. Even the outer surface of a machine structure can be used.

Grounding a PCB to the Drive Chassis

In the figure below, a PCB ground plane is extended by bonding it to the drive chassis.

Figure 2.4
PCB ground plane extended to the drive chassis



Guidelines for the system builder include:

- When permitted, the control circuit common should be grounded.
- Some products do not permit grounding of the control common, but may allow grounding to chassis via a 1.0 µF, 50V ceramic capacitor. Check your installation manual for details.

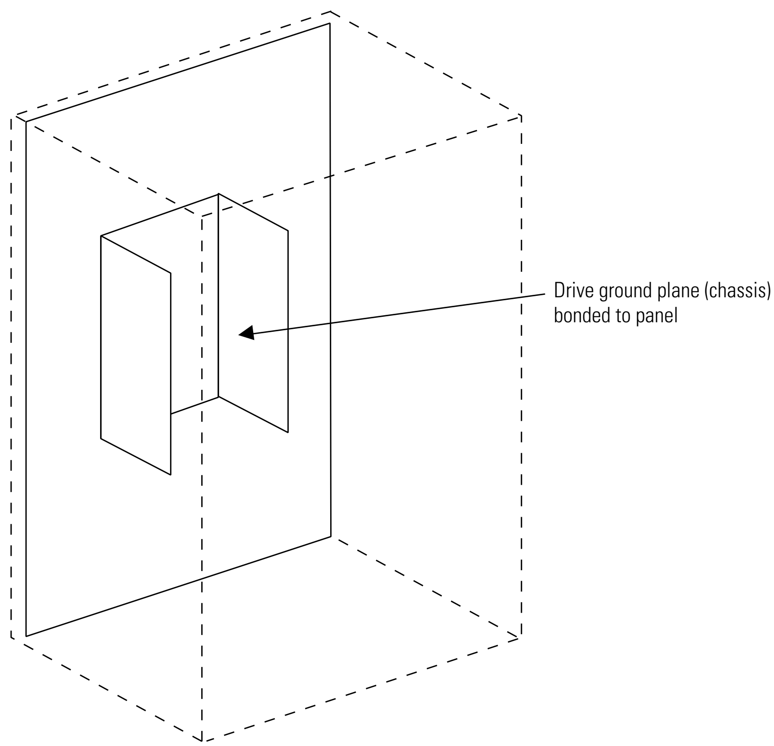
Noise Solutions Using the Ground Plane Principle

In this section, examples of how to apply the ground plane principle are described.

Grounding to the Component Mounting Panel

In the example below, the drive chassis ground plane is extended to the mounting panel. The panel is made of zinc plated steel to ensure a proper bond between chassis and panel.

Figure 2.5
Drive chassis ground plane extended to the panel



Note: Where TE and PE terminals are provided, ground each separately to the nearest point on the panel using flat braid.

Plated vs. Painted Panels

In an industrial control cabinet, the equivalent to the copper ground layer of a PCB is the mounting panel. To make use of the panel as a ground plane it must be made of zinc plated mild steel or if painted, the paint must be removed at each mounting point of every piece of metal-clad equipment (including DIN rails).

Zinc plated steel is strongly recommended due to its inherent ability to bond with the drive chassis and resist corrosion. The disadvantage with painted panels, apart from the cost in labor time to remove the paint, is the difficulty in making quality control checks to verify if paint has been properly removed, and any future corrosion of the unprotected mild steel will compromise noise performance.

Plain stainless steel panels are also acceptable but are inferior to zinc plated mild steel due to their higher ohms-per-square resistance.

Though not always available, a plated cabinet frame is also highly desirable since it makes HF bonding between panel and cabinet sections more reliable.

Painted Components

Mating surfaces must be cleaned of paint and the exposed surfaces protected against corrosion with conductive paint or petroleum jelly.

Anodized Aluminum Components

Mating surfaces must be cleaned of anodizing and the exposed surfaces protected against corrosion.

EMC Filters

Filter performance depends entirely on close coupling between the filter case and the drive chassis (or other load chassis). They should be mounted as close as possible to the load and on the same panel. If a painted panel is used, short braid straps should be used to tie the two chassis together. As a temporary remedy, an effective means of coupling filter case and drive chassis is to lay a single piece of aluminum foil beneath the two chassis.

Doors

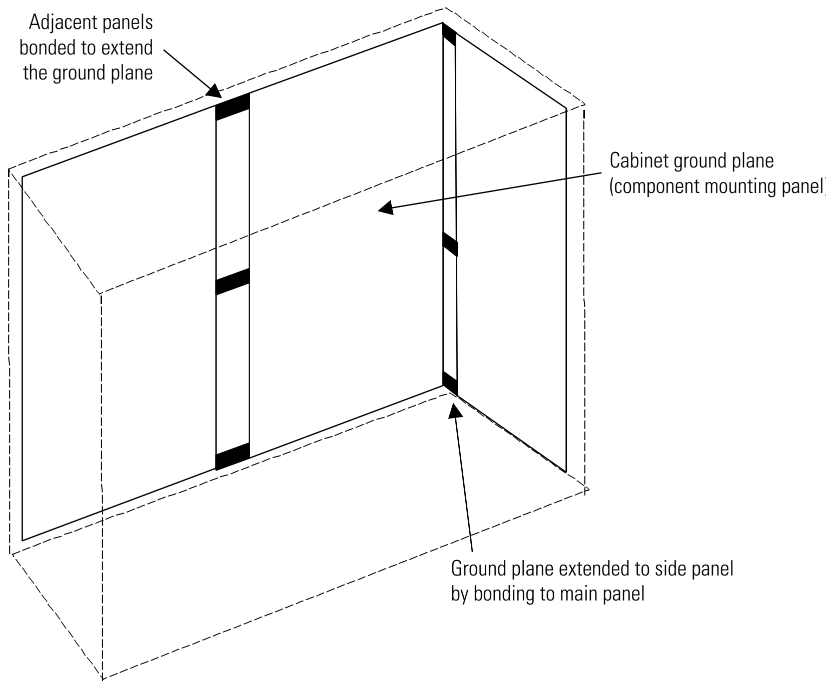
For doors 2 m (78 in.) in height, bond with two or three (three is preferred) braided straps (top, bottom, and center).

EMC seals are not normally required for industrial systems.

Adjacent Panels

Bond adjacent panels by mounting multiple flat straps between the panels. As an alternative, mount a filler plate between the panels using multiple fasteners along the edges of the plate.

Figure 2.6
Panel ground plane extended to adjacent panels

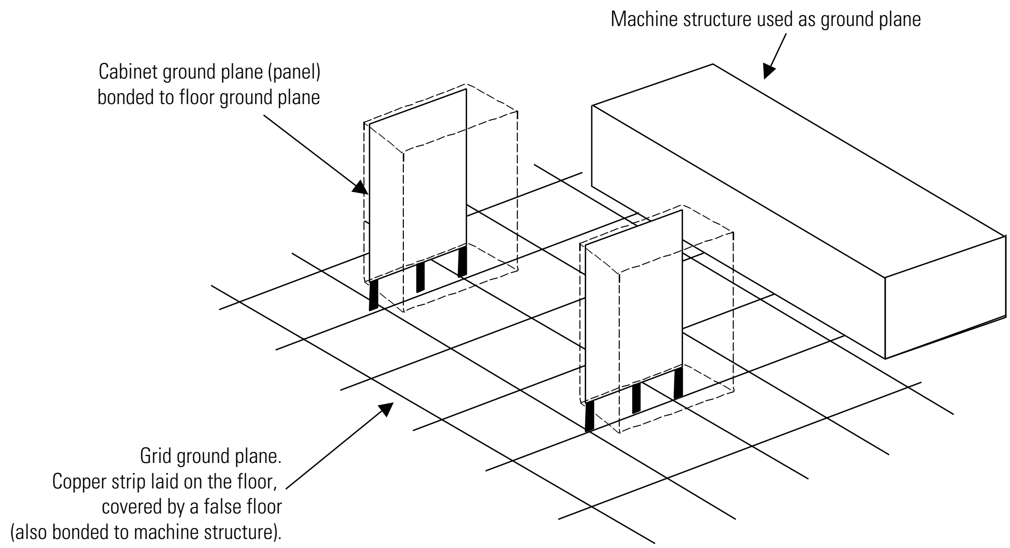


Grid and Raised Floor

Bonding cabinet panels and machine chassis to a ground grid below a raised floor is the best possible grounding scheme and commonly used in computer mainframe installations, but rarely used in industrial environments.

Ideally the grid squares should be 1 m (39 in.) or less.

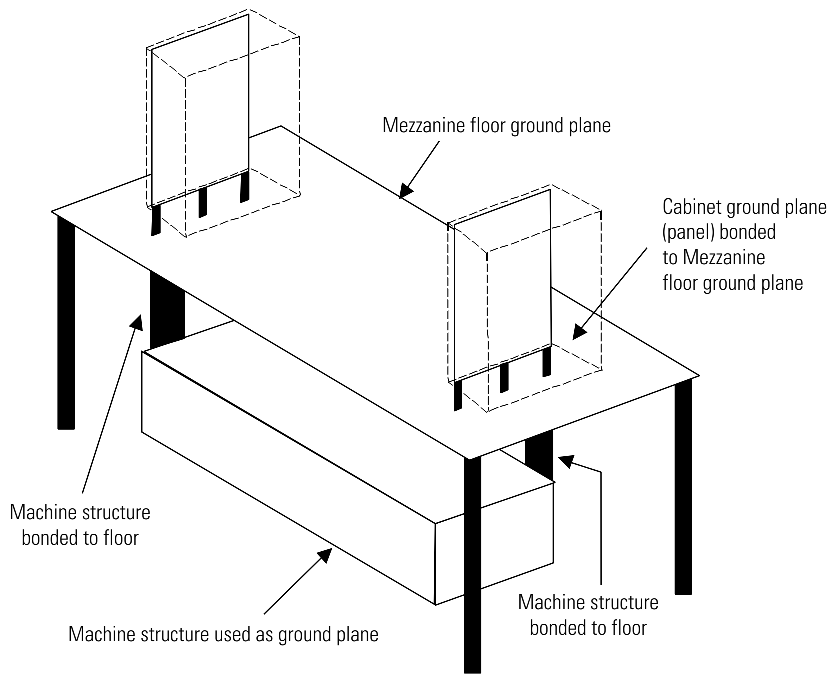
Figure 2.7
Panel ground plane extended to a grid beneath a raised floor



Mezzanine Floor

A mezzanine floor makes a very effective ground plane if the floor panels are aluminum or galvanized steel and bonded at their edges every 1 m (39 in.) minimum. Machine structure, floor, and both panels form one large ground plane.

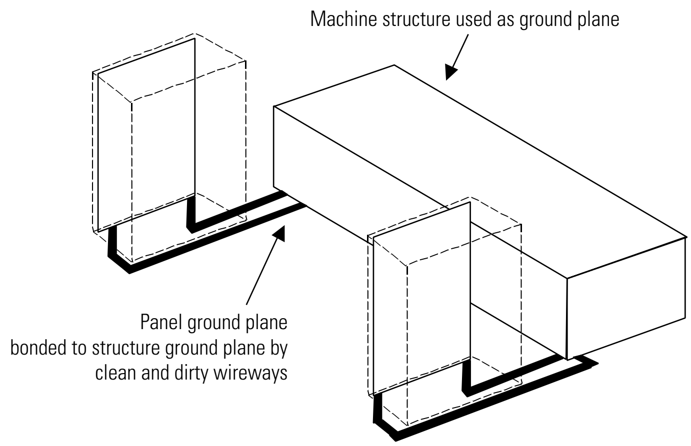
Figure 2.8
Panel ground plane extended to a mezzanine floor



Machine Structure

If the machine structure covers a large portion of the system area and is constructed of a conductive material with all sections closely bonded, then it too will form an excellent ground plane. Care should be taken to ensure paint is removed at the bonds and the connections protected against corrosion.

Figure 2.9
Panel ground plane extended to the machine structure

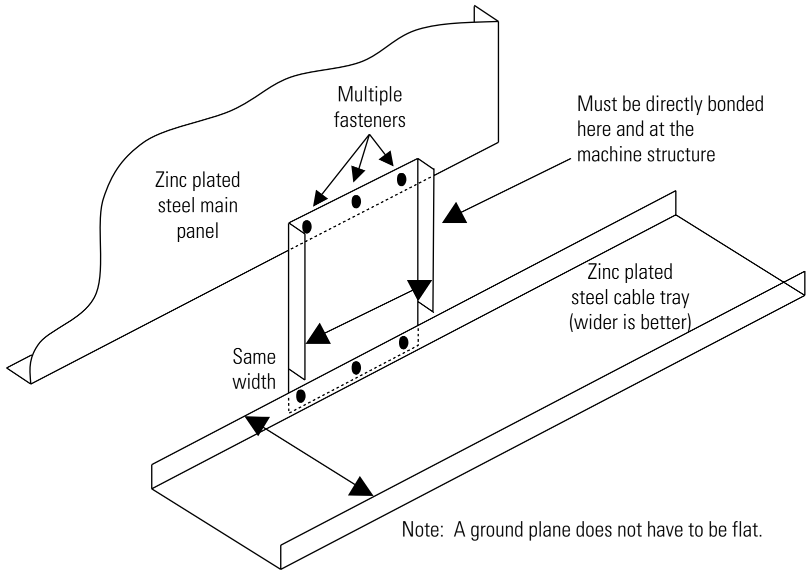


Bond the panel(s) to the machine structure as tight as possible, but if this proves difficult, construct a low impedance path using the following guidelines:

- Use a zinc-plated tray, as wide as practical, and join sections by overlapping with several fasteners across the width. The perforations will not reduce performance (refer to Figure 2.10).
- EMC trunking (plated at joint surfaces with conductive gaskets) also makes a good bond.
- Short and wide is the requirement for any HF bonding material. Panel(s) should be located as close to the machine structure as practical and the bond should be firmly attached at both the machine structure and the control panel (not the cabinet outer panels).
- Multiple trays/trunking are better.

Note that copper wire safety earth bonding is still required. Refer to the section *Grounding (Safety Earth)* at the end of this chapter for more information.

Figure 2.10
Extending the panel ground plane using cable tray

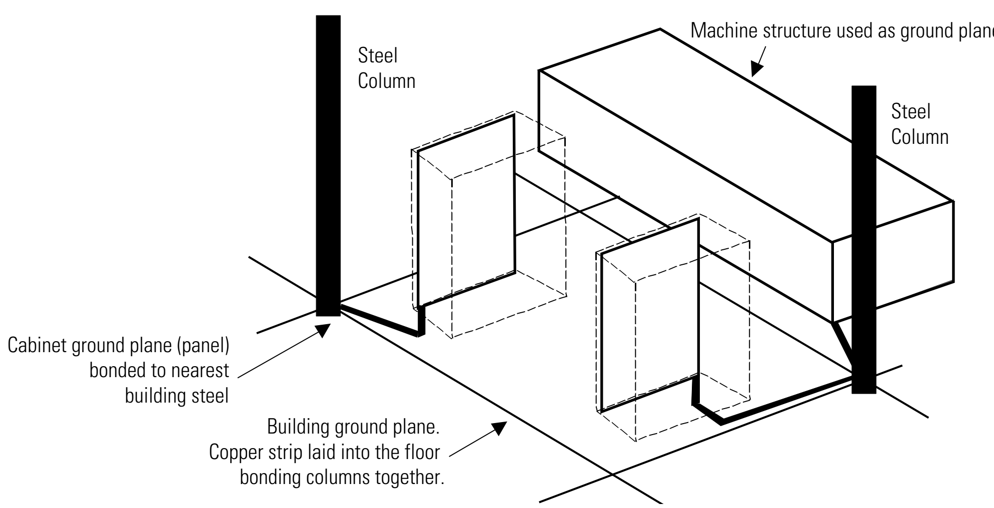


New Buildings

In new installations it is possible to specify that the structural steel columns are bonded together beneath the floor. This is similar in concept to the special floor grid shown earlier (refer to Figure 2.7), but inferior due to the large grid squares.

The panels are bonded by a flat strip or braid to the nearest steel column. The floor, machine structure, and panels form a large, but relatively ill-defined ground plane.

Figure 2.11
Panel ground plane extended to the building



Existing Buildings

The nearest building steel structures between the machine and control cabinets may be used to bond to.

If there is more than 20 m (65 ft) between the building structural steel closest to the motor and the building structural steel closest to the control panel, the ground between these two structural points should be checked and enhanced, if necessary, using at least 25 mm (1 in.) wide wire braid.

Limits

A ground plane sub-panel may only be considered part of a larger ground plane when bonded sufficiently well at RF. For this purpose wide thin strips are more effective than wire. Refer to the section *Bonding Surfaces* in *Appendix A* for more information.

- Length ≤ width x 10 is the generally accepted maximum ratio.
- Shorter = better
- Wider = better
- Thickness is not an issue. Thin is acceptable (even foil is very effective, but fragile).

The building example shown in Figure 2.11 normally falls outside these requirements.

In cases where the maximum 10:1 bonding aspect ratio limit cannot be satisfied, a differential noise voltage must be assumed to exist between each semi-isolated ground plane. All wiring entering a ground plane will carry this noise voltage and must be dealt with at the point of entry.

A ground plane is just as effective if it is perforated or made up of a matrix of flat conductors, provided that the apertures are smaller than one quarter of the wavelength of the highest troublesome frequency.

Grounding (Safety Earth)

Grounding refers to safety grounding and although the safety ground circuit and the noise current return circuit may sometimes share the same path and components, they should be considered as totally different circuits with different requirements. The object of safety grounding/bonding is to ensure that all metalwork is at the same, ground (or Earth) potential at power frequencies.

The copper wire typically specified by regulatory bodies has little effect at the high frequencies involved in noise problems.

ATTENTION

Safety ground circuits are extremely important and all relevant local and international regulations must be adhered to and take precedence over any guidance given in this document.

Generally, safety dictates that all metal parts are connected to safety earth with separate copper wire of appropriate gauge.

Most equipment has specific provisions to connect a safety ground or PE (protective earth) directly to it.

These ground wires should be terminated directly to a bonded PE ground bar, but lengths are not important provided the ground plane strategy is followed (refer to the section *The Ground Plane Principle*).

Segregating Sources and Victims

Chapter Objectives

This chapter describes how establishing zones within your panel for noise sensitive or noise generating components can reduce coupling of electrical noise. This chapter covers the following topics:

- Understanding the segregation concept
- Zone classification
- Routing wires and cables within a panel
- Routing system wires and cables between panels

Understanding the Segregation Concept

You can avoid many of the problems caused by noise by grouping sources and victims (along with their associated wiring) in zones according to their noise performance rather than arranging for neatness, tradition, or convenience.

Noise Zones

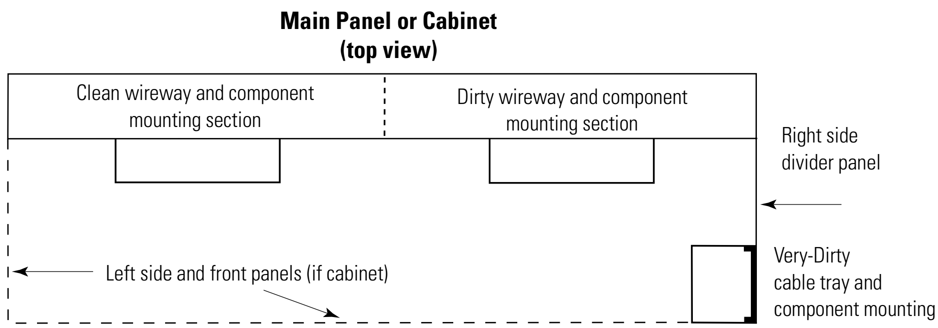
The three noise zones are defined in the table below.

This noise zone:	Has this relative noise level:
Very-Dirty	High
Dirty	Moderate
Clean	Low

This descriptive terminology (very-dirty, dirty, and clean) is chosen for maximum clarity. Most noise documents assign numbers to the zones, but there is no consistent numbering scheme. The descriptive approach allows you to see the true meaning of a zone at a glance, without having to remember a code.

Figure 3.1 shows how you can create three zones in a standard panel or cabinet enclosure. The very-dirty items are placed in the right/front section. The dirty items are placed behind them in the right/rear section and the least noisy (clean) items are placed in the left/rear section.

Figure 3.1
Relative position of noise zones on the panel



A side panel is fitted on the right to support the power cable shield clamps and any very-dirty wires, cables, or components. This leaves the main panel free for the clean and dirty zones.

Note: It is preferable to mount PLC and motion control equipment in a separate cabinet away from power control equipment (motor starters, etc.).

Ensuring CE Compliance at Build Time

Ensuring CE compliance is aided by the use of detailed physical panel layouts, together with wiring schedules to specify precise wire routing and zone categories. Periodic checks during installation are recommended to achieve full CE compliance.

As an aid to the technicians wiring the panel, the use of grey wireways for the clean zone and black wireways for the dirty zone helps ensure proper segregation of cables. For example, this makes a communication cable running in a dirty wireway easier to see.

Zone Classification

You can classify each cable or device based on these two factors:

- How much noise does the cable/device generate/radiate?
- How sensitive is the device connected via the cable to electrical noise?

Component Categories

The table below indicates which noise zone components fall into as a general reference for component segregation

Note: An X in multiple zones indicates that the component straddles the two zones. Under these circumstances it is important to position the component in the correct orientation.

Component	Very-Dirty	Dirty	Clean
PWM Drives/Amplifiers[1]	X	X	X
Dynamic braking components	X		
External Dump Resistor (unshielded)	X		
External Dump Resistor (shielded)[2]		X	
AC Line Filter	X	X	
Dump Resistor module (metal-clad)[2]		X	
Switch-mode DC power supply		X	
Ultrasonic Transducer[3]	X		
Contactors		X	
MCB		X	
Switched 24V dc loads[4] (e.g., E-stop/Piltz circuit, solenoids, relays, etc.)		X	
Encoder buffer board			X
PLC			X
Registration 24V dc supply filter			X
Dirty to Clean filter		X	X
Linear DC power supply			X
Other 24V dc none-switched loads			X
Data/Communication devices			X
Analog devices			X

[1] The connector/terminal block locations on the drive will normally dictate the zone geometry since it normally has connections in all categories. Design zones around the drive(s).

[2] Bond chassis to the main panel or drive chassis. Refer to the chapter *High Frequency (HF) Bonding* for more information.

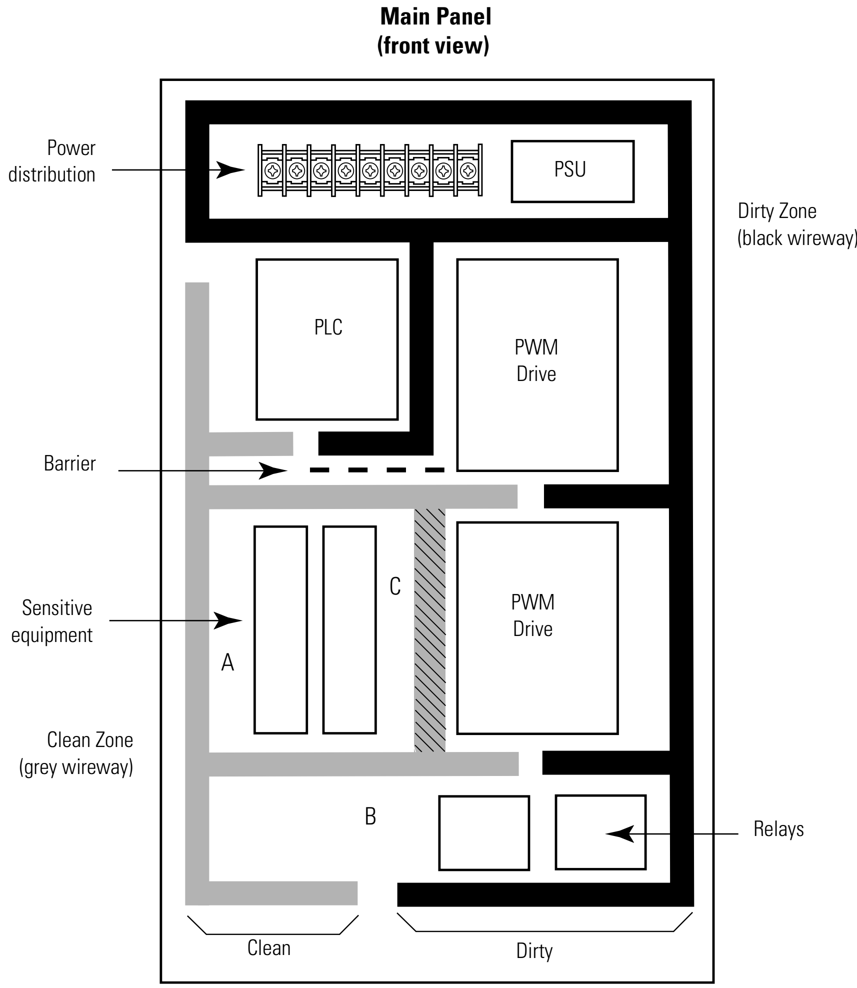
[3] Refer to the chapter *Filtering Noise* for more information.

[4] All inductive switched loads must be suppressed. Refer to the chapter *Contact Suppression* for more information.

Routing Wires and Cables Within a Panel

The following figures provide examples of how to route clean, dirty, and very-dirty wireways or cable trays within a panel.

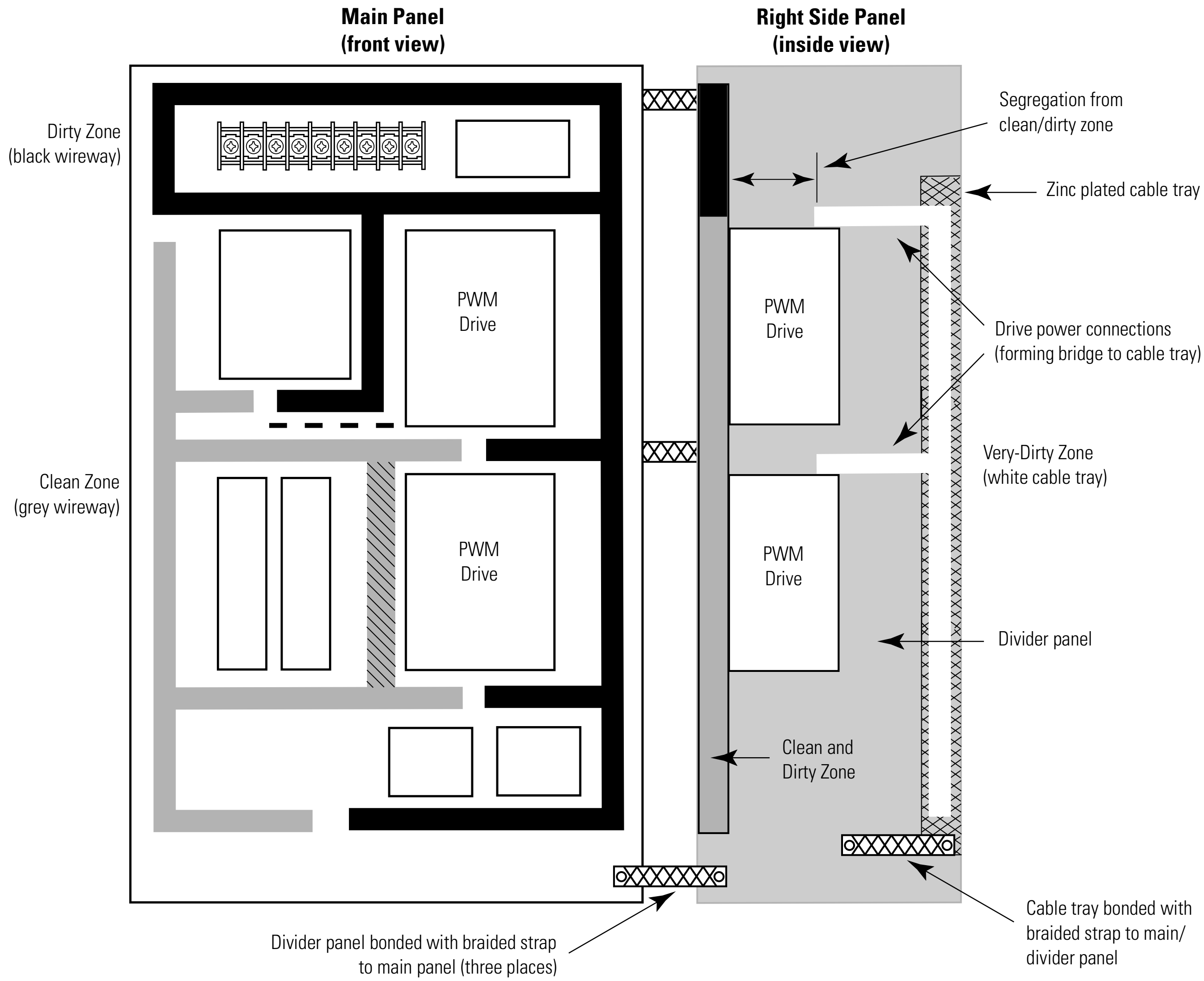
Figure 3.2
Routing clean and dirty cables



Observe the following guidelines when planning your panel layout for clean and dirty cables:

- The plated steel barrier between clean and dirty wireways allow them to run close together.
- If dirty power is required at A, then run it via wireway B using shielded cable. Refer to the chapter *Shielding Wires, Cables, and Components* for more information.
- The vertical wireway at C is not good practice as it encourages the creation of loops. Refer to the section *Minimizing Loops* later in this chapter.
- The use of different colored wireways (e.g., grey for clean and black for dirty) encourages good segregation.

Figure 3.3
Routing very-dirty cables



Observe the following guidelines when planning your panel layout for very-dirty cables:

- Power cables bridge across to the drive terminals from the cable tray on the right.
- The cable tray is bonded to the divider panel using braided strap. If no divider panel is used, then bond cable tray to main panel.
- A divider panel is used on the right to segregate very-dirty wiring from the clean zone of the next panel to the right.
- The divider panel is bonded with braided straps to the main panel at top, center, and bottom.
- Use 25.4 mm (1.0 in.) wide braided strap for bonding (preferred method). Braided strap 12.7 mm (0.5 in.) wide is acceptable.

Wire and Cable Categories

The table below indicates the best zone for running cables and wires. The table also shows how the use of ferrite sleeves and shielded cable can reduce the noise effects of dirty and very-dirty wires and cables.

Note: Some items have two entries (one shielded and one not shielded).

Cable and Wire Category	Zone			Method	
	Very-Dirty	Dirty	Clean	Ferrite Sleeve[1]	Shielded Cable[2]
Three Phase between Line Filter and Drive	X				
Three Phase between Line Filter and Drive		X			X
Extended DC bus	X				
Extended DC bus		X			X
PWM Drive/Inverter to Motor Power[3]	X				
PWM Drive/Inverter to Motor Power		X			X
PWM Drive/Inverter to Sine Wave Filter	X				
Sine Wave Filter to Motor		X			
CM Choke to Motor Power	X				
CM Choke to Motor Power		X			X
Line Terminator - Motor Power	X				
Line Terminator - Motor Power		X			X
External Dump Shunt Resistor	X				
External Dump Shunt Resistor		X			X
Contactor to AC Motor	X				
Contactor to AC Motor		X			X
Three Phase Supply Power		X			
Single Phase Supply Power		X			
24V Hydraulic/Pneumatic - solenoids		X			
Motor Feedback Resolver			X		X
PLC digital I/O		X			
Dedicated Drive Inputs (except registration)		X			
Limit Switches		X			
Push buttons		X			

Cable and Wire Category	Zone			Method	
	Very-Dirty	Dirty	Clean	Ferrite Sleeve[1]	Shielded Cable[2]
Proximity Switches (except registration)		X			
Photoelectric Cell		X			
24V dc Relay		X			
Transformer Indicator Lamp		X			
Data/Communications[4]			X	X	X
Encoder/Resolver			X		X
Logic circuit power			X		X
High Speed Registration inputs[5]			X		X
PLC Analog I/O			X		X
PLC High Speed Counter input			X		X

1 An X in this column indicates a ferrite sleeve fitted to the wire is recommended.

2 An X in this column indicates a shielded cable is recommended.

3 Keep unshielded conductors as short as possible and separated from dirty and clean cables as far as possible.

4 Refer to the section *Data/Communications Cables* below for more information.

5 Refer to the chapter *High Speed Registration Inputs* for more information.

Note: Grounding power cable shields at entry to the cabinet is recommended.

Data/Communications Cables

Data and communication cables that come from a remote structure (refer to the chapter *High Frequency (HF) Bonding*) will carry noise on their shields. Follow the guidelines listed below when installing data or communication cables.

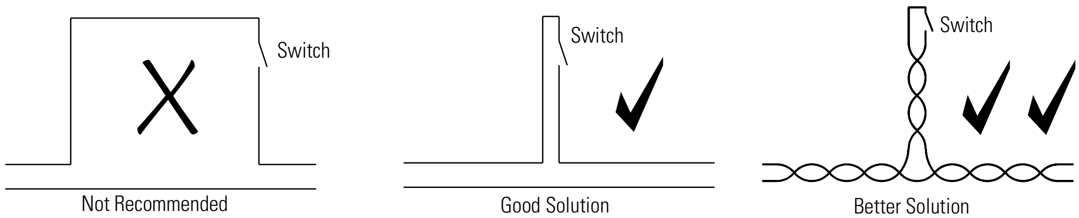
- Follow the product manual recommendations for termination resistors, minimum and maximum length, etc.
- Carefully segregate data and communication cables from dirty and especially very-dirty cables.
- Ground shields to the panel at the point of entry when permitted. Check your manual for the recommended procedure. Connecting to the 360° shield is preferable to the use of pigtails. If pigtails must be used, they should be kept short. Refer to the section *Grounding Cable Shields* in *Appendix A* for more information on grounding cable shields.
- Refer to the chapter *Filtering Noise* for more information.

Minimizing Loops

Wires that form a loop make an efficient antennae. Run feed and return wires together rather than allowing a loop to form. Twisting the pair together further reduces the antennae effects. Refer to the figure below for an illustration.

Note: This applies to potential victim wiring too. Antennae work equally well in both receive and transmit modes.

Figure 3.4
Avoiding loops in wiring designs



Routing System Wires and Cables Between Panels

Follow the same segregation guidelines when wiring between panels and machine devices.

- Maintain clean, dirty, and very-dirty noise zones.
- Always use separate, grounded, metal wireways.

Shielding Wires, Cables, and Components

Chapter Objectives

This chapter describes how using shielded cable or steel shields can reduce electrical noise coupling. This chapter covers the following topics:

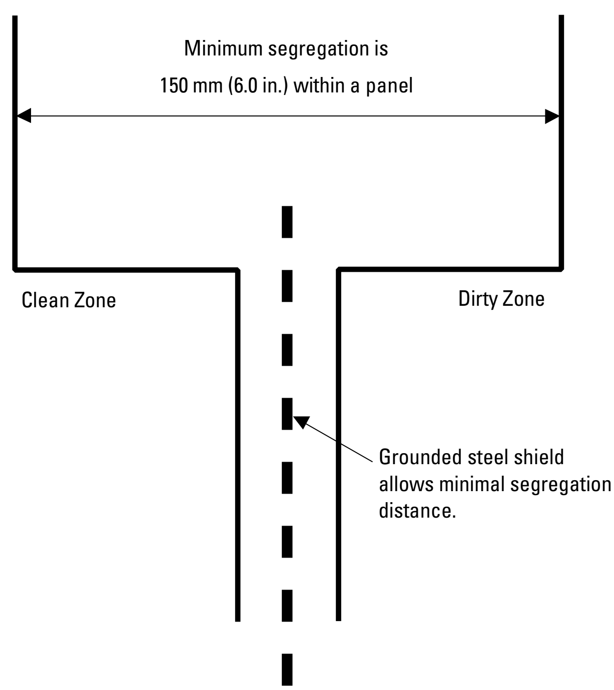
- Understanding the shielding concept
- Ferrite sleeves
- Mixing categories

Understanding the Shielding Concept

You can avoid many of the problems caused by noise by shielding sources and victims (along with their associated wiring) with the use of shielded cable or a supplementary steel shield.

If sources and victims cannot be sufficiently segregated it may be possible to prevent noise coupling by shielding as shown in the figure below.

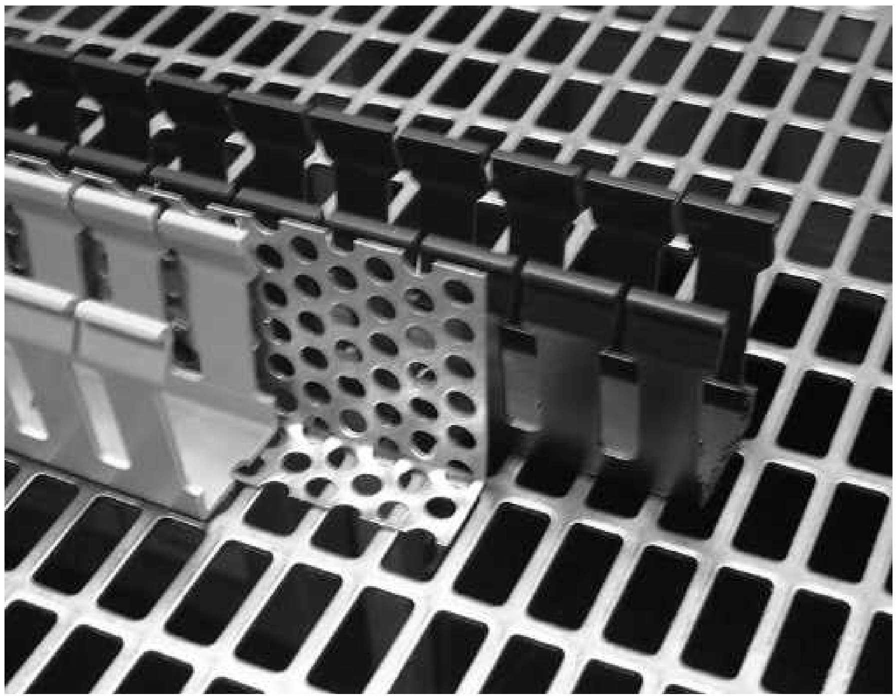
Figure 4.1
Wire segregation vs. shield



In the shielding example below the grey plastic wireway (front) is shielded by 0.7 mm (0.03 in.) thick perforated and plated sheet steel. The perforated steel is easy to cut and bend. You can safely route very-dirty wires in the other (black) wireway behind the shield.

Note: By using grey colored wireway for clean zones and black for dirty and very-dirty zones you will see more clearly when shielding is necessary.

Figure 4.2
Shielding example



Ferrite Sleeves

Shielded data cables grounded at both ends (important at high frequencies) may carry noise current due to voltage differences between the two ends. Because the shields have a low impedance, currents may be quite high even though voltage is low. These currents can cause spurious data reception.

By installing ferrite sleeves, the common-mode impedance of the cable is greatly increased at HF thus blocking the noise currents without affecting the signal currents.

In Figure 4.3 the capacitor grounding is very effective and avoids no-grounding rules, but it's awkward to implement.

Figure 4.3
Ferrite sleeves increase common mode impedance

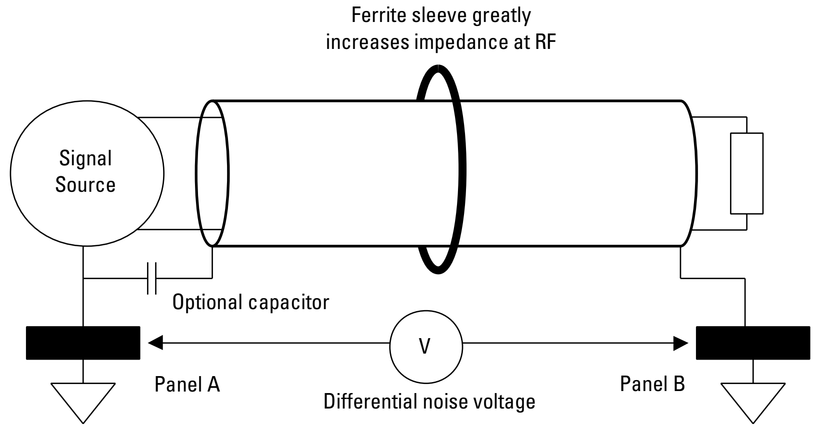


Figure 4.4
Common mode rejection in shielded cable

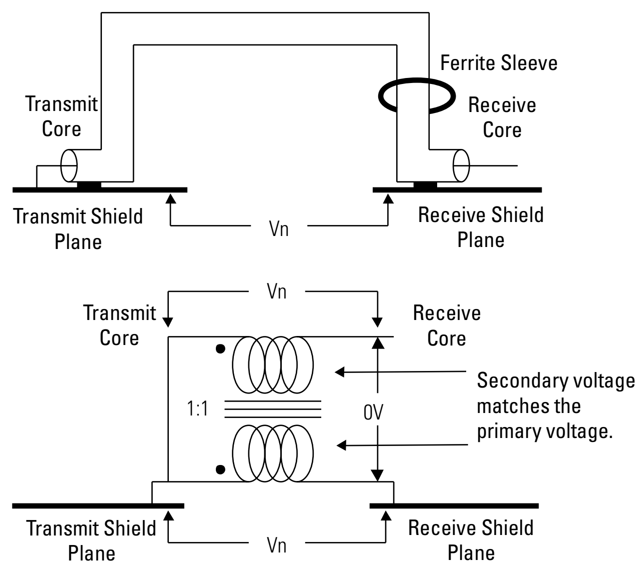
In this physical circuit, the core and shield are effectively connected together at the transmit end.

Vn is the noise voltage.

In this equivalent circuit, the core and shield form two windings of a 1:1 transformer.

The ferrite sleeve (more turns are better) forms a core increasing the magnetic coupling. The signal is unaffected.

This is known as a common-mode choke.



The following implementation guidelines apply to ferrite sleeves:

- Always install ferrite sleeves to data cables where specified.
- Always use ferrite sleeves when cable length is greater than 10 m (30 ft).
- If power frequency ground currents are expected, or measured by current clamp, one shield/ground connection could be made via a 1uF, 50V capacitor.

Ferrite Sleeve Limitations

After implementing all the guidelines presented in this manual, a properly built system should perform well without ferrite sleeves. However, by including sleeves in your installation, the system will avoid problems caused during future modifications.

System installations can benefit from ferrite sleeves, but you should also realize that ferrite sleeves alone are not a substitute for proper noise coupling reduction techniques.

As a rule, include sleeves as standard to obtain the most effective overall system.

For more information about ferrite sleeves, refer to *Appendix B*.

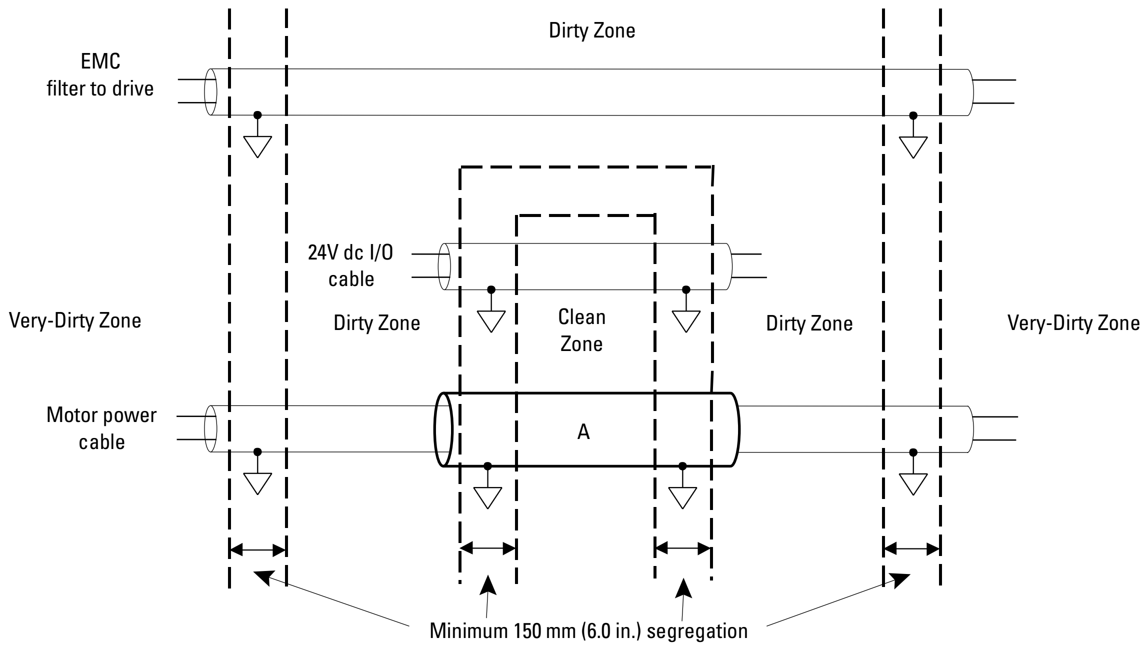
Mixing Categories

It is often difficult to segregate effectively in a confined space. When strict segregation isn't practical, minimize overlap and cross cables at right angles. Test results in *Appendix A* show that even a close parallel run of 0.5 m (20.0 in.) will allow significant noise coupling (refer to the section *Wire Segregation Test Results*).

You can convert wiring designated dirty or very-dirty to the next lower category by means of shielding using either shielded cable or conduit where required. Figure 4.5 and Figure 4.6 show how this technique may be used to mix categories without breaking the segregation rules.

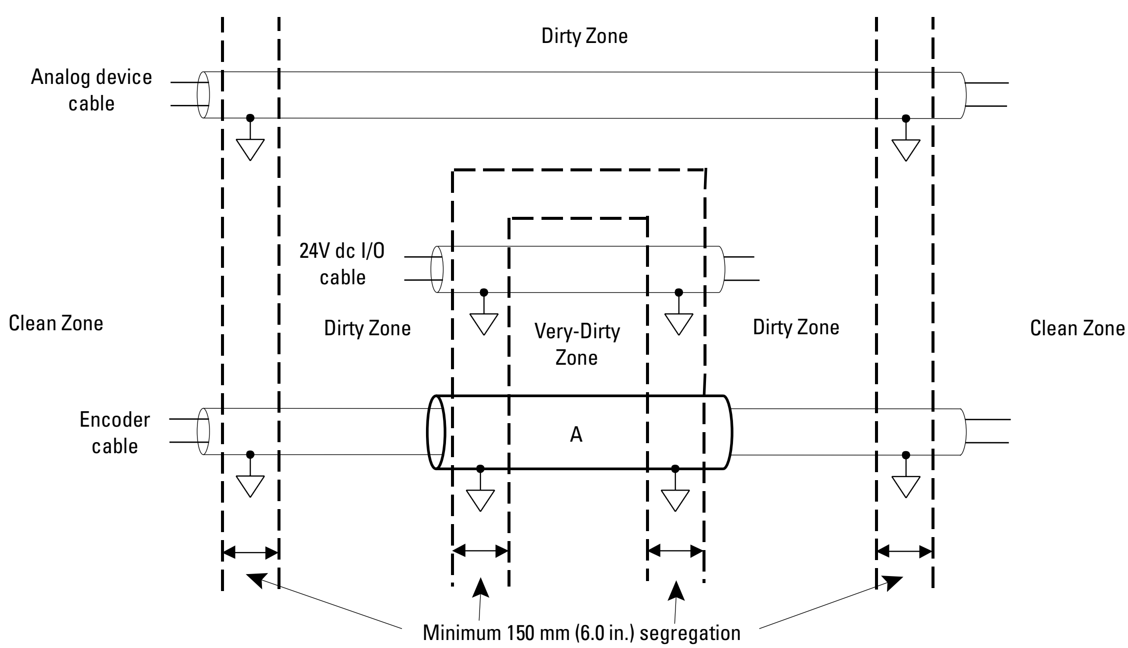
In Figure 4.5 the cable is locally shielded to cross another zone. Each shield is grounded at each boundary and the cable is run close to the panel. The outer shield A is a thick walled steel conduit.

Figure 4.5
Very-dirty cable in clean zone



The principle works both ways. In Figure 4.6 the clean cable passes through a very-dirty zone.

Figure 4.6
Clean cable in very-dirty zone



Filtering Noise

Chapter Objectives

This chapter describes how low-pass filters and ferrite sleeves can reduce electrical noise coupling. This chapter covers the following topics:

- Understanding the filtering concept
- Filter performance
- Ultrasonic transducers
- AC line filters

Understanding the Filtering Concept

If sources and victims are connected by wiring, you can prevent noise coupling by filtering. Low-pass filters attenuate high frequency noise without affecting the low frequency signals.

Commercial AC Line Filters for Low Voltage Circuits

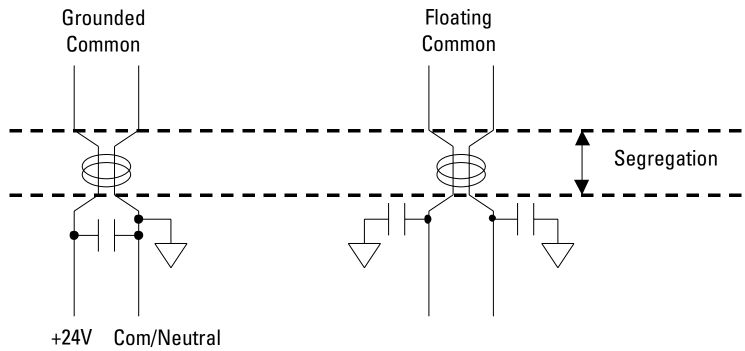
Provided that motor cable lengths are short, less than 20 m (60 ft), commercial AC line filters work well in low voltage circuits. Two-stage types are preferred.

If motor cable lengths are long, the natural ringing frequency is typically at too low a frequency (below 300k Hz) to be attenuated by commercial AC line filters. To determine if your cables are long, refer to the section *Installing Long Motor Cables* in *Appendix A*.

General Purpose 0-24V ac/dc Filters

The filter diagram shown below forms a classic LC low-pass filter.

Figure 5.1
Filter applied to 24V dc power circuit



IMPORTANT	The effectiveness of the LC low-pass filter depends on a perfect bond between the DIN rail and the ground plane panel.

Figure 5.2
Universal 0-24V ac/dc grounded common filter

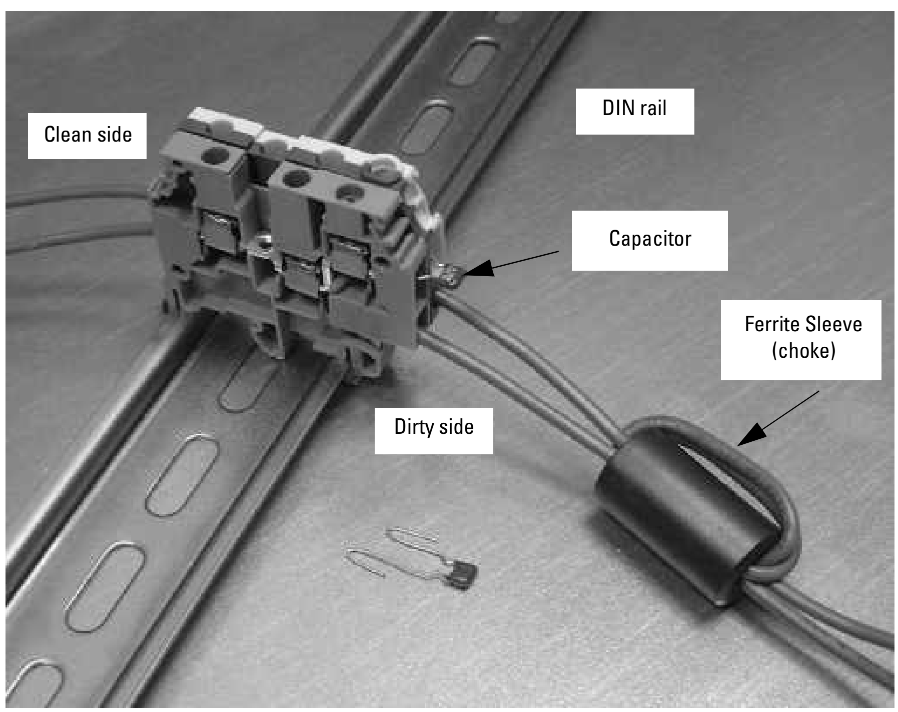
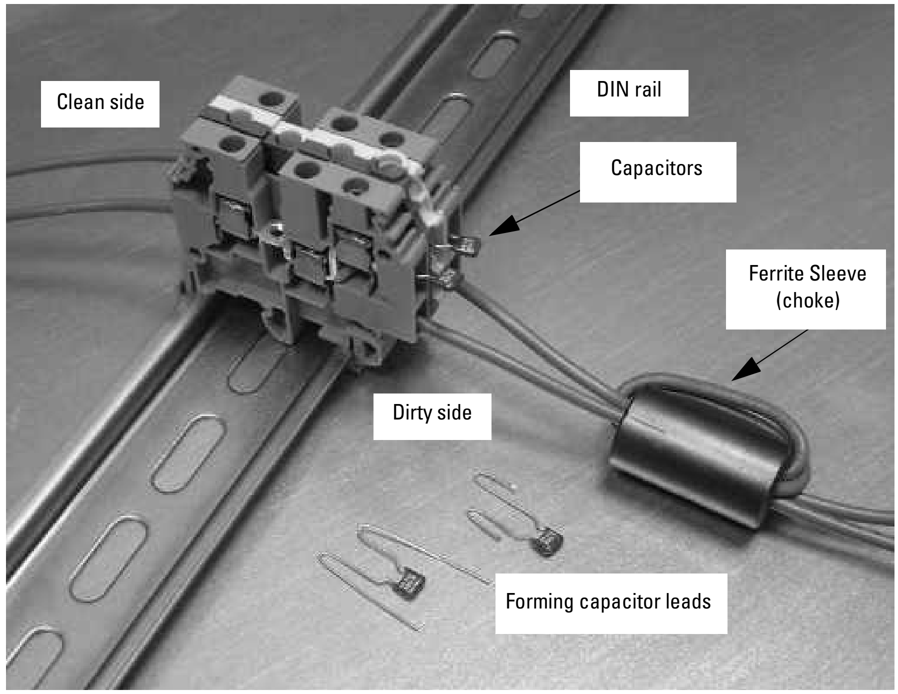


Figure 5.3
Floating-Common filter



The table below lists the part description and part numbers for the filters shown in Figure 5.2 and Figure 5.3.

Part Description	RS Components Part Number	Newark Part Number
Ground Terminal (1 in, 2 out type)	225-4372	N/A
Insulated Terminal (1 in, 2 out type)	426-193	N/A
1 µF, 50V Ceramic Capacitor[1]	211-5558	29F025
Small Ferrite Sleeve[2]	239-056[3]	91F6484

[1] Capacitor value is not critical, but it must be a ceramic type.

[2] The ferrite specification is not critical, but choose a low frequency type if possible.

[3] Alternative ferrite sleeve part numbers: Palomar (FB-102-43) or Schafner (2644665702)

Note: For more information regarding part vendors refer to *Appendix B*.

Filter Performance

The theoretical attenuation of one stage and two stage filters is shown in the table below.

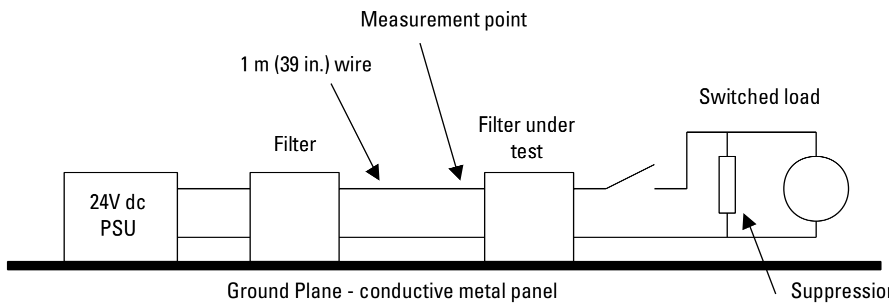
With this filter:	Attenuation @ 1M Hz is:
1 stage (2.8k Hz)	55 dB
2 stage (1.2k Hz	110 dB

Performance Test Set-up

The filter performance test included the following components:

- 24V dc power supply with grounded common filter
- Filter mounted to DIN rail
- Relay coil to simulate an inductive load
- 100M Hz sampling digital storage oscilloscope
- Test components mounted on a large zinc plated steel panel

Figure 5.4
Filter test block diagram



Test Results

This test condition:	With No filter:	With Capacitor only:	With Capacitor and ferrite sleeve:
No Suppression	200V pk	5.5V pk	674mV pk
R/C Across coil 100R/0.1uF	5.5V pk	932mV pk	168mV pk
R/C Across switch 100R/0.1uF	2.5V pk	103mV pk	70mV pk
Transorb Across coil	14.9V pk	1.8V pk	658mV pk
Transorb Across switch	8.1V pk	1.4V pk	1.2V pk
Diode	12V pk	63mV pk	63mV pk

Note: Voltages were measured between the measurement point and the ground plane (refer to Figure 5.4 for exact location.

Ultrasonic Transducers

Ultrasonic transducers often induce high noise levels onto their DC supply and signal lines. To reduce noise using ultrasonic transducers:

1. Mount two DC filters close to the device with ferrite sleeves between the capacitors and the sensor.

2. Feed the DC power supply through one sleeve.

3. Bring out the analog signal via the other sleeve.

Note: Use shielded cable for the analog signal.

The filter ground should be close coupled to the machine metalwork close to the sensor.

Xenon Flashing Beacons (strobe lights)

Strobe lights can generate high voltage transients on their 24V dc supply lines. To reduce this source of noise, try using one of these two alternatives.

- Mount a DC filter close to the lamp (ferrite sleeve on the lamp side) with its common attached to chassis ground.
- Use shielded cable between lamp and control panel, with DC filter at the point where the cable leaves the panel.

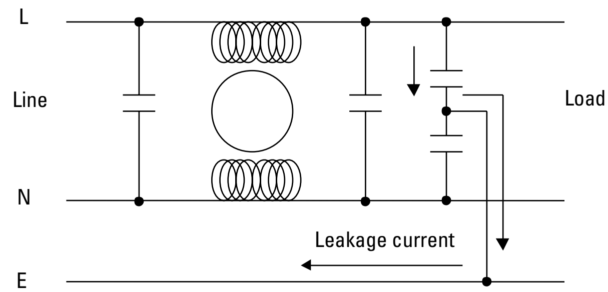
AC Line Filters

AC line filters contain capacitors connected between phase and the filter chassis. Line voltage is with respect to ground. The capacitor allows a small but potentially dangerous amount of current to flow to ground.

ATTENTION

To avoid personal injury and/or damage to equipment, ensure AC line filter capacitors are properly connected to safety (PE) ground.

Figure 5.5
Line filter earth leakage path



Three phase filters are theoretically balanced so the net ground current should be zero. However, a failure of any one capacitor or severe unbalance would cause ground current to flow and trip a circuit breaker.

Earth Leakage/Ground Fault

Earth Leakage Circuit Breakers (ELCB) and Ground Fault Interrupters (GFI) are typical European and US terms for the same device.

The ground/earth current may cause nuisance tripping of Earth Leakage Breakers. Uprated units may help in some cases.

Three phase filters, being balanced, are much less likely to give problems than single phase types.

Contact Suppression

Chapter Objectives

This chapter describes how contact suppressors for solenoids, relays, and various other switches can reduce electrical noise. This chapter covers the following topics:

- Understanding contact suppression for AC circuits
- Understanding contact suppression for 24V dc circuits
- Contact suppression effects

Understanding Contact Suppression for AC Circuits

The one potential noise source that the you can reduce directly is a contact switched load. Even circuits feeding resistive loads will produce significant switching noise. This is because the wiring both upstream and downstream of the contact is inductive. Thus, any switch contact will benefit from suppression.

IMPORTANT All switched, inductive loads in the system must be suppressed. This is standard practice in any PLC based control system.

Examples of AC devices requiring contact suppression include:

- Contactor controlled motors
- Solenoid coils
- Contactor coils
- Relay coils
- Transformer primaries
- Transformer driven indicator lamps
- Fluorescent cabinet lights (also require line filters close to the lamp)
- Line filters (often present an inductive load)

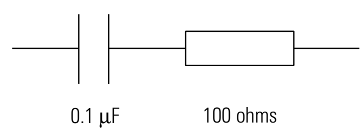
The only exception is a load driven by a Zero-Crossing Detector circuit such as Allen Bradley solid-state (Triac) output modules. Zero-crossing switches reduce noise generation virtually to zero. Preferred for frequent operation or close to clean zones.

Note: Sometimes the supply to a group of zero-crossing Triac outputs is switched by a mechanical contact for safety purposes. Suppress at the contact in this case.

Methods of AC Contact Suppression

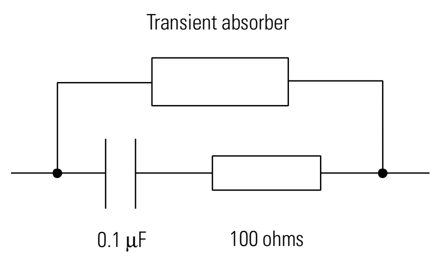
The typical RC suppressor circuit (shown below) consists of a 0.1 μF capacitor in series with a 100 ohm resistor. These components are readily available from many suppliers.

Figure 6.1
RC suppressor circuit



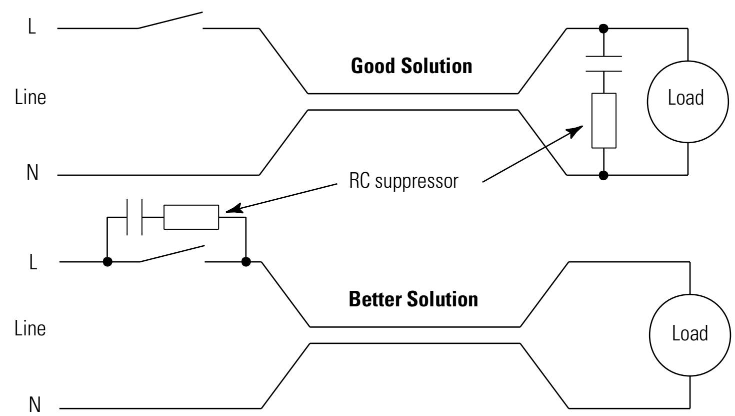
The typical RC plus transient absorber circuit (shown below) consists of the RC network shown in Figure 6.1 in parallel with a transient absorber. These are used in high current, high energy applications such as motor starters. A three-phase contactor requires three suppressors.

Figure 6.2
RC plus transient absorber circuit



The suppressor across the contact (as shown below, lower) reduces the noise from the wiring inductance as well as the coil inductance.

Figure 6.3
RC suppressor in circuit



Understanding Contact Suppression for 24V dc Circuits

Examples of DC devices requiring contact suppression include:

- Solenoid coils
- Contactor coils
- Relay coils

Methods of DC Contact Suppression

First choice for DC circuit suppression is a flywheel diode (shown in the figure below), but this does increase the release time which may not be acceptable in all applications. For the transient absorber method, refer to Figure 6.5.

Figure 6.4
Flywheel diode

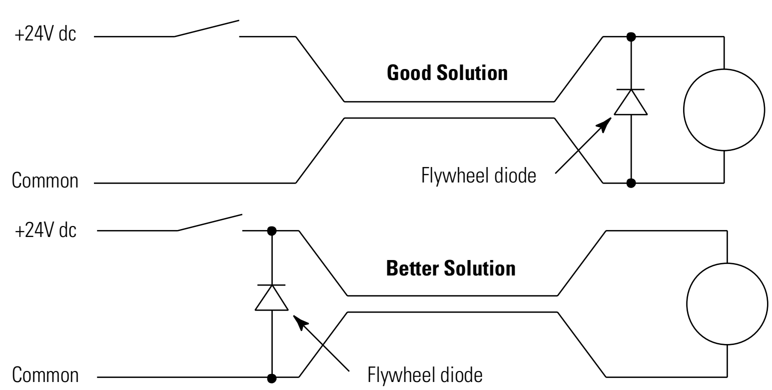
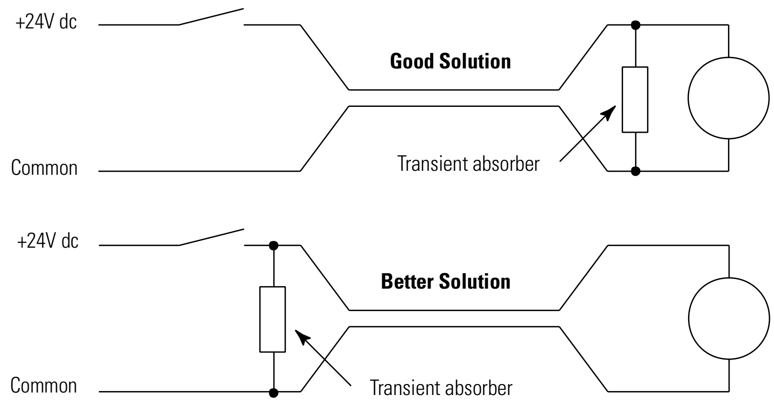


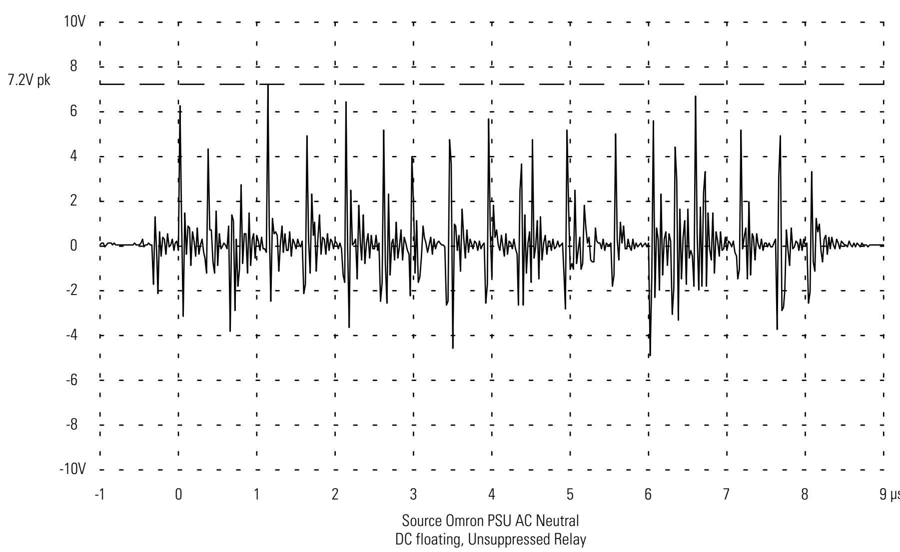
Figure 6.5
Transient absorber



Contact Suppression Effects

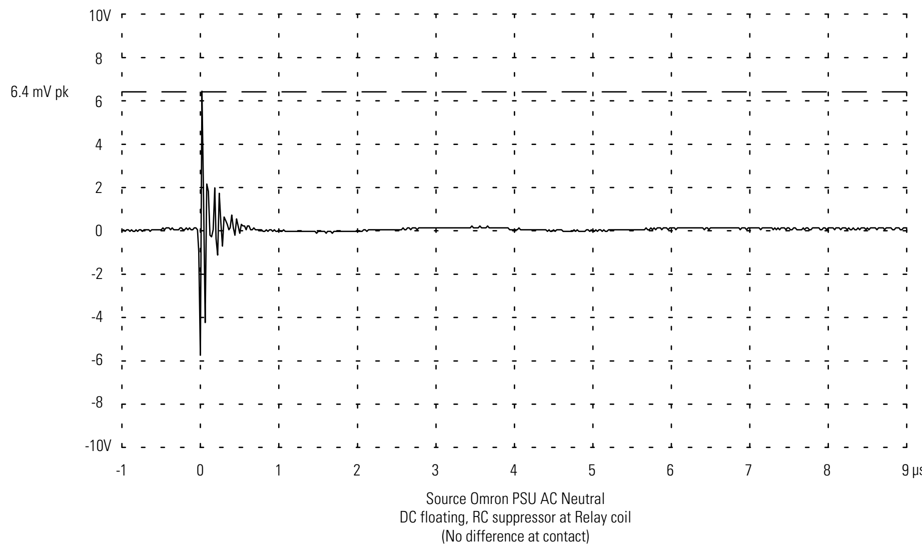
The waveform below displays 7.2V peaks across the AC terminals of a +24V dc power supply. Noise is due to load on the DC circuit being switched.

Figure 6.6
Unsuppressed inductive load on the DC circuit



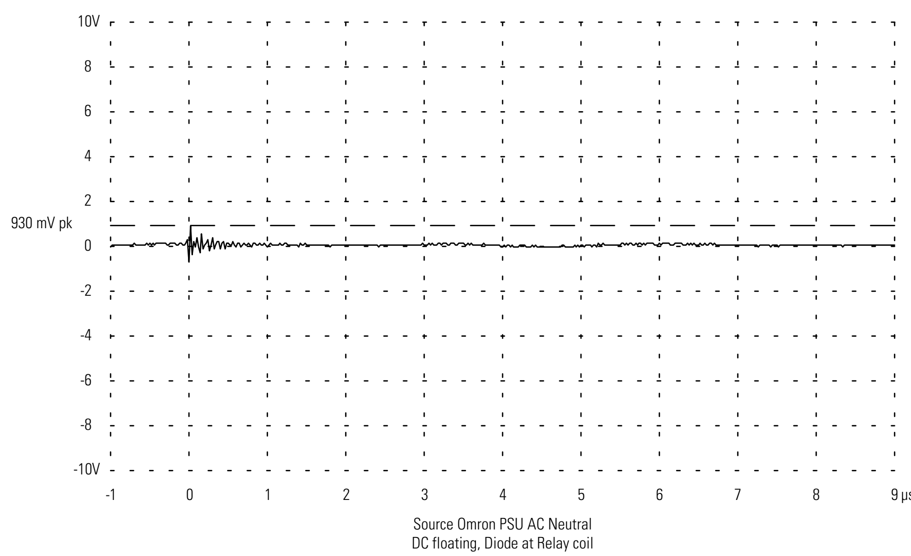
The waveform below displays the effects of an RC suppressor added across the coil on the noise shown in Figure 6.6. Peaks are reduced to 6.4V with significant reduction in duration. Refer to Figure 6.3 (upper) for example of RC suppressor across a coil.

Figure 6.7
Effects of RC suppressor mounted at the load



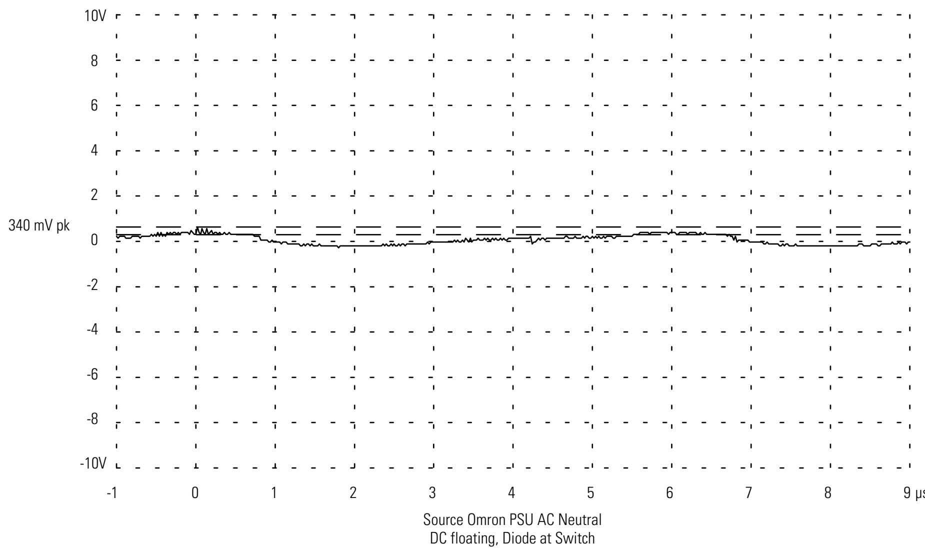
The waveform below displays the effects of a flywheel diode across the coil (refer to Figure 6.4, upper). The peak voltage is reduced to 0.9V.

Figure 6.8
Effects of Flywheel Diode at the load



The waveform below displays the effects of a flywheel diode across the switch (refer to Figure 6.4, lower). The peak voltage is reduced to 0.3V.

Figure 6.9
Effects of Flywheel Diode at the switch



The small additional noise reduction, when the suppressor is fitted across the switch, is because the wiring between switch and load is also inductive and creates the same inductive spike.

Power Distribution

Chapter Objectives

This chapter describes bonding, segregating, shielding, and filtering techniques when routing AC and DC power. This chapter covers the following topics:

- Understanding noise in power wiring
- Three-phase power supplies
- Single-phase power supplies
- 24V dc power supplies

Understanding Noise in Power Wiring

AC and DC power wiring usually extends to all parts of a system. Without precautions, noise coupled into any power wiring conductor is distributed throughout the entire system.

Three-Phase Power Supplies

To avoid noise related problems caused by three-phase power supplies, observe the following guidelines.

- Treat three-phase wiring as dirty.
- Include line filters for loads that create noise, such as PWM devices.

Line Filters

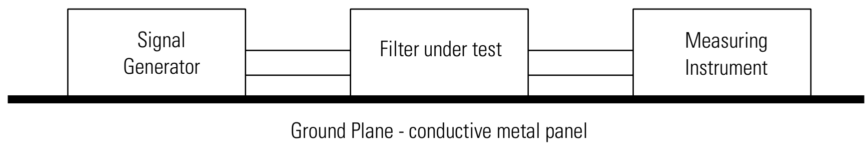
Observe the following guidelines when installing line filters.

- Install an individual filter as close as possible to each PWM load (this is the preferred configuration).
- Install the filter and PWM device on the same panel.
- Treat wiring between filter and drive as very-dirty (provide shielding as required).
- Segregate input and output wiring as far as possible.

IMPORTANT The effectiveness of the line filter depends solely on the HF bond between filter case and drive chassis.

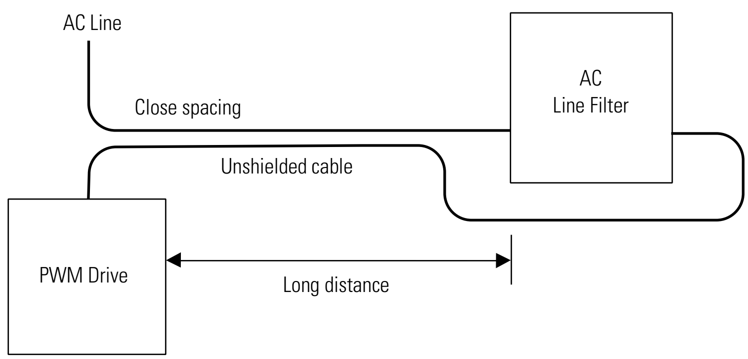
Commercial filters are tested, as shown in the figure below, with all devices properly bonded to a conductive metal ground plane. Proper bonding techniques are essential to achieve the published attenuation figures. Refer to the chapter *High Frequency (HF) Bonding* for more information on bonding.

Figure 7.1
Filter test set-up



In the example below, noise couples directly from the filter input wires to the filter output wires and bypasses the filter. You can avoid this common mistake by shielding and/or segregating the cables and reducing the cable length.

Figure 7.2
Improper line filter installation example

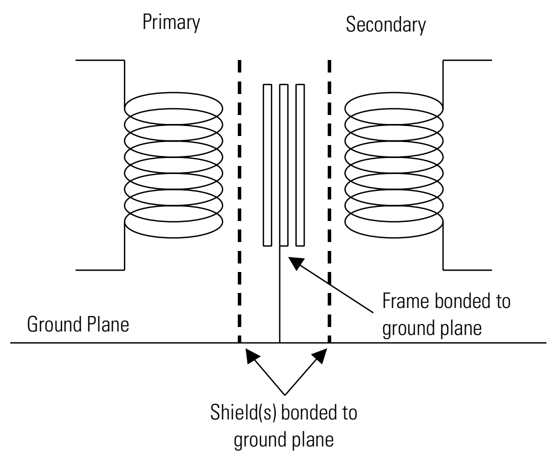


ATTENTION To avoid personal injury and/or damage to equipment, ensure AC line filter capacitors are properly connected to safety (PE) ground.

Transformers

An isolation transformer is frequently assumed to give good noise isolation. In fact, this only applies if the transformer is equipped with one or more electrostatic (ES) shields, as shown in the figure below.

Figure 7.3
Electrostatically shielded transformer



This technique is very effective, though generally EMC filters are required to meet European regulation standards. Observe the following guidelines when installing transformers.

- Install the transformer to the same panel as the rest of your system (or HF bond from panel-to-panel).
- Treat wiring between transformer and drive as very-dirty (provide shielding as required).
- Bond shield, if used, with braid directly to the panel. The transformer mounting bolts are useful for this purpose.
- Segregate input and output wiring as far as possible.

IMPORTANT The effectiveness of the transformer depends solely on the HF bond between shields and drive chassis.

Single Phase Power Supplies

To avoid noise related problems caused by single-phase power supplies, observe the following guidelines:

- Treat single-phase wiring as dirty.
- Include line filters for loads that create noise, such as PWM devices with DC switch-mode power supplies and fluorescent cabinet lights.
- Include line filters for potentially sensitive loads, such as PLC logic power.
- Mount the line filter as close to the load as possible.

24V dc Power Supplies

Switch-mode power supplies do not isolate noise and may generate common-mode noise on both AC and DC lines. Refer to the section *Switch-Mode DC Power Supplies* in *Appendix A* for more information.

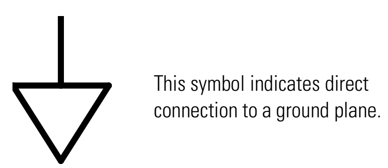
Linear power supplies normally generate very little noise, but AC line filters or DC output filters are required to attenuate incoming line noise to achieve a clean category.

To avoid noise related problems caused by 24V dc power supplies, observe the following guidelines.

- Connect the common through a ground terminal.
- Decouple the +24V dc line to the same ground terminal with a 1 µF, 50V ceramic capacitor to achieve the clean category.

The simplest method for making the ground connection is to use a ground terminal installed on the DIN rail fastened to a zinc plated panel. Refer to Figure 7.4 for an example of the symbol used in diagrams.

Figure 7.4
Ground Plane Symbol



24V dc Distribution

Route power wiring according to clean/dirty zones. Segregate the following load classifications:

- Clean loads that are potentially sensitive to noise and which do not create significant noise, e.g. controller logic supplies.
- Dirty loads that are insensitive to noise but may emit moderate levels of noise, e.g. relay circuits.

Note: Refer to the chapter *Segregating Sources and Victims* for a detailed listing of categories.

Note: Refer to the chapter *High Speed Registration Inputs* for special treatments of registration input devices.

24V dc PSU Zoning Methods

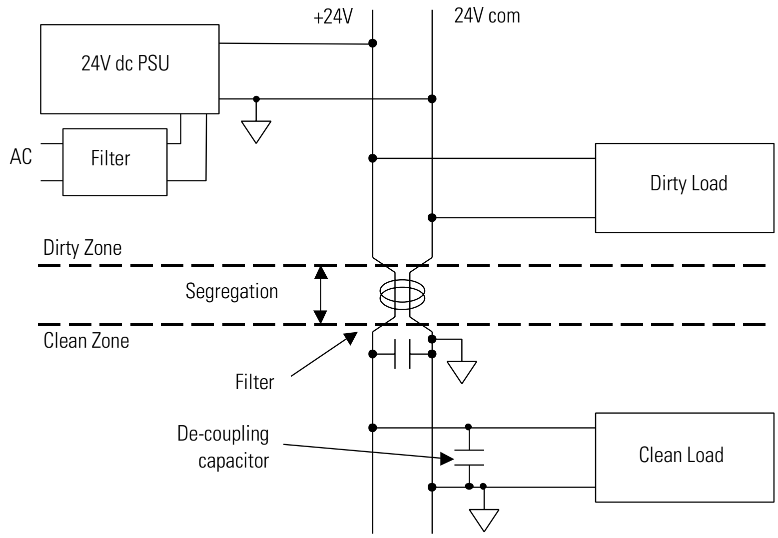
The following two methods of 24V dc power supply zoning are described in this chapter.

- Single 24 volt power supply with filtering between zones.
- Dual 24 volt power supplies.

Single 24V dc Switch-Mode PSU Zoning Example

In the figure below, a 24V dc supply is mounted in the dirty zone, because it may create noise. But, the noise is reduced by filtering before the output enters the clean zone.

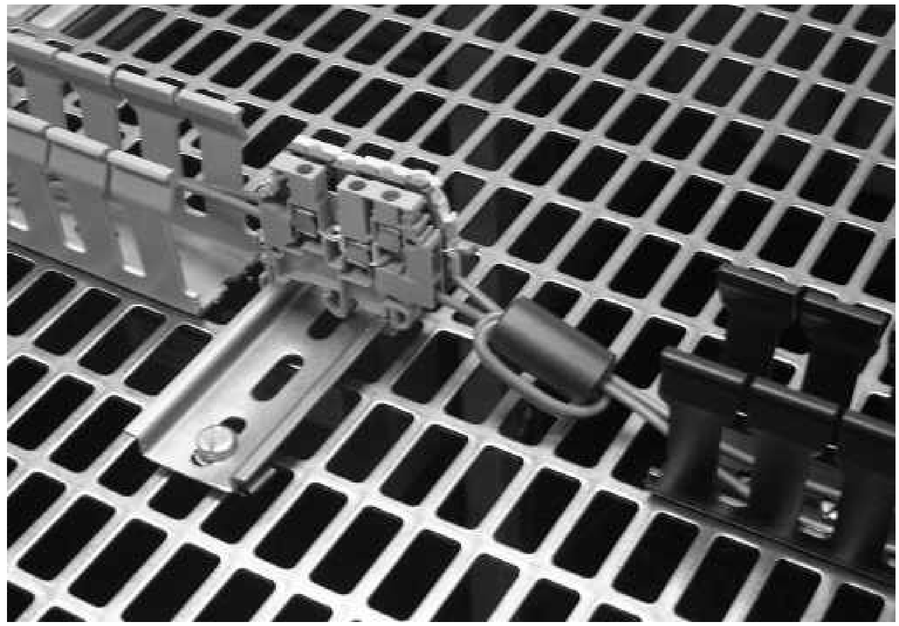
Figure 7.5
24V dc power distribution with single PSU



Grounded, de-coupling capacitors are used at each clean load (refer to the chapter *High Frequency (HF) Bonding* for details). Provided the system is correctly bonded, the multiple common/ground connections are not a problem. The copper becomes a backup conductor. No segregation or filtering is necessary for the load in the dirty zone.

In the figure below, a filter is pictured between the clean zone (grey wireway) and the dirty zone (black wireway). Refer to the chapter *Filtering Noise* for details regarding filters.

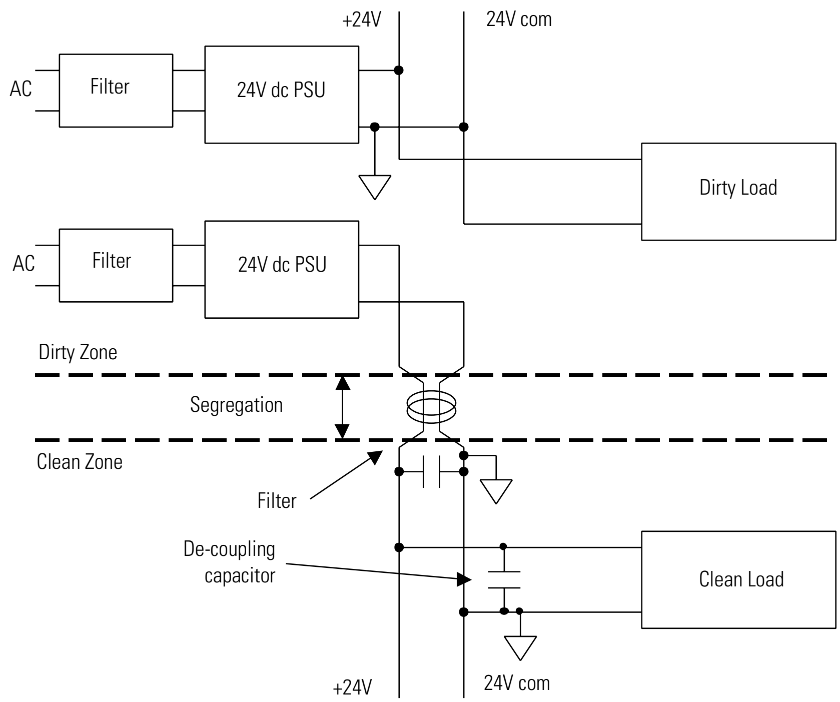
Figure 7.6
Filter between zones



Dual Switch-Mode 24V dc PSU Example

In the figure below, dirty and clean zone loads have dedicated power supplies. Segregation and filtering are used (as in Figure 7.5) to reduce the noise in the power supply for clean zone needs.

Figure 7.7
24V dc power distribution with dual PSU



Note: Clean PSU is mounted in the dirty zone because it typically generates noise in the switching process.

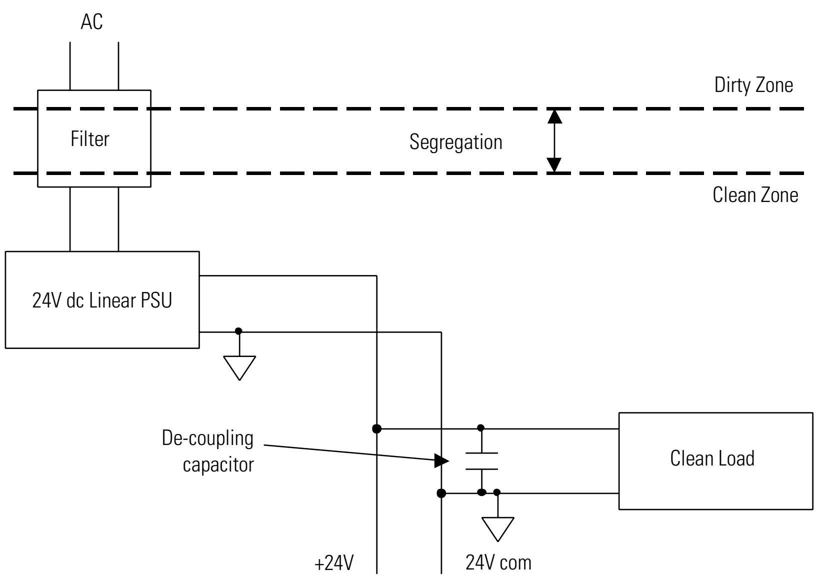
Linear PSU

The linear PSU does not generate noise on its AC terminals, as does a switch-mode supply, however, some noise reduction provisions are still recommended.

Linear PSU Mounted in Clean Zone

In the figure below, the linear power supply is mounted in the clean zone, but the AC line feeding it requires filtering. The AC line filter is positioned between zones and attenuates line noise which may otherwise be passed through to the DC circuit.

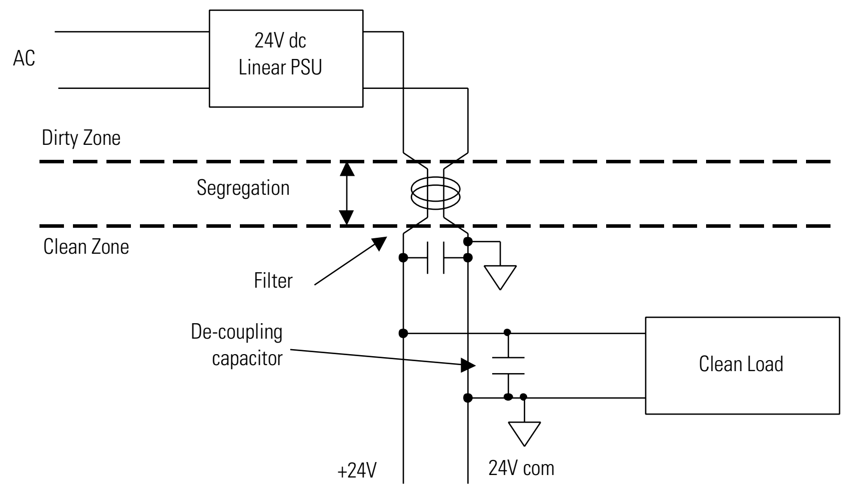
Figure 7.8
Linear PSU mounted in Clean Zone



Linear PSU Mounted in Dirty Zone

In the figure below no AC line filter is required because the linear PSU does not generate noise and the AC line noise is filtered by the DC filter.

Figure 7.9
PSU mounted in Dirty Zone



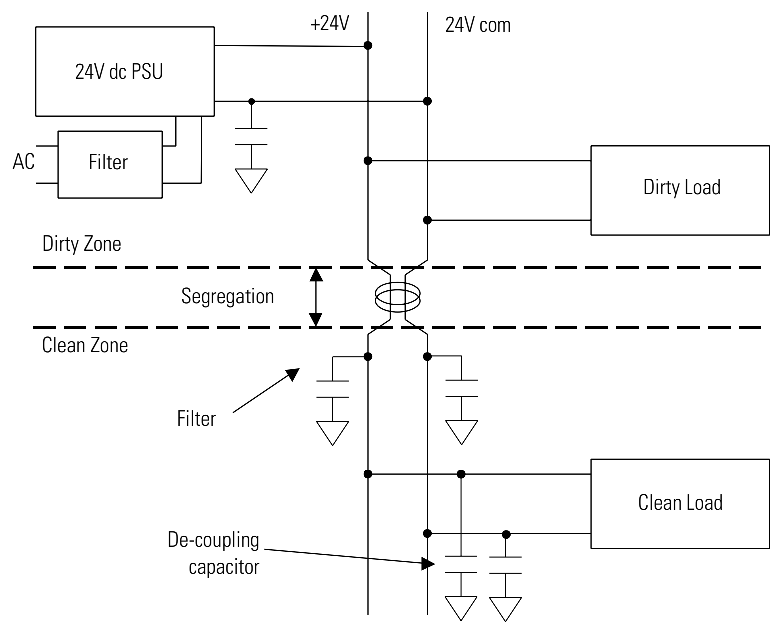
Special Applications for 24V dc PSUs

This section contains information considered application specific and does not apply to all installations.

Floating Requirement

If it is necessary to maintain a floating common, a modified filter may be used to ground the common at HF frequencies only. Refer to the chapter *Filtering Noise* for details regarding filters.

Figure 7.10
Floating Common

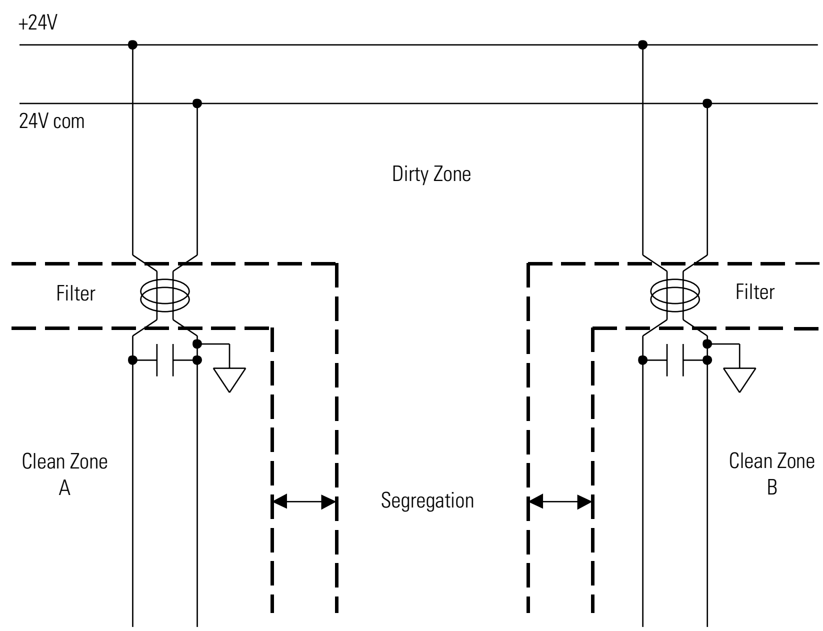


Segregation and Filtering Variations

Once the principles of segregation and filtering are understood it is possible to vary the strategy to suit special requirements.

For example, the clean zone does not have to be a single entity. As shown in the figure below, you can create separate local clean zones. Refer to the chapter *Segregating Sources and Victims* for guidelines on crossing zones.

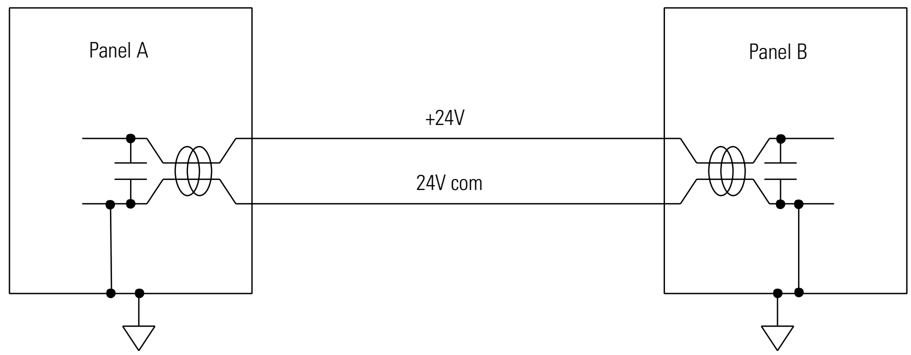
Figure 7.11
Separate Clean Zones



Long Power Cable Runs

The 24V dc lines entering or leaving panels that cannot be bonded together by flat strips (no longer than 10 times the width) should have filters at the point of entry.

Figure 7.12
Long cable runs between panels



Note: If heavy circulating currents at power frequency are likely, the floating filter technique or separate, local PSU's, may be safer to use.

Motor Wiring

Chapter Objectives

This chapter describes shielding, grounding, and splicing techniques for use with motor wiring. This chapter covers the following topics:

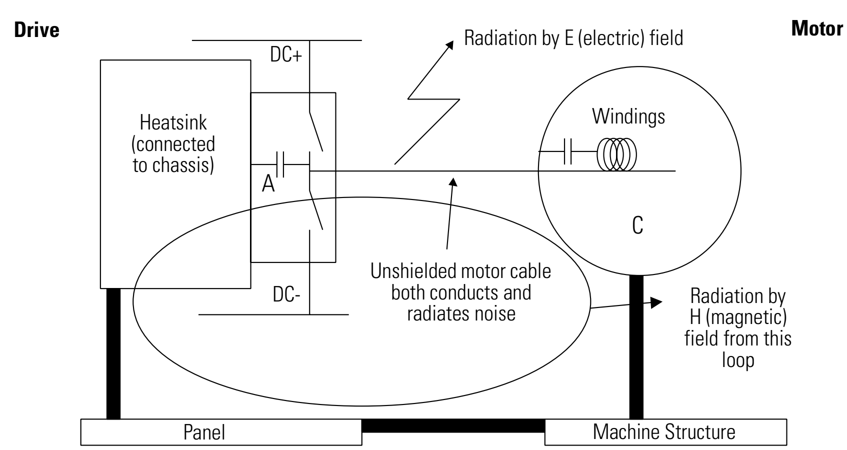
- Understanding noise in motor power wiring
- Shielding motor power cables
- Grounding motor power cable shields
- Applying ferrite sleeves
- Splicing motor power cables
- Handling excess cable
- Installing long motor cables

Understanding Noise in Motor Power Wiring

The PWM Drive to motor power conductors are typically the most intense noise source in a system. Proper implementation of shielding, grounding, splicing, and treatment of excess cable is essential to reducing noise in your system. In the figure below:

- The unshielded conductors radiate an electric noise field that couples capacitively with adjacent wiring.
- Stray capacitance at A & C cause ground currents to flow creating a magnetic noise field that couples inductively with adjacent wiring.

Figure 8.1
Motor power cable noise



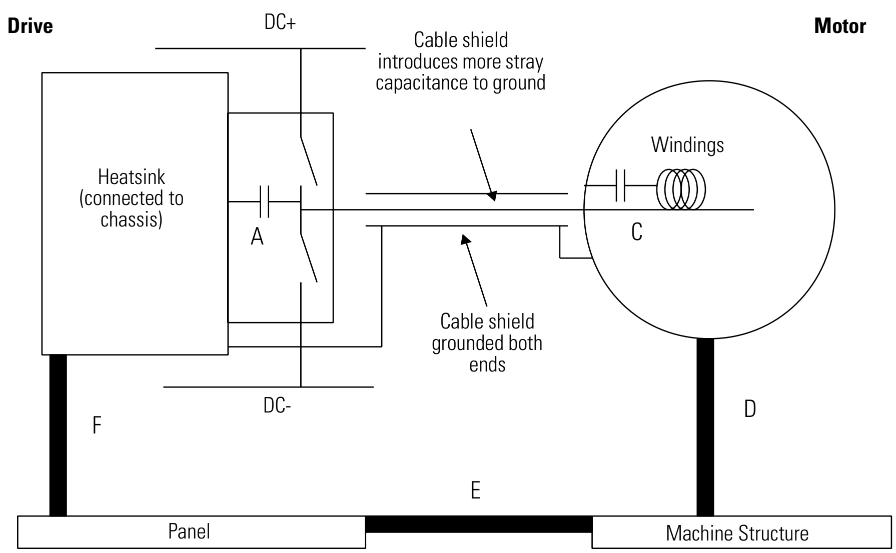
Shielding Motor Power Cables

The benefits of using shielded cable are listed below (also refer to Figure 8.2).

- The shield strongly attenuates the electric field (E field) noise.
- Core to shield capacitance is added to the stray capacitance at A & C increasing ground currents in the loop A, C, D, E, and F.
- These currents generate a magnetic field (H field).

It is important to minimize the area of this loop as far as possible by routing the cable close to grounded metalwork.

Figure 8.2
Shielded motor power cable



Grounding Motor Power Cable Shields

Observe the following guidelines when bonding the motor power cable shield to ground. Bond motor power cable shields:

- At the motor frame.
- To the panel at entry to the cabinet (optional).
- To the drive (amplifier) chassis. If a connection point is not provided, bond to the adjacent panel.

These connections must be made at the circular section, not by creating pigtails. Refer to the section *Grounding Cable Shields* in *Appendix A* for examples of grounding at the circular section.

Applying Ferrite Sleeves

A ferrite sleeve around the three power conductors as they leave the drive will help to reduce common-mode noise current. Take all three conductors two or three times through the core. If it runs hot reduce the number of turns.

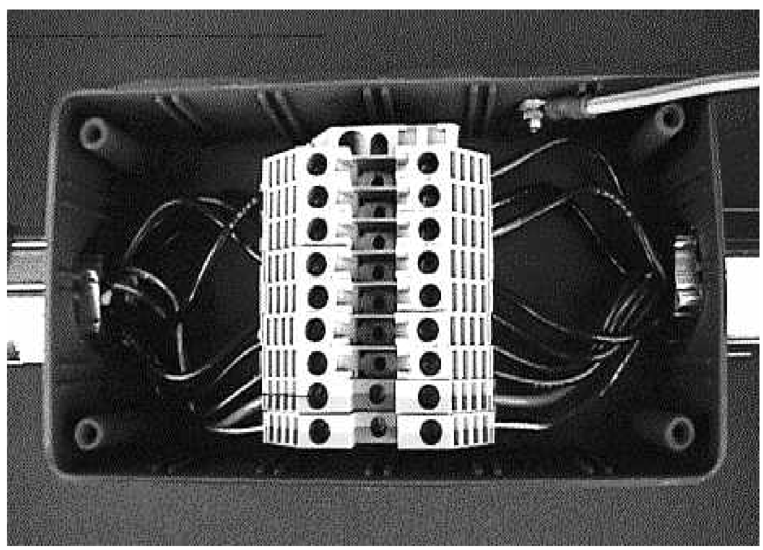
Note: Not all drives allow the use of a ferrite sleeve around power conductors. Refer to your manual for specific applications.

Splicing Motor Power Cables

Avoid splicing motor power cables when ever possible. Ideally, motor power cables should run continuous between the drive and motor terminals. The most common reason for splicing is to incorporate high-flex cable for continuous flexing applications.

If necessary, the preferred method of splicing is to use a fully shielded bulkhead connector. Splicing can also be accomplished using a grounded and shielded junction box, as shown in the figure below.

Figure 8.3
Spliced cable using junction box



Observe the following guidelines when installing a junction box:

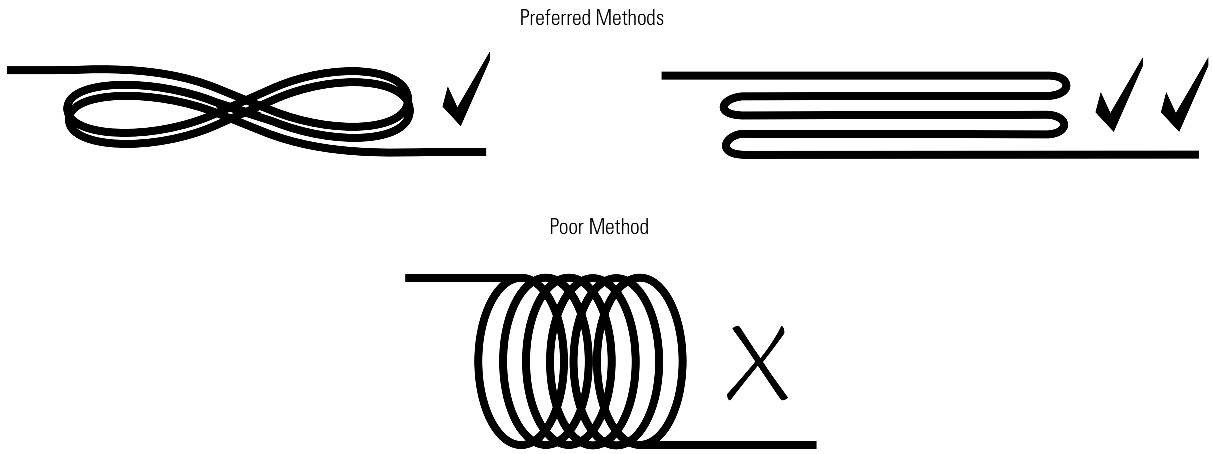
- Shield drain wire must be spliced only to mating shield drain wires and not grounded at the junction box.
- Feedback shields must be passed through pin for pin.
- Separate junction boxes for power and feedback are required.

Handling Excess Cable

Observe the following guidelines when handling excess cable:

- Do not coil excess cable of different types (i.e. motor power and feedback) together. An efficient transformer is formed at HF.
- Cable lengths should ideally be trimmed to fit the application.
- If excess cable cannot be trimmed, it should be laid in an 'S' or figure eight pattern (refer to the figure below).

Figure 8.4
Excess cable treatment



Installing Long Motor Cables

Motor cables are defined as long when the motor frame is not bonded close enough to the drive panel to be considered a single ground plane. To be considered a single ground plane, the parts must be connected by a surface which is no longer than ten times its width. Refer to the chapter *High Frequency (HF) Bonding* for methods of achieving a single ground plane.

Observe the following guidelines when installing long motor cables:

- Bonding should be by the widest practical means. Wide cable tray is effective when it is made of zinc plated steel and carefully bonded at the ends to control panel and motor frame.
- Zinc plated sheet steel channel is also effective. The fact that the width is folded into a U shape does not matter. A closing lid helps.
- Solid steel conduit bonded at both ends is effective.
- The spiral construction of flexible conduit makes it less attractive for RF shielding because the spiral shape forms an inductor, even with partially shorted turns.

High Speed Registration Inputs

Chapter Objectives

This chapter describes how wiring, sensitive to electrical noise, benefits from proper noise reduction strategies. This chapter covers the following topics:

- Understanding registration inputs
- Noise reduction methods
- Power supply wiring options
- Signal noise filter options
- Registration error

Understanding Registration Inputs

High speed registration inputs are potentially sensitive to noise by design. Typically, the specification states that the input responds within 1 microsecond of the signal going high, while in practice, the response is often even faster. Noise pulses of this duration are common in a typical drive system.

IMPORTANT Coupling is usually capacitive if unshielded cable is run near noisy cables or if voltage differentials exist between the detector mounting and the equipment carrying the registration input. For these reasons, treat high speed registration input circuits with special care.

Noise Reduction Methods

This section provides installation guidelines for reducing noise coupling into high speed registration inputs.

Wiring

Follow these guidelines to reduce noise coupling in wiring:

- Always use shielded cable.
- Connect shields at both ends and at the circular section.
- Always run the cable in a clean zone.
- Segregate the cable as far as practical from dirty and (especially) very-dirty wiring.
- Always make cable runs as short as possible.

Power

Follow these guidelines to reduce noise coupling in power supplies:

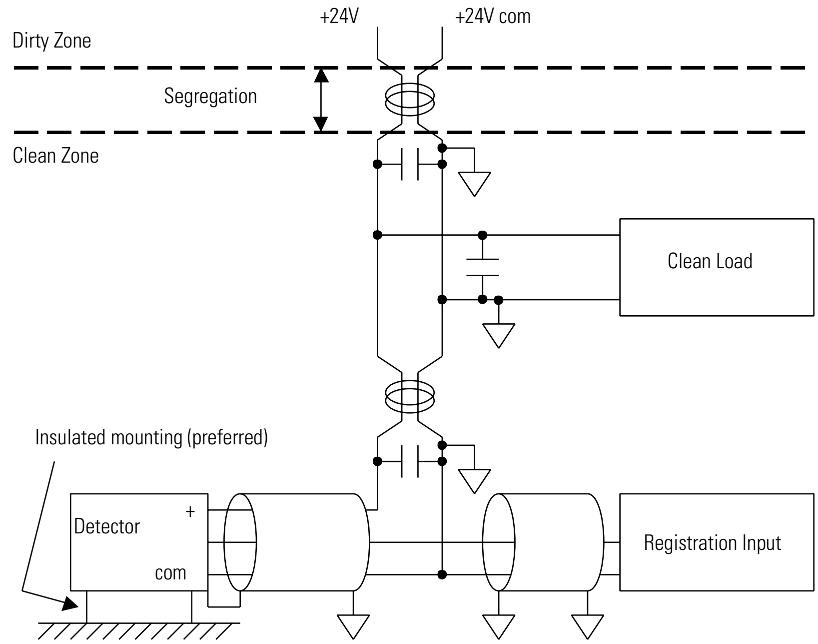
- The power supply should be as clean as possible.
- Use a filter if a switch-mode supply is used (refer to the chapter *Filtering Noise* for more information).
- Obtain +24V dc power from a clean supply and provide a filter (refer to the chapter *Filtering Noise* for more information).
- Always ground the common.

Shared Power Supply

Observe the following guidelines when sharing power between the registration input and other clean loads. Refer to Figure 9.1 for a shared power wiring diagram.

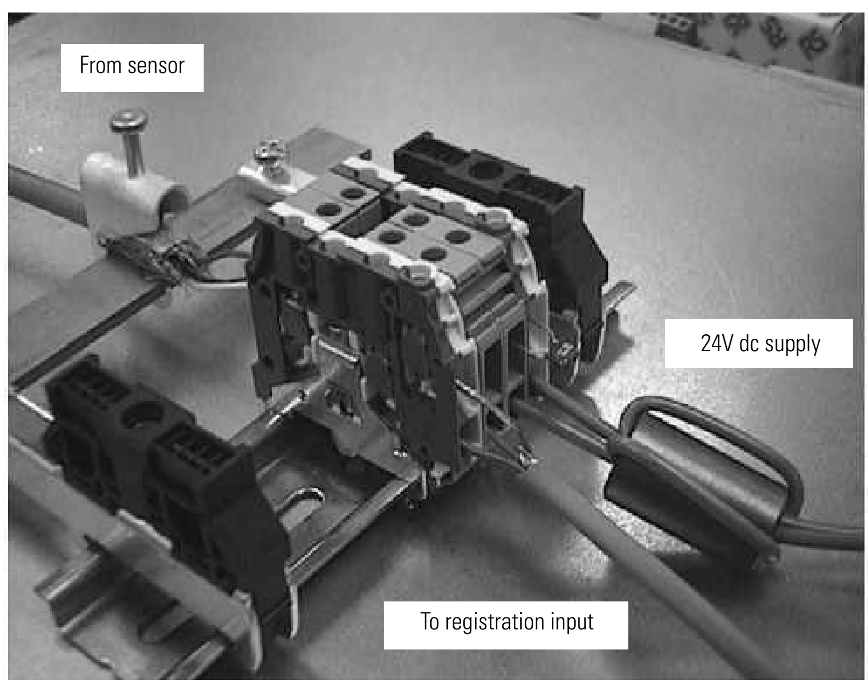
- Provide a filter just prior to the registration input, even if the +24V dc supply has a clean rating.
- Mount the filter on a separate DIN rail, especially if a painted panel is used.

Figure 9.1
Shared registration power supply



In figure below a pigtail shield connection is used for the short cable run to the input and a clamp connection for the long run from the sensor. Refer to *Appendix A* for more information on grounding cable shields.

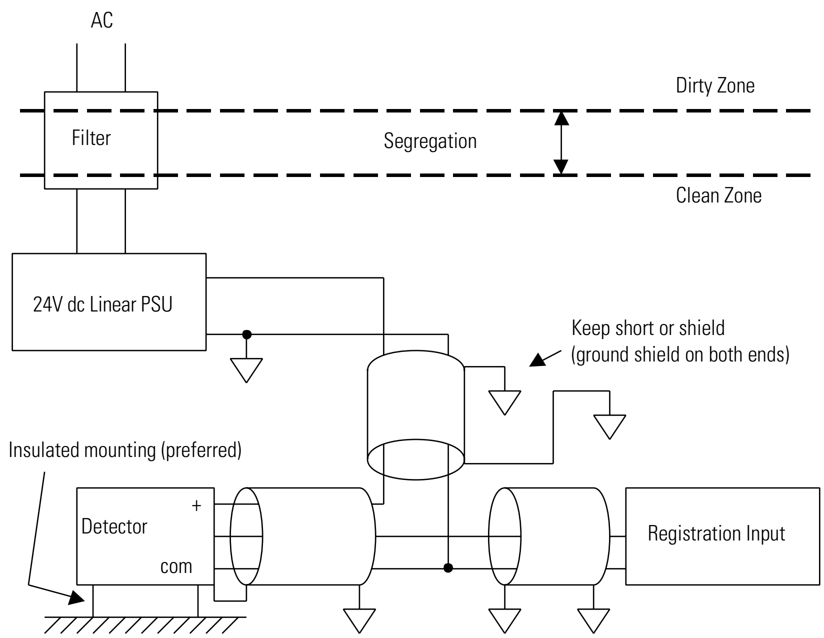
Figure 9.2
Registration power filter



Dedicated Power Supply

In the figure below, the registration input has a dedicated linear power supply.

Figure 9.3
Dedicated registration power supply



Detection Device Mounting

A line driver or push-pull output is preferred, but not widely available except in specialized photoelectric sensors for mark detection.

Ideally, the device body should be insulated from the machine structure and connected to the cable shield.

If the sensor cannot be insulated, ground the shield to the structure or sensor mounting.

Proximity Switches

Proximity switches are especially vulnerable in the off state since the signal line is disconnected at the switch, forming an efficient antenna. Observe the following guidelines when using proximity switches:

- Insulate the mounting, if possible, and connect the body to the cable shield.
- Arrange to be normally on (i.e. hole-operated instead of target-operated).
- Register on the falling edge. With the line effectively disconnected (off condition) stray capacitance causes the signal voltage to fall slowly. Even low levels of noise may then cause false triggering of inputs without hysteresis.
- When the proximity switch is supplied with unshielded cable, keep the unshielded length to a minimum by joining to shielded cable inside a shielded terminal box mounted close to the switch. Bond the terminal box to the sensor body.

Signal Noise Filter Options

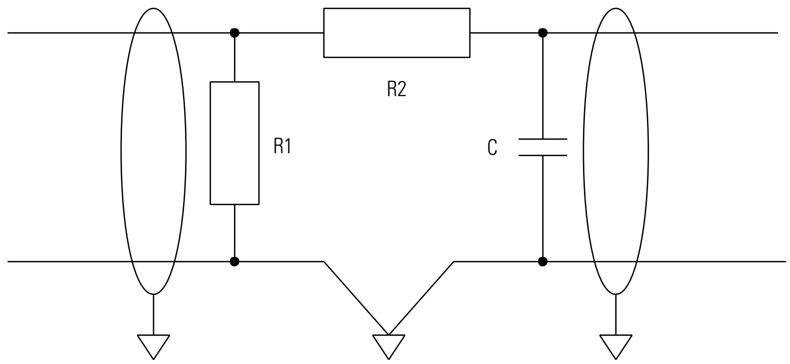
Most registration inputs have a response time of 1 microsecond or less. In practice, such speed is rarely required. A simple, low-pass filter will slow the response time but will increase the noise immunity. Observe the following guidelines for best results in all configurations.

- Keep the length of cable between filter and control to a minimum.
- Bond the filter common securely to the controller chassis.

Single Voltage Input (24V or 5V)

The figure below illustrates a typical registration filter circuit.

Figure 9.4
Registration filter circuit



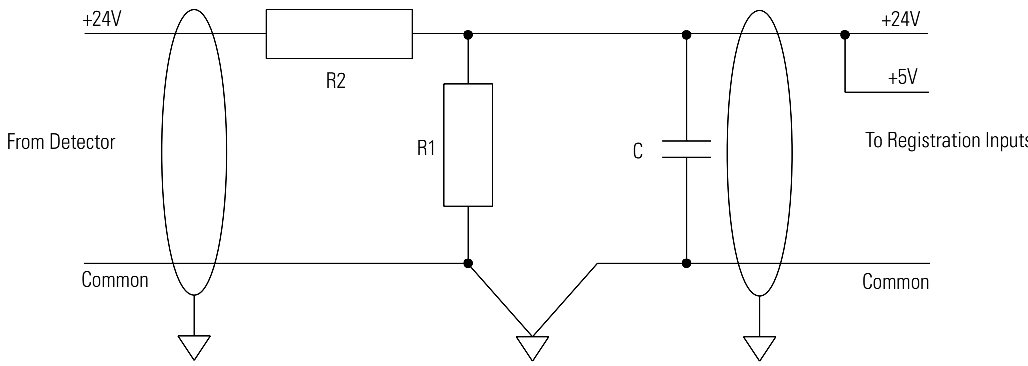
- R1 lowers the circuit impedance which improves noise immunity. It also ensures that the signal voltage falls rapidly when the detector turns off. A lower R value is better, but is limited by the drive capability of the detector and the dissipation in the resistor. A 470 ohm resistor will dissipate 1.2W at 24V dc if on continuously, hence it should be rated at 2W.
- The maximum value of R2 depends on the impedance of the registration input (a volt drop to 10% of nominal is ideal). If input impedance is less than 4.7k ohms, then R2 will require a lower value (i.e., 10% of input impedance). If R2 is changed, use this formula for the on-delay: Delay (uS) = R2 (ohm) x C (μF). A value of 470 ohms should be acceptable for most cases.
- Capacitor C, together with R2, determines the on-delay. Capacitor C, together with R1 + R2, determines the off-delay (as shown in the table below).

R1 k ohm	**R2** k ohm	**C** nF	**Delay On** μs	**Delay Off** μs	**Noise Attenuation factor** @ 1MHz	**Noise Attenuation** @1MHz dB
0.47	0.47	4.7	2	4	14	23
0.47	0.47	10	5	9	30	29
0.47	0.47	22	10	21	65	36
0.47	0.47	47	22	44	139	43
0.47	0.47	100	47	94	295	49
0.47	0.47	220	100	207	649	56

Dual Voltage Inputs (24V or 5V)

Where the input is split into 5V and 24V, with inputs sharing the same common, it is important that the 5V input is not left floating. In the figure below, the 24V and 5V inputs are shorted together and fed at 5V.

Figure 9.5
Registration filter circuit (24V/5V)



The on-delay and off-delay times are shown in the table below.

R1 k ohm	R2 k ohm	C nF	Delay On µs	Delay Off µs	Noise Attenuation factor @ 1MHz	Noise Attenuation @1MHz dB
0.100	0.390	220	22	2	14	23
0.100	0.390	220	22	5	30	29
0.100	0.390	220	22	10	65	36
0.100	0.390	220	22	22	139	43
0.100	0.390	470	47	47	295	49
0.100	0.390	1000	100	100	649	56

Registration Error

The following charts help to estimate the error due to time delays. The detector delay may be much greater than the filter delay, so it is important to add the two together.

Figure 9.6
Registration Error vs. Delay (metric units)

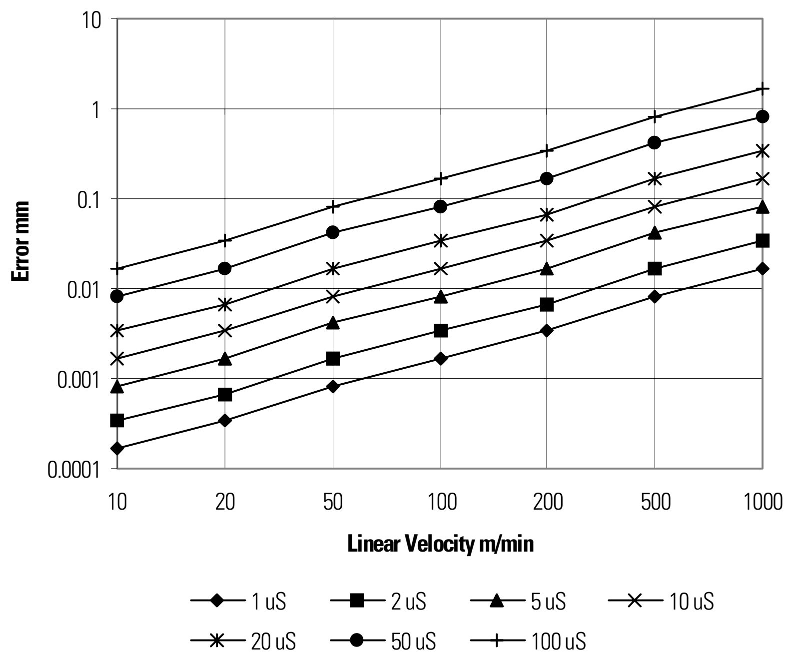


Figure 9.7
Registration Error vs. Delay (British units)

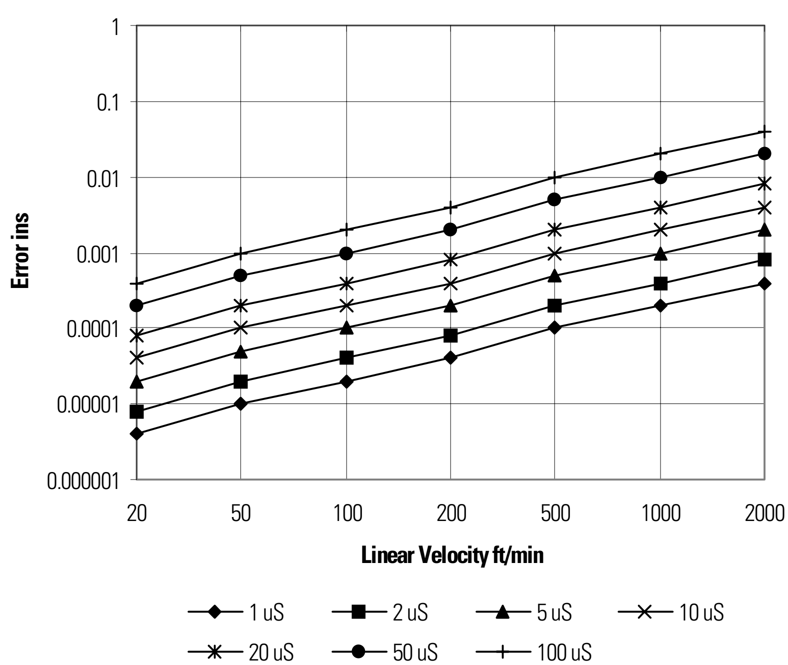
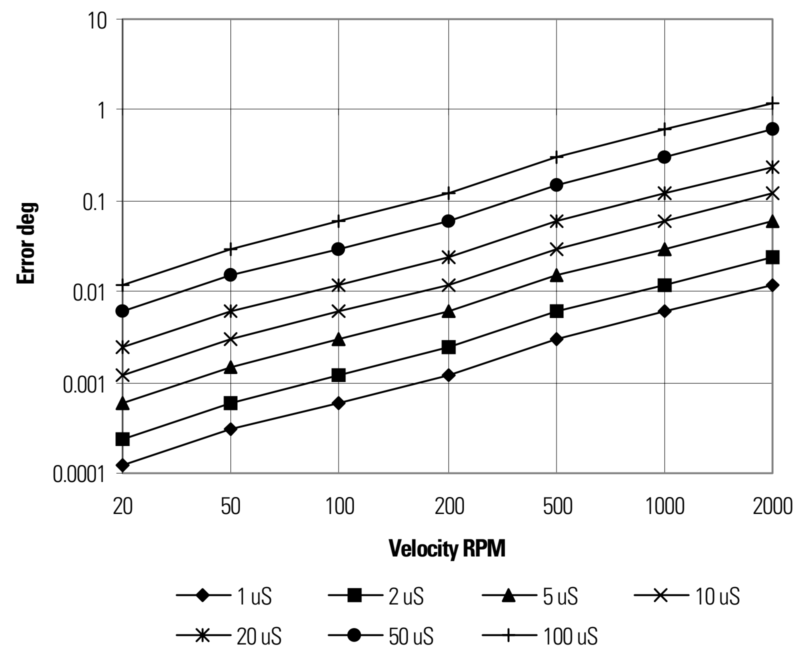


Figure 9.8
Registration Error vs. Delay (rotary units)



Error Compensation

If the registration signal delay is constant, it will have the effect of applying a position error proportional to velocity. In this case it may be possible to apply a software correction.

Software Solutions

It is possible to increase noise resistance with your software, especially if the problem is false triggering on the falling edge (which is usually much slower than the rising edge).

Try one of the following techniques before re-arming or looking for the next registration event.

- Add wait-for-registration-input-low.
- Add a timer after a registration event (to allow the switch signal to go low).
- Add wait-for-position-greater-than-x (to allow the switch signal to go low).

Encoders

Chapter Objectives

This chapter describes bonding, segregating, shielding, and filtering techniques for use with encoders. This chapter covers the following topics:

- Understanding encoders
- Noise reduction methods
- Power supply wiring options

Understanding Encoders

Encoder input circuits are, by their nature, potentially sensitive to noise. The signal is typically a square wave of about 500kHz at maximum speed. In order to preserve a reasonable square pulse, the circuit must handle at least ten times higher frequencies. Unfortunately, a response of 5MHz is ideally suited to detecting the noise spikes in a drive system.

The internal encoder circuitry should be relatively immune if it is well designed but there is often a long cable run to the control input circuitry. Coupling is usually due to voltage differentials between the encoder mounting and the drive input.

Noise Reduction Methods

This section provides installation guidelines for reducing noise sources near encoder input circuits.

Driver Type

IMPORTANT Driver type is generally dictated by the drive product but A quad B, differential, or line driver outputs are preferred.

Wiring

- Always use shielded cable (manufacturers usually specify appropriate cable).
- Segregate the cable as far as practical from dirty and especially very-dirty wiring.

Power

- Always use the internal power supply when available.
- Ensure the power supply has a clean rating (refer to Figure 10.1 and Figure 10.2 for linear and switch-mode power supply examples).
- Use a filter if a switch-mode supply is used (refer to the chapter *Filtering Noise* for more information).
- Always ground the common.

Mounting

- Insulate the encoder body from the machine structure and connect it to the cable shield.

  Note: This strategy also requires an insulated shaft coupling.
- If the encoder cannot be insulated, connect the cable shield to ground at the encoder case and drive chassis (or dedicated termination).

Power Supply Wiring Options

This section provides filtering options of power supply configurations for your encoder. For more information regarding filters, refer to the chapter *Filtering Noise*.

Figure 10.1
Linear power supply example

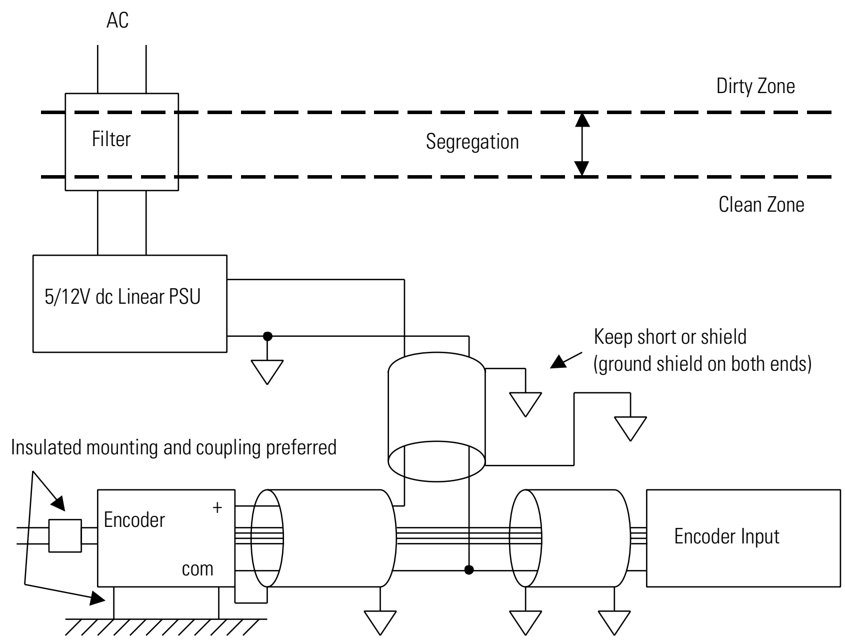
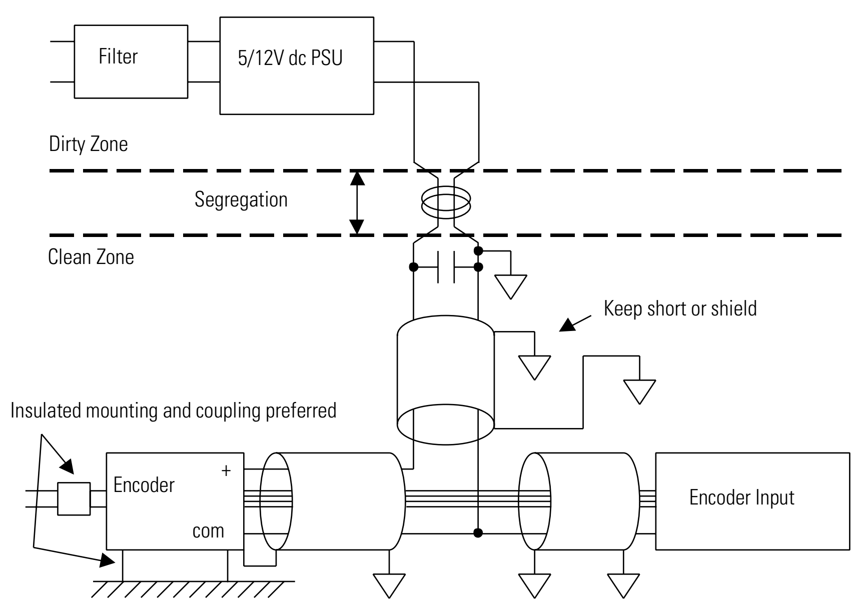


Figure 10.2
Switch-mode power supply example



Measuring Noise Reduction Effectiveness

Chapter Objectives

This chapter describes the equipment, methods, and various guidelines for measuring noise reduction effectiveness. This chapter covers the following topics:

- Understanding noise measurement
- Methods for measuring noise
- Measuring noise
- General guidelines for measuring noise

Understanding Noise Measurement

The ability to measure the effectiveness of noise reduction efforts and to determine if a system is within tolerance is important. However, it can be very difficult to obtain meaningful and repeatable results.

Methods for Measuring Noise

European EMC regulations are based on spectrum analysis (displaying amplitude vs. frequency). An RF spectrum analyzer is an expensive specialist tool, but necessary for pre-compliance testing if this is the requirement. Usually, a specialist EMC testing company is hired to perform such tests and the subject is beyond the scope of this document.

For troubleshooting drive systems, an oscilloscope (displaying amplitude vs. time) is more practical. You can determine the effectiveness of your noise reduction efforts by measuring the amplitude of the largest noise spikes at various points in the system.

There are three primary methods of measuring noise:

- E-field sniffing (electric field)
- H-field sniffing (magnetic field)
- Direct voltage measurements

The first two methods (E-field and H-field sniffing) are best used to quickly check for intense noise sources, however direct voltage measurements along the system wiring is the most reliable indicator of noise performance. Conducted noise (via capacitance and system wiring) is the most common cause of functional problems.

Professional probes are available in each category and would be mandatory for testing to EMC regulations but simple methods are sufficient for this purpose and are described below (refer to *Appendix B* for EMC suppliers).

Measuring Noise

This section describes the tools and methods used to measure noise.

Oscilloscope Specifications

When measuring noise, choose an oscilloscope with the following features:

- Digital storage
- At least 100 MHz sampling rate
- Trigger that is easily set to a known voltage
- Standard voltage probes
- Differential-mode function (differential voltage probe is a good alternative, but an additional cost)
- Probe bandwidth of at least 20 MHz.
- Battery power (optional)

Oscilloscope Settings for Measuring Noise Peaks

Measuring noise peaks is often difficult since PWM induced peaks are short and typically vary in amplitude widely with time.

To set up your system and oscilloscope for measuring noise peaks:

1. Set the timebase to 1 microsecond per division.
2. Set the trigger so that peaks are captured.
3. Gradually increase the trigger level until triggering just stops.
4. Measure the maximum peak voltage displayed.

E-Field Sniffing Method

The E-field is the electric field capacitively coupled to the probe. To use the E-field sniffing method:

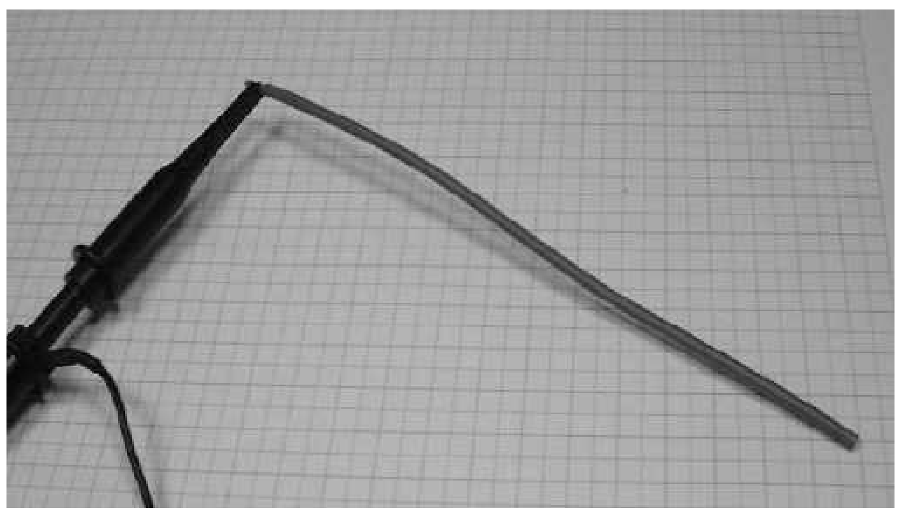
1. Attach a 150 mm (6 in.) length of stiff insulated wire to the probe tip to form an antenna.

2. Remove the probe ground clip or attach it to the scope cable to ensure it does not contact anything.

3. Hold the wire parallel to and touching potential victim wiring and measure the voltage spikes.

Note: The signal observed is with respect to the scope ground. Check the method by holding the wire against the panel. There should be little noise observed (refer to the section *Ground Loops* for more information).

Figure 11.1
Simple E-field probe



H-Field Sniffing Method

The H-field is the magnetic field inductively coupled to the probe. Connect the scope probe ground clip to the probe tip forming a small loop. Hold the loop close to potential victim wiring. The loop antenna is sensitive to orientation, so test all three axes to determine the maximum reading at each location.

Figure 11.2
Simple H-field probe

Direct Voltage Measurement Method

Direct voltage measurement methods exist for both AC and DC circuits. Each category are described in the paragraphs below.

Measuring DC Circuits

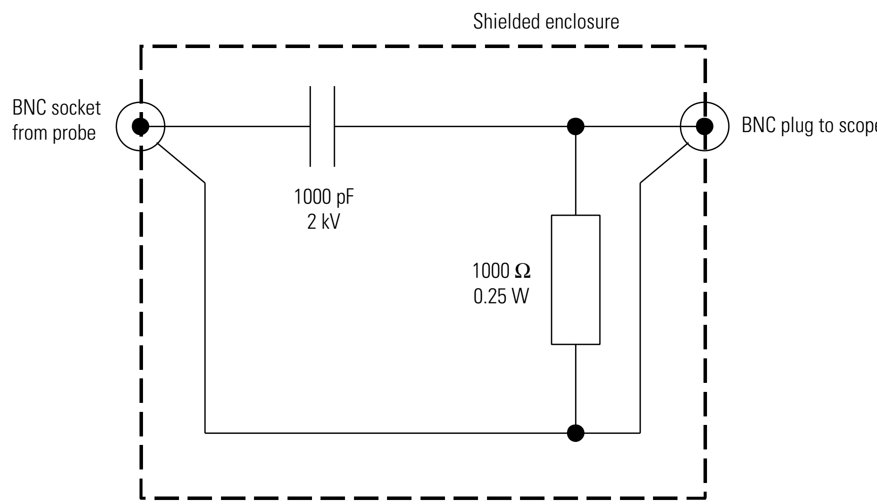
Direct voltage measurements with respect to a known good ground are made at chosen points in your DC circuit using a standard 1x scope probe. Set signal coupling to AC.

Measuring AC Circuits

Line voltage AC circuits are more difficult to measure since 50/60Hz AC waveforms will swamp the noise signals if a standard 10x or 100x scope probe is used.

Professional noise probes include a 150kHz high-pass filter to attenuate power frequency signals, but such a filter is easily built (refer to Figure 11.3).

Figure 11.3
High-pass filter circuit, 150kHz, 1 pole



ATTENTION

To avoid personal injury or damage to equipment, the capacitor must be rated at 2 kV or higher.

With this filter installed between a 1x scope lead and the scope input, AC lines may be examined for noise. The 50/60 Hz waveform will be reduced to around 200 mV peak.

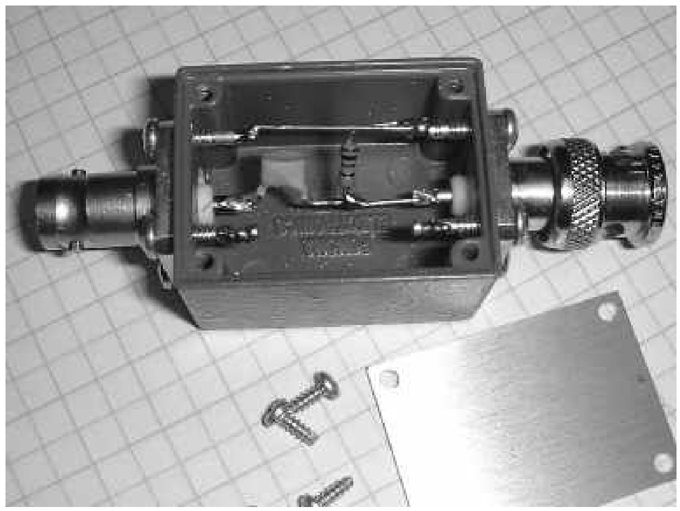
Note: Note that a 10x probe will attenuate far more than 10x in this situation and should not be used.

For BNC cases (as shown in Figure 11.4) refer to the following list of suppliers:

- Pomona Electronics, Part # 3752
- RS Components, Part # 189-0258

For more information on these and other suppliers, refer to *Appendix B*.

Figure 11.4
High-pass filter construction, 150 kHz, 1 pole (signal flow is left to right)



ATTENTION

To avoid personal injury or damage to equipment, always connect the probe ground clip to reference ground. Connecting the ground clip to line voltage may cause the scope chassis and controls to reach potentially lethal line voltage.

Grounding Your Probe (reference ground)

If the panel is plated and everything is bonded to it then the nearest point on the panel is the best reference ground point. With proper bonding the whole panel is a ground plane and the ideal reference. With a painted panel it is almost impossible to define a good ground because all the components are at different RF potentials. However, because a properly bonded panel (even one that's painted) maintains the same electrical potential at all points, it is still the best reference ground.

Ground Loops

A line-powered oscilloscope may introduce noise via the ground loop formed by the separate line supply and the connection of the probe to system ground. Methods to reduce this type of noise are listed below.

- Connect a braided strap between the scope chassis and the panel. Most scopes have a ground terminal provided for this purpose.
- Pass the scope lead through a ferrite sleeve several times.
- Use a battery powered scope and place it inside the control cabinet close to the panel.
- Use a scope with differential inputs. Refer to the section *Differential Measurements* for more information.
- Extend the scope probe lead. Refer to Figure 11.6 for an illustration.

Differential Measurements

Differential measurements eliminate ground loops and allow the scope to be grounded to its own supply ground. Two methods to reduce this type of noise are given below.

Differential Voltage Probes

Differential voltage probes, as shown in Figure 11.5, use only one scope input. Since they cancel common-mode voltage between the measured circuit and the scope common, ground loop problems are greatly reduced.

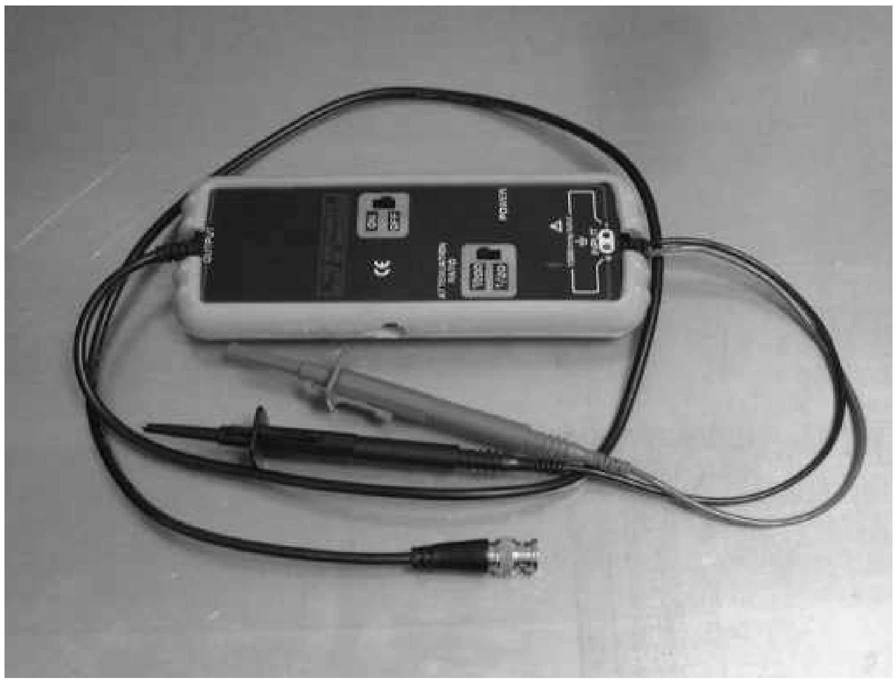
The main limitation is that of limited common-mode rejection. To avoid saturating the amplifier when measuring noise at line voltage the attenuation must be set to 1/100 or 1/200. This way the noise signal of interest is attenuated by the same amount. Increasing the scope sensitivity to compensate amplifies any internal probe or scope noise. Tips for using differential scope probes are listed below.

- Connect both probe tips to the same point in the circuit under test. No signal should be seen if the differential function is working correctly. Refer to the section *Checking Your Method for Effectiveness* for details. For best results, use the method as described.

- Use a high-pass filter between the probe and the scope input when checking AC circuits. Refer to Figure 11.4 for filter construction details.

  Note: Before installing the high-pass filter, check that the signal does not overload the voltage probe at the chosen division ratio.

Figure 11.5
Typical differential voltage probe



Differential Scope Inputs

Refer to these guidelines using an oscilloscope with two inputs in differential mode.

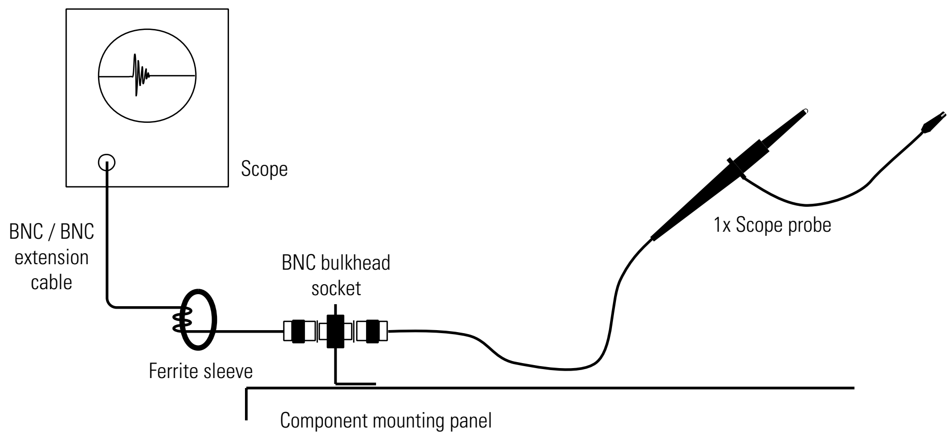
- The trigger must also operate in differential mode. Check your user manual for compatibility and instructions.
- Use two matched high-pass filters (one for each probe) for AC line checks as described above. Refer to Figure 11.4 for filter construction details.
- Connect both probe tips to the same point in the circuit under test. The residual noise signal should be much smaller than the measured value if the differential function is working. Refer to the section *Checking Your Method for Effectiveness* for details.
- Avoid forming large loops with your probes by twisting the two leads together as far as possible.

Scope Probe Lead Extension

Refer to these guidelines, and the figure below, when extending the scope probe.

- Keep the extension cable as short as possible.
- Make several turns through the ferrite sleeve.
- Only use 1x probes (10x probes will attenuate HF signals by more than ten times).

Figure 11.6
Extending the scope lead



Checking Your Method for Effectiveness

Connect the probe ground clip to the chosen ground reference and then connect the probe to the same point. It would be reasonable to expect zero signal, but it is common to see significant levels of noise. The main sources of such noise are given below.

- Poor ground reference. Refer to the section *Grounding Your Probe (reference ground)* for guidelines.
- Scope power supply introducing noise. Refer to the section *Ground Loops* for guidelines.
- Local magnetic noise field. Refer to the section *H-Field Sniffing Method* for details.

  Note: It can be seen from this why extending the scope probe ground wire is not recommended.

Without constant checking, it difficult to know when the observed noise waveform is real or a measurement artifact.

Identifying the Noise Source

Two methods for identifying the source of a noise spike are listed below.

- Disable each potential source in turn until the spike disappears.
- Correlate the noise signal with PWM sources by displaying the PWM waveform on a second channel. If the PWM source is the culprit, the noise signal will remain synchronized to the edges of the PWM waveform. Use a differential probe (phase to phase) or high-pass filter (phase to ground), connected to the suspect drive terminals, to display the PWM edges.

Intermittent Noise

If noise from mechanical contacts (e.g., a motor contactor) is suspected, the technique is a little different. Because of the variable nature of the peak amplitude, the best method is to operate the suspect device (for example) ten times in quick succession by overriding the control system. If this is not practical, monitor the device long enough to observe a number of operations. Progressively increase the trigger level as before.

General Guidelines for Measuring Noise

This section contains general guidelines for measuring noise. Tips on understanding acceptable noise levels, noise measurement methods that don't work, and system monitoring methods are discussed.

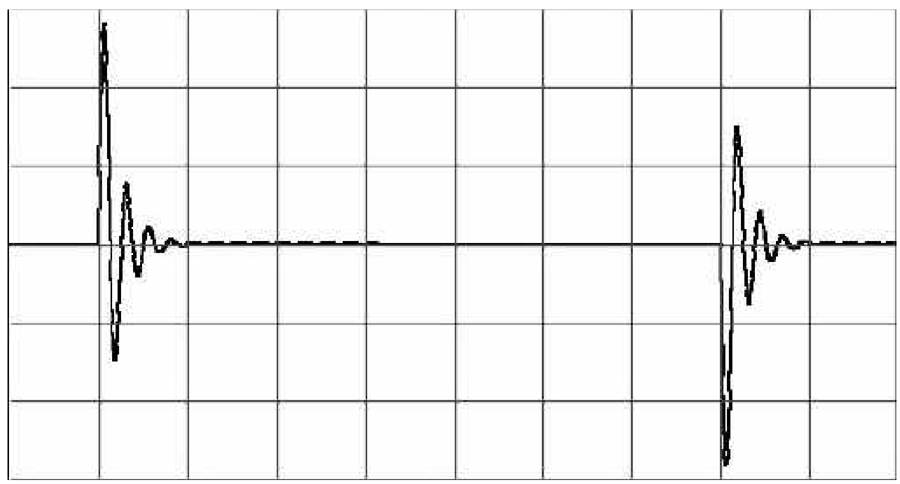
What are Acceptable Noise Levels?

No national or international standards for instantaneous peak voltage levels are known, but a very conservative approach would be to assume that a TTL gate may be closely coupled to a nominally clean circuit. Then, the noise immunity of a TTL gate (around 1.0V) becomes the critical level. This implies an allowable maximum of (for example) 500mV to allow for some margin of safety.

Field Strength Meters

Field strength meters (RF sniffers) are commercially available to aid in the alignment of transmitters and antennae. They are small hand-held instruments with a row of LED's or a meter to indicate level and respond to a wide range of signal frequencies. They appear to be an ideal instrument for measuring noise, but are not. They are designed to respond to a continuous sine wave signal, however the typical noise signal is comprised of a ringing effect lasting a few microseconds and repeated at the PWM switching frequency, usually a few kHz. As an example, consider the noise trace shown in the figure below.

Figure 11.7
Typical noise trace



The peak to average ratio of this waveform is 35:1, but this trace has been altered to show noise pulses from both positive and negative going edges of a PWM output. In practice the distance between these two events would be ten times greater. The actual peak to average ratio would then be 350:1.

Monitoring for Noise

By adding simple monitors to a system, you can check the noise level of your clean zones and the on-going effectiveness of the system HF bonding.

Monitoring Panels

To monitor your system panel:

1. Route a wire around all the clean zone wireways, ensuring that it lays on top of all other wires (furthest from the panel).
2. Measure voltage peaks between one end of the wire and the adjacent panel to assess E-field noise.
3. Repeat with the other end grounded to assess B-field noise.
4. Enable each potential noise source in turn to assess its contribution if required.

Monitoring Systems

This is a good test of system HF bonding techniques. To monitor your system:

1. Run wires connected to the metal structure of each remote panel and machine frame to the main panel via the clean zone.
2. Measure voltage peaks between the wire and the adjacent main panel to assess noise level.

Monitoring General System Conditions

If the wires are made permanent (preferably in a unique color) and terminated with insulated terminals, useful long term measurements may be made. To monitor for changes that may affect noise levels:

1. Document system noise levels during commissioning.
2. Re-check noise levels (for example) at twelve month intervals. Check for deterioration due to corrosion of bond joints or improper modifications to the wiring.
3. Check for reduced performance due to excessive noise levels during service.
4. Re-check noise levels after modifications have been made.

An OEM could check for consistency in a series of machines incorporating this into the quality procedures.

Noise Control Supplement

Chapter Objectives

This appendix is designed to offer additional information on specific topics related to electrical noise control. The topics include:

- Grounding cable shields
- Wire segregation test results
- Switch-mode DC power supplies
- Using a dynamic braking contactor
- Bonding surfaces

Grounding Cable Shields

This section describes different methods for grounding cable shields.

Pigtails

To form a pigtail and attach a flying ground lead:

1. Pull and twist the exposed shield after separation from the conductors into a braid (often referred to as a pigtail).

2. Solder a flying lead to the braid to extend its length.

Refer to the table below for guidelines on when to use this cable shield grounding method.

<table>
<tr><th>Pigtails are acceptable for cables:</th><th>Pigtails are not acceptable for cables:</th></tr>
<tr><td>Less than 1 m (39 in.) and confined to the panel</td><td>Greater than 1 m (39 in.) or extending beyond the panel</td></tr>
<tr><td rowspan="3">In clean zones</td><td>In very-dirty zones</td></tr>
<tr><td>With very noise sensitive signals (for example, registration or encoder cables)</td></tr>
<tr><td>That require strain relief</td></tr>
</table>

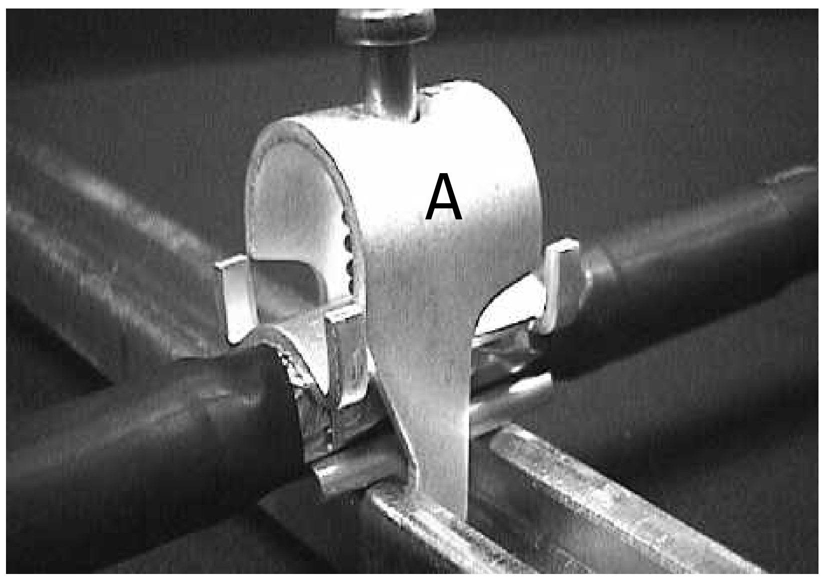
Clamping at the Circular Section

When using a pigtail is not acceptable, clamp your cable to the main panel closest to the shield terminal using the circular section clamping method.

Clamping at the circular section or 360° bonding, as shown in Figure A.1 below, is the preferred method for grounding cable shields. Several types of clamps are shown on the next page. Refer to the table associated with each type of clamp for advantages and disadvantages. All of the clamps shown are acceptable for use.

Note: The clamps shown are by Wieland Electric. For more information on product suppliers refer to *Appendix B*.

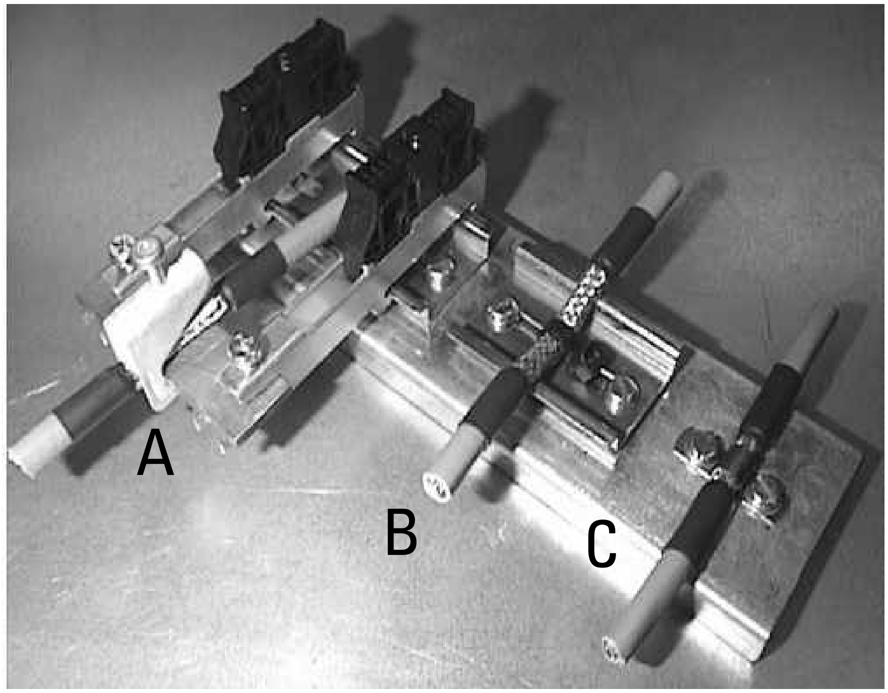
Figure A.1
Commercial cable clamp (heavy duty)



The table below lists advantages and disadvantages of the heavy duty commercial cable clamp as shown in Figure A.1. A similar clamp is also shown in Figure A.2 (refer to the cable labeled A).

Advantages of the heavy duty commercial cable clamp:	Disadvantages of the heavy duty commercial cable clamp:
Very effective method	Cost
Each size covers a wide range of diameters	Limited strain relief
No additional drilling or tapping required	Poor availability in some areas

Figure A.2
Cable clamping methods



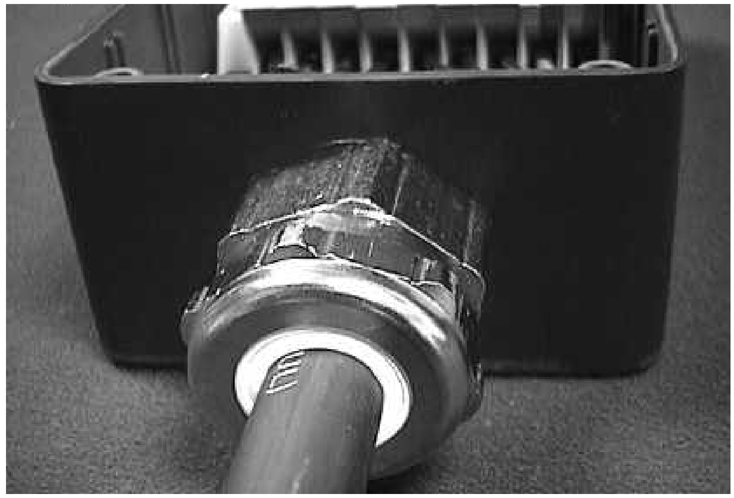
Strapping your cable to a DIN rail, as shown in Figure A.2 (the cable labeled B) is crude, but just as effective. The DIN rail is raised off the panel slightly by using washers to allow nylon cable ties to pass underneath. The table below lists advantages and disadvantages of strapping the cable to the DIN rail.

Advantages of the strapping to DIN rail method (refer to B above):	Disadvantages of the strapping to DIN rail method (refer to B above):
Very effective method	Appearance
Each size covers a wide range of diameters	
Moderate strain relief	
Low cost	

Plain copper saddle clamps, as shown in Figure A.2 (the cable labeled C) are sold for plumbing purposes, but are very effective and available in a range of sizes.

Advantages of saddle clamp method (refer to C above):	Disadvantages of saddle clamp method (refer to C above):
Very effective method	Requires two drilled and tapped holes per cable
Available in a wide range of sizes	
Excellent strain relief	Each size will accommodate a limited range of diameters
Low cost	

Figure A.3
Gland clamping method



Conductive gland grounding, as shown in Figure A.3, is only required for extreme applications, such as radar, aerospace, etc. The table below lists advantages and disadvantages of the gland clamp method.

Advantages of gland clamp method:	Disadvantages of gland clamp method:
Most effective method	Cost (very expensive)
	Each size will accommodate a limited range of diameters
Excellent strain relief	Only appropriate when passing through a bulkhead

Wire Segregation Test Results

Tests were conducted to obtain objective comparisons between levels of segregation. This section describes how the tests were conducted, the results achieved, and the conclusions reached.

Test Set-up

The tests were conducted using a typical source circuit, victim circuit, and segregation methods as described below.

Source Circuit

The loads were switched on and off by mechanical switch contacts.

- Omron S82K-03024 switch-mode PSU
- 240V ac contactor (unsuppressed)
- 24V dc contactor (unsuppressed)
- 24V dc resistive load

Victim Circuit

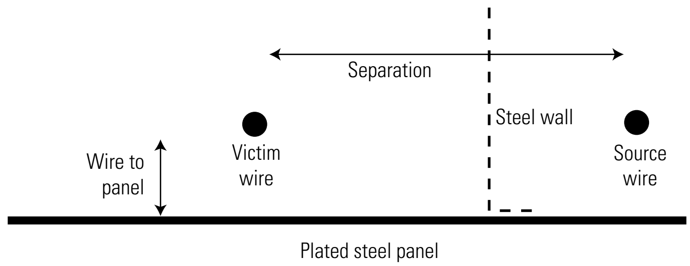
All components were mounted on a zinc plated, steel panel.

- Omron S82K-03024 switch-mode PSU
- 24V dc resistive load

Method

- Both 24V dc commons were grounded to the panel (refer to Figure A.4).
- 500mm parallel wire runs were set up at varying distances apart (separation) and different heights above the panel (wire to panel).
- Peak voltages were measured on the victim wire referenced to the panel.

Figure A.4
Wire segregation test set-up



Results

The results of the segregation testing is shown in the table below.

Source and Victim Separation:	Wire to Panel Separation:					
	3.0 mm (0.1 in.) 24V dc Resistive Load	**3.0 mm (0.1 in.)** 24V dc Contactor	**3.0 mm (0.1 in.)** 240V ac Contactor	**40 mm (1.6 in.)** 24V dc Resistive Load	**40 mm (1.6 in.)** 24V dc Contactor	**40 mm (1.6 in.)** 240V ac Contactor
3mm (0.1in)	500mV	10V	10V	500mV	20V	20V
25mm (1in)	100mV	500mV	200mV	100mV	5V	2V
50mm (2in)	100mV	200mV	200mV	100mV	2V	2V
100mm (4in)	100mV	200mV	200mV	100mV	1V	1V
200mm (8in)	100mV	100mV	100mV	100mV	200mV	200mV
3mm + Steel wall	100mV	500mV	100mV	100mV	500mV	500mV
25mm + Steel wall	100mV	100mV	100mV	100mV	500mV	200mV

Figure A.5
Wire segregation test results

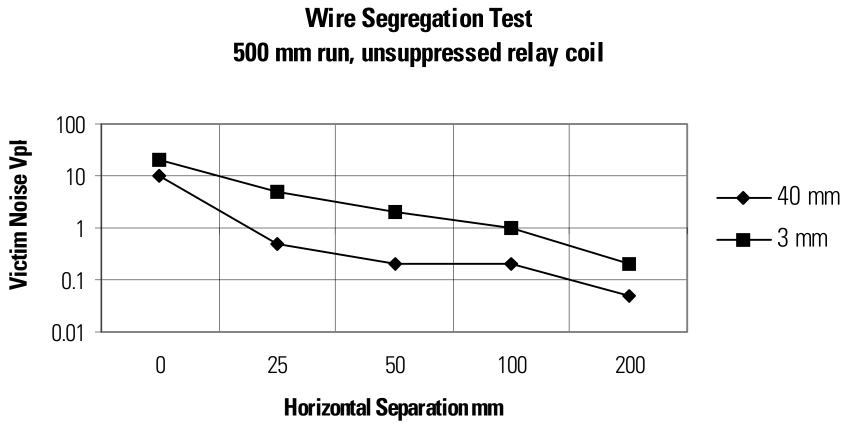
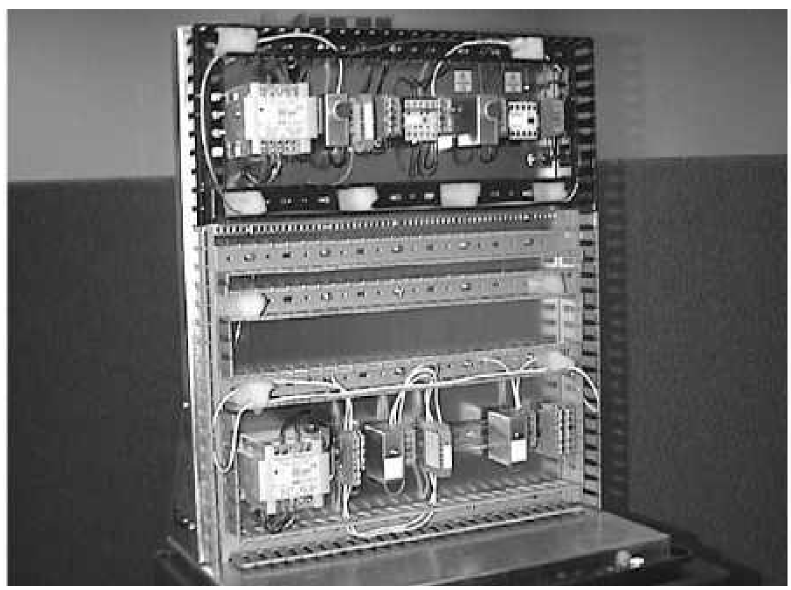


Figure A.6
Wire segregation test panel



Conclusions

The following statements summarize the results of the testing.

- 150 mm (6 in.) is a reasonable minimum separation required even for short runs.
- A well grounded steel dividing wall is as good or better than 200 mm (8 in.) of separation.

Very noisy or very sensitive wires are best placed close to the backplate if possible (this is good EMC practice).

Switch-Mode DC Power Supplies

This section describes the advantages and disadvantages of switch-mode DC power supplies and how to reduce common-mode noise.

IMPORTANT Switch-mode power supplies do not always isolate noise and may generate common-mode noise on both AC and DC lines.

Background Information

Switch-mode power supplies have become very popular due to their small size and low weight compared to the traditional 50/60 Hz transformer/rectifier/capacitor construction. They achieve this by rectifying and smoothing at line voltage then driving the primary of a transformer at high frequency by switching transistors. The low voltage secondary is then rectified and smoothed again to produce the required DC voltage. This high frequency operation allows the use of a much smaller transformer and smoothing capacitor than those required at 50/60 Hz.

The disadvantage is that the transistors produce transients similar to those of a PWM drive (given the same line voltage) but since only DC output is required, the rectification and smoothing process largely (but not always completely) contains the noise currents within the power supply frame.

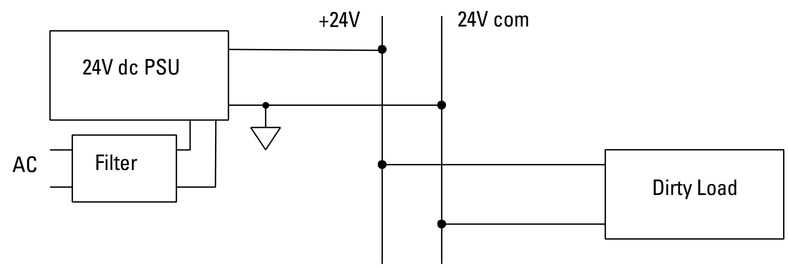
Differential-mode noise is always well controlled, typically less than 50mV peak to peak. However, potentially troublesome common-mode noise is common. In addition, plastic cased supplies have a significant noise radiation field around them, which is easily picked up on sensitive wiring.

Noise is also propagated back into the AC line.

Grounding the Common

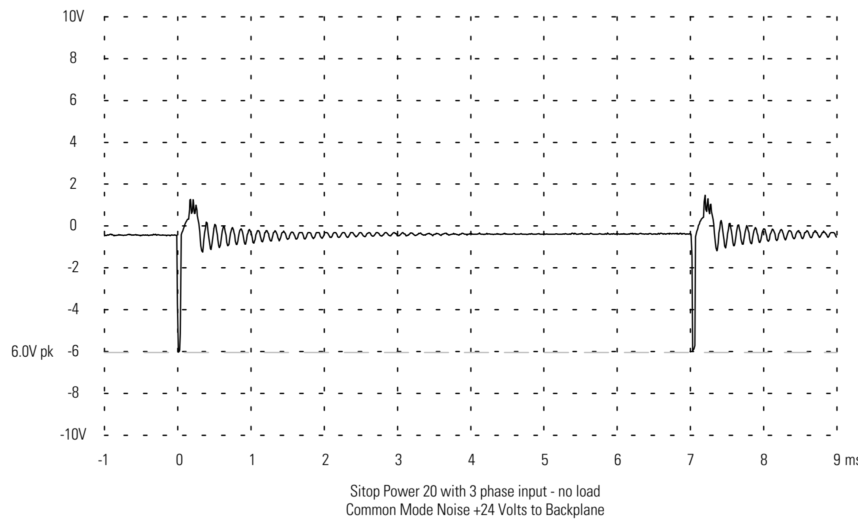
Grounding the DC common of the power supply attenuates common-mode noise dramatically. A sample wiring diagram is shown in the figure below.

Figure A.7
DC power supply wiring (grounded common)



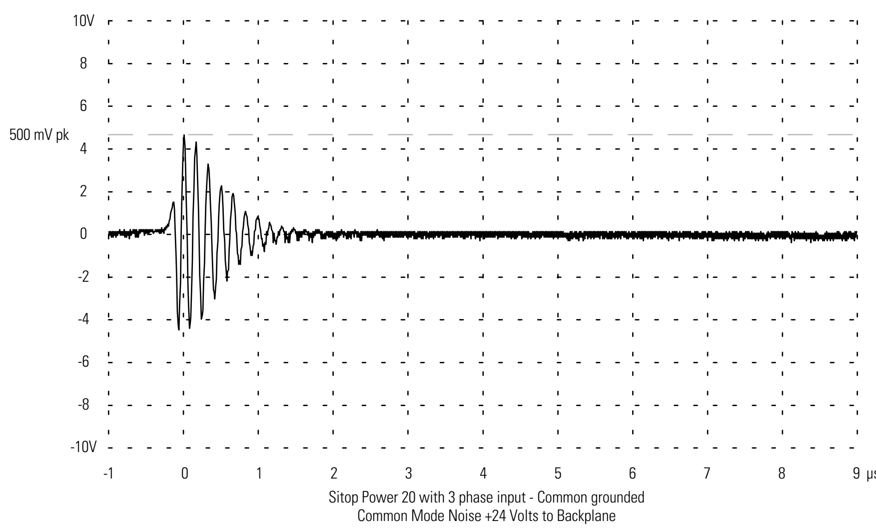
In Figure A.8, 6.0V common-mode noise spikes are seen at the +24V dc terminal relative to ground.

Figure A.8
20A, 24V dc PSU (ungrounded, no-load)



In Figure A.9 the noise amplitude is reduced to around 500mV pk, adequate for general-purpose, dirty loads.

Figure A.9
Grounded common



DC Filtering

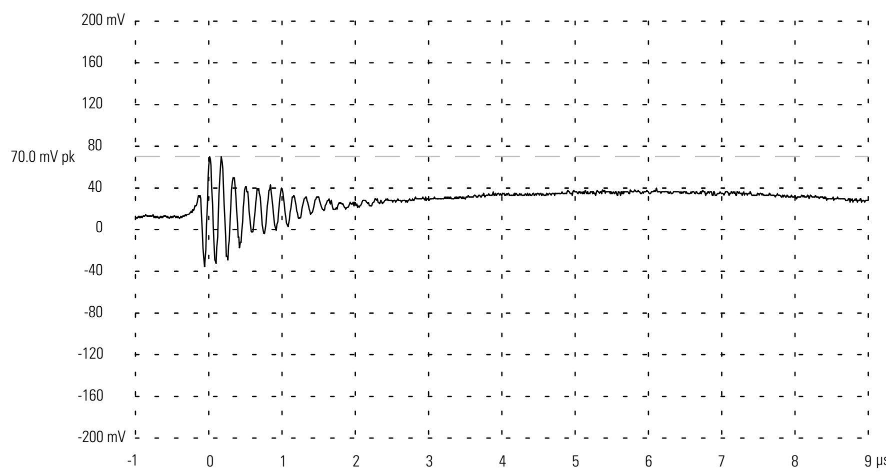
If sensitive clean loads are to be connected, further noise reduction is required. A simple low-cost filter is all that is required (refer to the chapter *Filtering Noise* for an example). A commercial AC line filter can be used, but may not be effective when using long motor cables. The low ringing frequency of such cables may be below the filter break frequency.

In Figure A.10 the noise is reduced to around 70mV (clean enough for most industrial applications).

IMPORTANT	Apply this method to 5V dc and 12V dc supplies for encoders and ±15V dc supplies for analog devices.

For more information regarding filters and power distribution refer to the chapters *Filtering Noise* and *Power Distribution*.

Figure A.10
Grounded common (after filtering)



Sitop Power 20 with 3 phase input - Common grounded + filter
Common Mode Noise +24 Volts to Backplane

Positioning the PSU within the Panel

Assume that electromagnetic noise fields exist around a switch-mode PSU and position it in the dirty zone of the control panel.

AC Line Filters

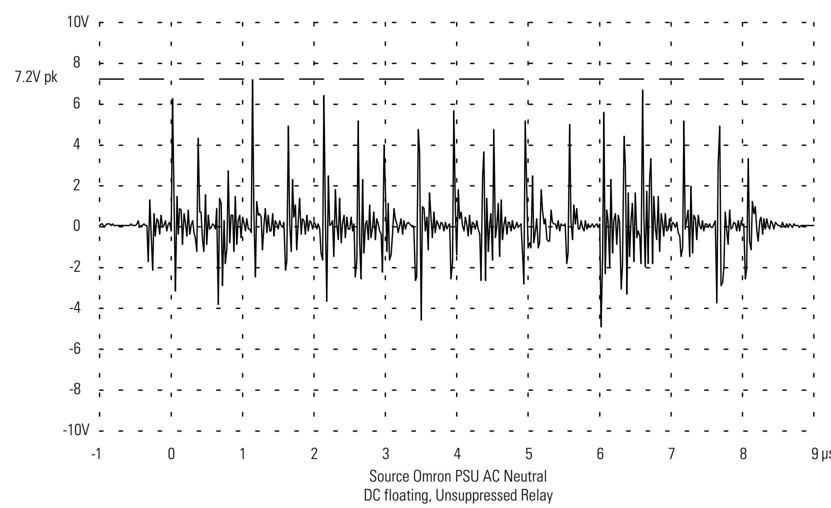
Always install a suitably rated AC line filter on the main panel as close as possible to a switch-mode PSU.

Using Separate DC Power Supplies

It is often assumed that the use of separate DC PSU's will isolate noise. In fact, noise will travel in either direction through a power supply. It can be demonstrated that a noise transient caused by switching an inductive load connected to one PSU is easily detected in the load circuit of a second PSU that shares the same AC line supply. Suppressing inductive loads and feeding each PSU via a line filter will reduce the effect.

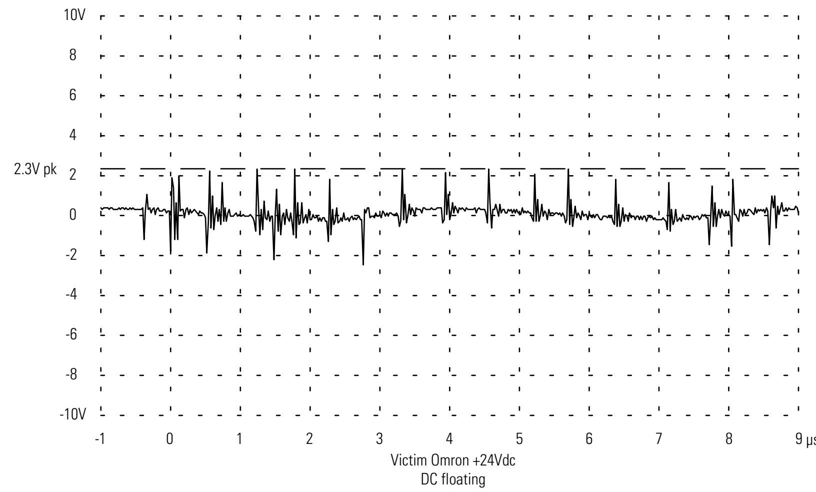
In the figure below, 7V noise spikes are seen at the AC line terminals of the PSU.

Figure A.11
Noise spikes on PSU AC line terminals



In Figure A.12 noise spikes greater than 2V, from an unsuppressed inductive load are seen on the DC circuit of the second PSU.

Figure A.12
Noise spikes on +24V dc terminal of second PSU



Using a Dynamic Braking Contactor

Dynamic braking (as shown in Figure A.13) requires the insertion of a three-phase contactor between drive and motor and satisfies two requirements.

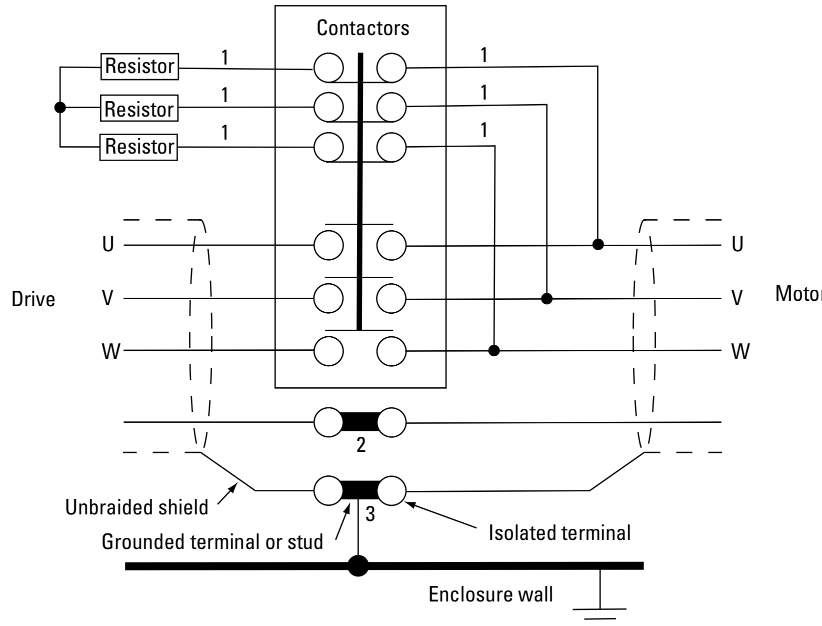
- Safety isolation where an operator must physically intervene in a process. Usually combined with safety sensors such as a light curtain.
- Emergency braking in the event of power failure. This requires three resistors connected across the motor windings by normally closed contacts. The motor acts as a generator and the power is dissipated by the resistors.

ATTENTION

To avoid personal injury and/or damage to equipment, the resistors must be installed. Opening the circuit without resistors can result in very high voltages due to motor inductance, prolonged arcing, and eventually cause a fire in the contactor.

Note: Dynamic braking resistors are frequently confused with dump-resistors which dissipate excess power from the DC bus of a drive when a motor is regenerating.

Figure A.13
Typical dynamic brake contactor interconnections



Note: Exposed power wiring conductors that are not shielded are a source of RFI noise. Keep exposed conductors as short as possible and isolated from sensitive devices and wiring.

Note: The safety ground (GND) and shield connections are permanently connected. This is essential for electrical safety.

Note: Unbraid all cable shields and bond together, connecting directly to the grounded terminal or stud. Do not use the shield drain wire for this bonded connection.

ATTENTION

Implementation of safety circuits and risk assessment is the responsibility of the machine builder. Please reference international standards EN1050 and EN954 estimation and safety performance categories. For more information refer to *Understanding the Machinery Directive* (publication SHB-900).

Reducing Dynamic Braking Circuit Noise

Because the contactor and resistors are connected to the motor power leads they carry the most intense noise levels in the system and require special treatment to avoid noise related problems. Refer to the guidelines below to reduce dynamic braking noise.

- Mount unshielded components and wiring in the very-dirty zone.
- Use shielded cable as much as possible. In some low-risk applications it may be acceptable to twist the wires together instead of shielding.

- Segregate unshielded wires at least 150 mm (6.0 in.).
- Keep unshielded wiring as short as possible.
- Suppress the contactor coil.
- Mount all components in a shielded enclosure.

Bonding Surfaces

When two or more surfaces (such as panels) require bonding, wide flat braid is preferred to wire due to its low impedance when compared with wire.

Wire Forms an Antenna

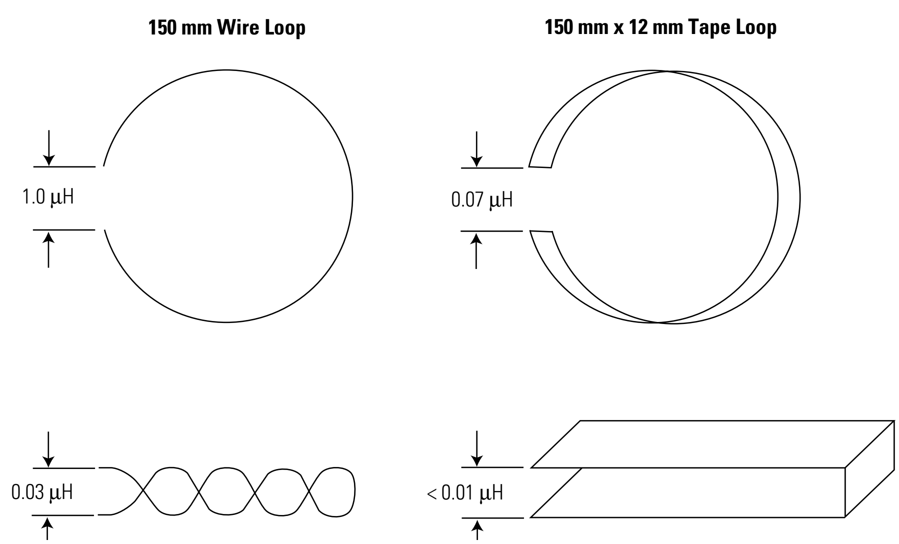
An efficient whip antenna for the 2 m (144 MHz) amateur radio band is just 500 mm (20 in.) long.

An antenna has an impedance varying between 75 and 300 ohms along its length. For bonding purposes, 300 ohms is considered much too high.

Inductance

A flat strip is typically 1/10th the inductance of wire. However, twisting wires together reduces inductance by more than 10x. Refer to Figure A.14 for examples.

Figure A.14
Wire vs. flat strip inductance



Noise Checklist

Use the following checklist to ensure that the number of potential noise sources in your system is reduced and that the noise sensitive components are not affected by the remaining noise.

System Identification:	
Checked by:	
Date:	

Chapter	Title	Technique	Done
2	*High Frequency (HF) Bonding*	Zinc plated panels, bonded together top, middle, bottom	
		Panels bonded to machine structure by continuous low impedance paths	
3	*Segregating Sources and Victims*	Components segregated into Clean, Dirty and Very Dirty zones	
		Wiring segregated using color coded wireways with added shields, if required	
		Wiring loops avoided	
		Wire run around the clean zone wireway to monitor for noise	
4	*Shielding Wires, Cables, and Components*	Additional shields between closely spaced zones	
		All clean signal cables shielded where appropriate	
		Shields grounded both ends at their circular cross section	
5	*Filtering Noise*	EMC filters fitted adjacent to PWM loads	
		DC filters fitted where low voltage DC power crosses between zones	
6	*Contact Suppression*	All contact-switched loads suppressed	
7	*Power Distribution*	Grounded DC power commons	
		De-coupled DC power at clean loads	
8	*Motor Wiring*	Shielded cable for all VS motor power, grounded at both ends	
		Cable joints minimized (direct drive/motor preferred). Bulkhead connectors or shielded junction boxes used.	
9	*High Speed Registration Inputs*	Shielded cable grounded to detector body and main panel	
		Clean power supply	
10	*Encoders*	Shielded cable grounded to detector body and main panel	
		Clean power supply	
11	*Measuring Noise Reduction Effectiveness*	Measure initial noise levels on DC distribution lines and install monitor wires for periodic checks and recording	

EMC Product Suppliers

This appendix contains a list of the EMC product suppliers referenced in this document. The list is not intended to be all inclusive, but the supplier names, products they provide, and websites are given below.

Supplier:	Product(s):	Website/Email:
Alpha Wire, Manufacturer (USA)	Standard and specialty wire and cable products (e.g. flat and oval braid)	www.alphawire.com
Chomerics, Div. Parker Hannifin Corp. Manufacturer (USA)	EMI shielding products (ferrite sleeves)	www.chomerics.com
Elmac Services, Consultants (UK)	Training & Consultancy in EMC	www.elmac.co.uk
Fair-Rite Products (USA)	Ferrite sleeves	www.ferrites@fair-rite.com
Magnetics (USA)	Ferrite sleeves	www.mag-inc.com
Newark Electronics (USA)	Ferrite sleeves, capacitors, line filters, general components	www.newark.com
Palomar Engineers, Distributor (USA)	Ferrite sleeves	www.palomar-engineers.com
Pomona Electronics, Manufacturer (USA)	BNC cases	www.pomonaelectronics.com
RS Components, Distributer (UK/Europe)	Ferrite sleeves, capacitors, line filters, general components	rswww.com
Schaffner, Manufacturer (Switzerland)	EMC components (ferrite sleeves, line filters)	www.schaffner.com
Van Doren Company (USA)	Near Field probes, educational videos, training	vandoren@umr.edu
Warth International (UK)	Earthing (grounding) straps	www.warth.co.uk
Weidmuller (Germany)	Shield clamp systems	www.weidmuller.com
Wieland Electric, Manufacturer (Germany)	Shield clamp systems	www.wieland-electric.com

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www.rockwellautomation.com

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Asia Pacific: Rockwell Automation, Level 14, Core F, Cyberport 3, 100 Cyberport Road, Hong Kong, Tel: (852) 2887 4788, Fax: (852) 2508 1846

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