Wiring and Grounding Guidelines for Pulse Width Modulated (PWM) AC Drives

Installation Instructions

Important User Information

Solid state equipment has operational characteristics differing from those of electromechanical equipment. *Safety Guidelines for the Application, Installation and Maintenance of Solid State Controls* (Publication SGI-1.1 available from your local Rockwell Automation sales office or online at **http://www.rockwellautomation.com/literature**) describes some important differences between solid state equipment and hard-wired electromechanical devices. Because of this difference, and also because of the wide variety of uses for solid state equipment, all persons responsible for applying this equipment must satisfy themselves that each intended application of this equipment is acceptable.

In no event will Rockwell Automation, Inc. be responsible or liable for indirect or consequential damages resulting from the use or application of this equipment.

The examples and diagrams in this manual are included solely for illustrative purposes. Because of the many variables and requirements associated with any particular installation, Rockwell Automation, Inc. cannot assume responsibility or liability for actual use based on the examples and diagrams.

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Throughout this manual, when necessary we use notes to make you aware of safety considerations.

WARNING: Identifies information about practices or circumstances that can cause an explosion in a hazardous environment, which may lead to personal injury or death, property damage, or economic loss.

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

ATTENTION: Identifies information about practices or circumstances that can lead to personal injury or death, property damage, or economic loss. Attentions help you identify a hazard, avoid a hazard, and recognize the consequences.

Shock Hazard labels may be located on or inside the equipment (e.g., drive or motor) to alert people that dangerous voltage may be present.

Burn Hazard labels may be located on or inside the equipment (e.g., drive or motor) to alert people that surfaces may be at dangerous temperatures.

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Summary of Changes

This is the initial release of the VTAC Wiring and Grounding Guidelines for Pulse Width Modulated AC Drives, publication VTAC-IN002.

Changes made to subsequent versions of this manual will be listed on this page.

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Summary of Changes

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Glossary

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Overview

The purpose of this manual is to provide you with the basic information needed to properly wire and ground Pulse Width Modulated (PWM) AC drives.

Who Should Use This Manual

This manual is intended for qualified personnel who plan and design installations of Pulse Width Modulated (PWM) AC drives.

Recommended Documentation

The following publications provide general drive information.

Title	Publication	Available…
Installing, Operating and Maintaining Engineered Drive Systems (Reliance Electric)	D2-3115-2	
Safety Guidelines for the Application, Installation and Maintenance of Solid State Control	SGI-1.1	www.rockwellautomation.com/ liiterature
IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources	IEEE 518	
Recommended Practice for Powering and Grounding Electronic Equipment - IEEE Emerald Book	IEEE STD 1100	
Electromagnetic Interference and Compatibility, Volume 3	N/A	RJ White - publisher Don White Consultants, Inc., 1981
Grounding, Bonding and Shielding for Electronic Equipment and Facilities	Military Handbook 419	
IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems	IEEE Std 142-1991	
National Electrical Code (ANSI/NFPA 70)	Articles 250, 725-5, 725-15, 725-52 and 800-52	
Noise Reduction Techniques in Electronic Systems	N/A	Henry W. Ott Published by Wiley-Interscience
Grounding for the Control of EMI	N/A	Hugh W. Denny Published by Don White Consultants
Cable Alternatives for PWM AC Drive Applications	IEEE Paper No. PCIC-99-23	
EMI Emissions of Modern PWM AC Drives	N/A	IEEE Industry Applications Magazine, Nov./Dec. 1999
EMC for Product Designers	N/A	Tim Williams Published by Newnes
Application Guide for AC Adjustable Speed Drive Systems	N/A	NEMA www.nema.org
IEC 60364-5-52 Selection & Erection of Electrical Equipment - Wiring systems	N/A	IEC www.iec.ch
Don’t Ignore the Cost of Power Line Disturbance	1321-2.0	www.rockwellautomation.com/ liiterature

Manual Conventions

The following words are used throughout the manual to describe an action:

Word	Meaning
Can	Possible, able to do something
Cannot	Not possible, not able to do something
May	Permitted, allowed
Must	Unavoidable, you must do this
Shall	Required and necessary
Should	Recommended
Should Not	Not recommended

General Precautions

ATTENTION: To avoid an electric shock hazard, verify that the voltage on the bus capacitors has discharged before performing any work on the drive. Measure the DC bus voltage at the +DC & –DC terminals of the Power Terminal Block. The voltage must be zero.

Wire/Cable Types

AC drive installations have specific requirements for cables. Wire or cable selection for a drive application must consider a variety of criteria.

The following section covers the major issues and proper selection of cable. Recommendations are made to address these issues. Cable materials and construction must consider the following:

- Environment including moisture, temperature and harsh or corrosive chemicals.
- Mechanical needs including geometry, shielding, flexibility and crush resistance.
- Electrical characteristics including cable capacitance/charging current, resistance/voltage drop, current rating and insulation. Insulation may be the most significant of these. Since drives can create voltages well in excess of line voltage, the industry standard cables used in the past may not represent the best choice for customers using variable speed drives. Drive installations benefit from using cable that is significantly different than cable used to wire contactors and push buttons.
- Safety issues including electrical code requirements, grounding needs and others.

Choosing incorrect cable can be costly and may adversely affect the performance of your installation.

General

Material

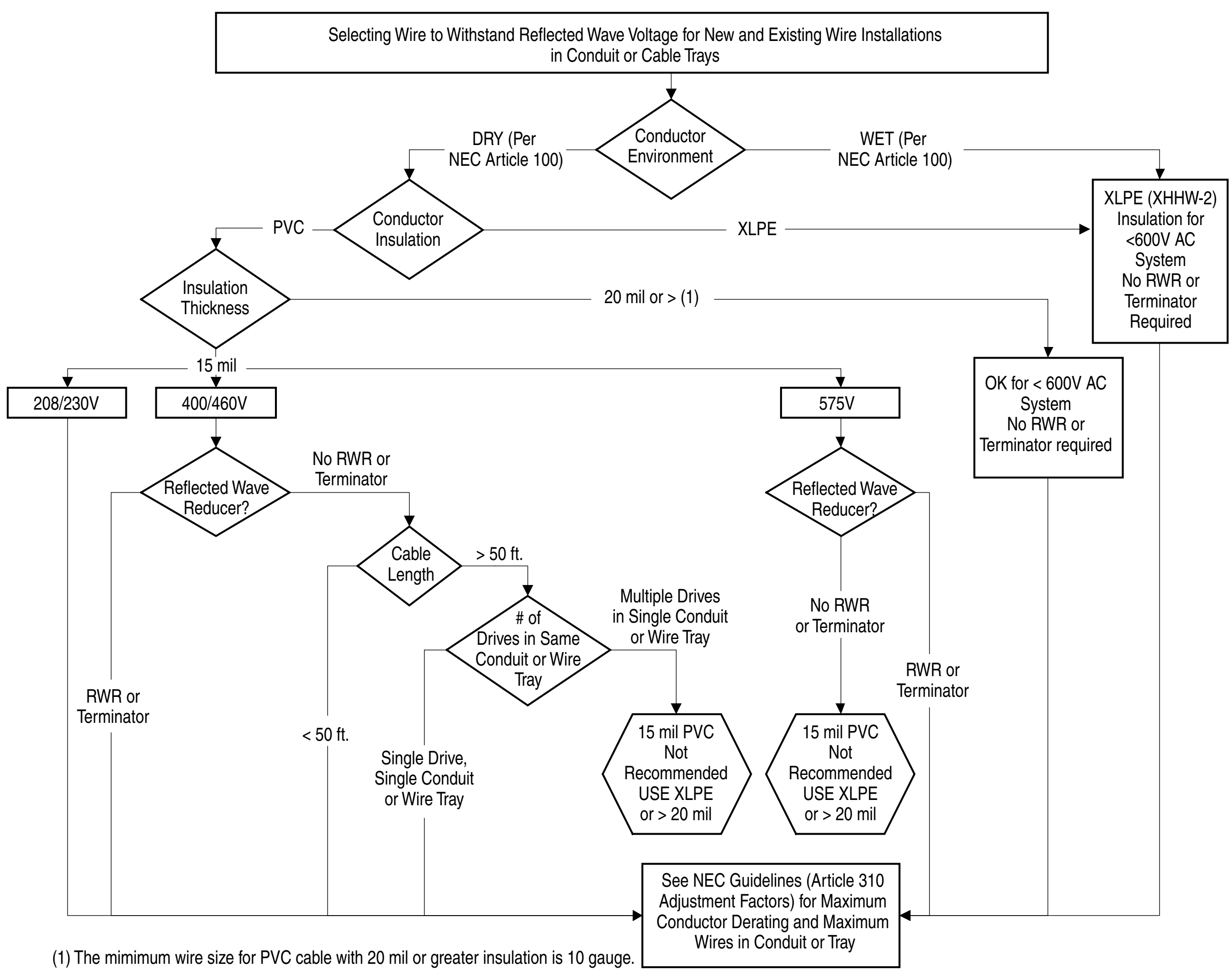
Use Copper wire only. The wire clamp type terminals in VTAC drives are made for use with copper wire only. If you use aluminum wire the connections may loosen.

Wire gauge requirements and recommendations are based on 75 degrees C. Do not reduce wire gauge when using higher temperature wire.

Exterior Cover

Whether shielded or unshielded, the cable must be chosen to meet all of the application requirements. Consideration must be given to insulation value and resistance to moisture, contaminants, corrosive agents and other invasive elements. Consult the cable manufacturer and the chart below for proper selection.

Figure 1.1 Wire Selection Flowchart



(1) The mimimum wire size for PVC cable with 20 mil or greater insulation is 10 gauge.

Temperature Rating

In general, installations in surrounding air temperature of 50ºC should use 90ºC wire (required for UL) and installations in 40ºC surrounding air temperature should use 75ºC wire (also required for UL). Refer to the drive user manual for other restrictions

The temperature rating of the wire affects the required gauge. Be certain to meet all applicable national, state and local codes.

Gauge

The proper wire size is determined by a number of factors. Each individual drive user manual lists a minimum and maximum wire gauge based on the amperage rating of the drive and the physical limitations of the terminal blocks. **Local or national electrical codes also set the required minimum gauge based on motor full load current (FLA).** Both of these requirements should be followed.

Number of Conductors

While local or national electrical codes may determine the required number of conductors, certain configurations are recommended. Figure 1.2 on page 1-3 shows cable with a single ground conductor, which is recommended for drives up to and including 200 hp (150 kW). Figure 1.3 on page 1-4 shows cable with three ground conductors, which is recommended for drives larger than 200 hp (150 kW). The ground conductors should be spaced symmetrically around the power conductors. The ground conductor(s) should be rated for full drive ampacity.

Figure 1.2 Cable with One Ground Conductor

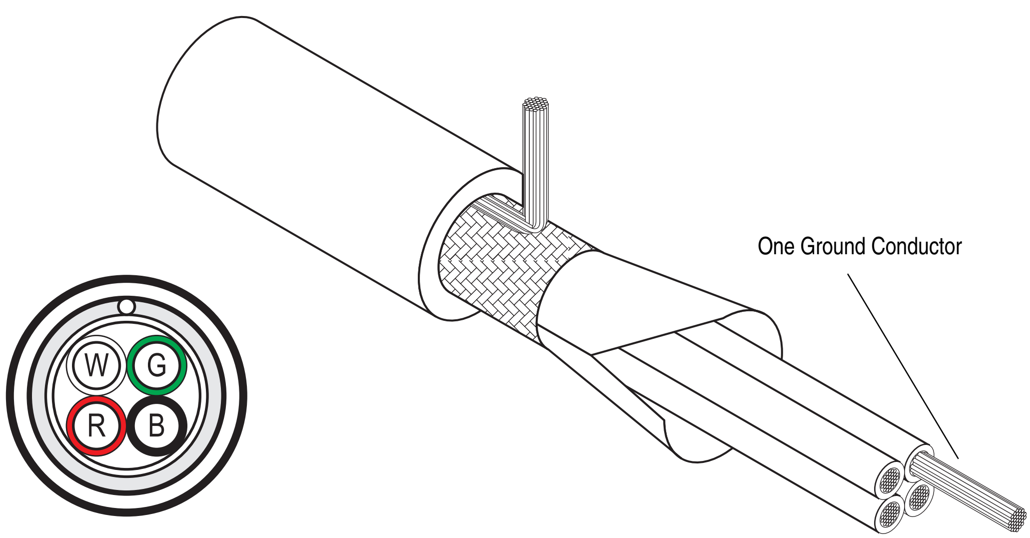
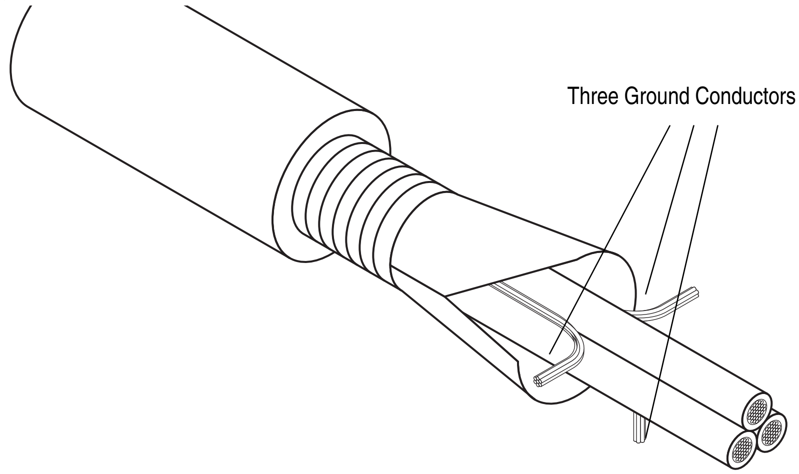


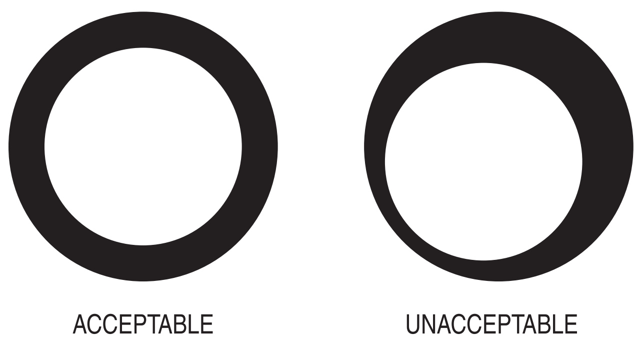
Figure 1.3 Cable with Three Ground Conductors



Insulation Thickness and Concentricity

Selected wire must have an insulation thickness of equal to or more then 15 mils (0.4 mm / 0.015 in.). The quality of wire should not have significant variations on concentricity of wire and insulation.

Figure 1.4 Insulation Concentricity



Geometry

The physical relationship between individual conductors plays a large role in drive installation.

Individual conductors in conduit or cable tray have no fixed relationship and are subject to a variety of issues including: cross coupling of noise, induced voltages, excess insulation stress and others.

Fixed geometry cable (cable that keeps the spacing and orientation of the individual conductors constant) offers significant advantages over individual loose conductors including reducing cross coupling noise and insulation stress. Three types of fixed geometry multi-conductor cables are discussed below: Unshielded, shielded, and armored.

Table 1.A Recommended Cable Design

Type	Max. Wire Size	Where Used	Rating/Type	Description
Type 1	2 AWG	Standard Installations 100 hp or less	600V, 90°C (194°F) XHHW2/RHW-2	Four tinned copper conductors with XLPE insulation
Type 2	2 AWG	Standard Installations 100 hp or less with Brake Conductors	600V, 90°C (194°F) RHH/RHW-2	Four tinned copper conductors with XLPE insulation plus one (1) shielded pair of brake conductors.
Type 3	500 MCM AWG	Standard Installations 150 hp or more	Tray rated 600V, 90°C (194°F) RHH/RHW-2	Three tinned copper conductors with XLPE insulation and (3) bare copper grounds and PVC jacket.
Type 4	500 MCM AWG	Water, Caustic Chemical, Crush Resistance	Tray rated 600V, 90°C (194°F) RHH/RHW-2	Three bare copper conductors with XLPE insulation and three copper grounds on 10 AWG and smaller. Acceptable in Class I & II, Division I & II locations.
Type 5	500 MCM AWG	690V Applications	Tray rated 2000V, 90°C (194°F)	Three tinned copper conductors with XLPE insulation. (3) bare copper grounds and PVC jacket. **Note**: If terminator network or output filter is used, connector insulation must be XLPE, not PVC.

Unshielded Cable

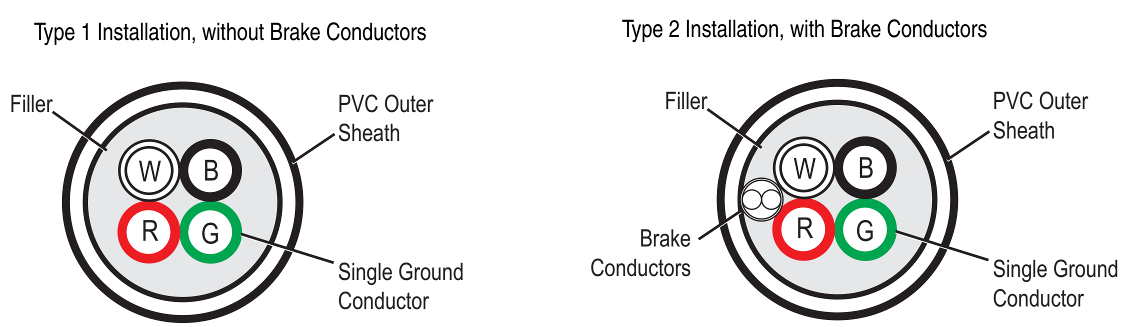
Properly designed multi-conductor cable can provide superior performance in wet applications, significantly reduce voltage stress on wire insulation and reduce cross coupling between drives.

The use of cables without shielding is generally acceptable for installations where electrical noise created by the drive does not interfere with the operation of other devices such as: communications cards, photoelectric switches, weigh scales and others. Be certain the installation does not require shielded cable to meet specific EMC standards for CE, C-Tick or FCC. Cable specifications depend on the installation Type.

Type 1 & 2 Installation

Type 1 or 2 installation requires 3 phase conductors and a fully rated individual ground conductor without or with brake leads. Refer to Table 1.A on page 1-5 for detailed information and specifications on these installations.

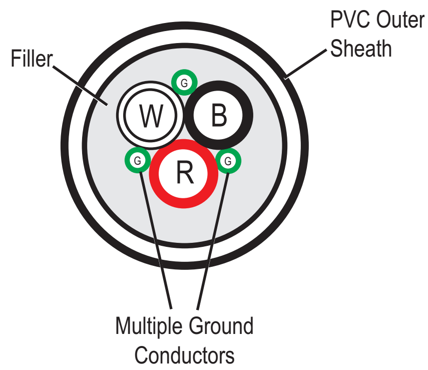
Figure 1.5 Type 1 & 2 Unshielded Multi-Conductor Cable without and with Brake Leads



Type 3 Installation

Type 3 installation requires 3 symmetrical ground conductors whose ampacity equals the phase conductor. Refer to Table 1.A on page 1-5 for detailed information and specifications on this installation.

Figure 1.6 Type 3 Unshielded Multi-Conductor Cable



The outer sheathing and other mechanical characteristics should be chosen to suit the installation environment. Consideration should be given to surrounding air temperature, chemical environment, flexibility and other factors as necessary in all installation types.

Shielded Cable

Shielded cable contains all of the general benefits of multi-conductor cable with the added benefit of a copper braided shield that can contain much of the noise generated by a typical AC Drive. Strong consideration for shielded cable should be given for installations with sensitive equipment such as weigh scales, capacitive proximity switches and other devices that may be affected by electrical noise in the distribution system. Applications with large numbers of drives in a similar location, imposed EMC regulations or a high degree of communications / networking are also good candidates for shielded cable.

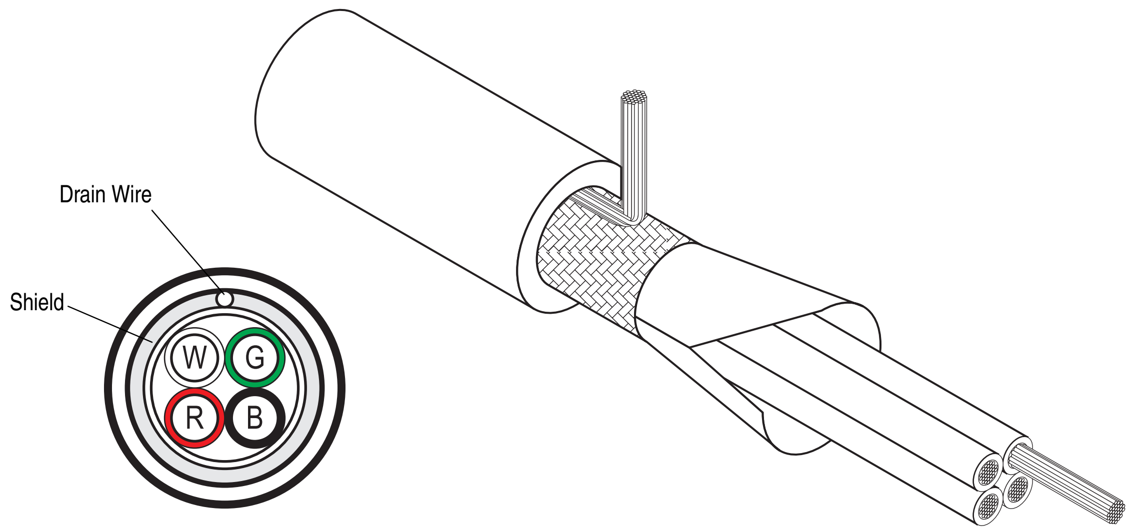
Shielded cable may also help reduce shaft voltage and induced bearing currents for some applications. In addition, the increased size of shielded cable may help extend the distance that the motor can be located from the drive without the addition of motor protective devices such as terminator networks. Refer to Chapter 5 for information regarding reflected wave phenomena.

Consideration should be given to all of the general specifications dictated by the environment of the installation, including temperature, flexibility, moisture characteristics and chemical resistance. In addition, a braided shield should be included and specified by the cable manufacturer as having coverage of at least 75%. An additional foil shield can greatly improve noise containment.

Type 1 Installation

A good example of acceptable shielded cable for Type 1 installation is Belden® 295xx (xx determines gauge) or Anixter B209500-B209507. These cables have 4 XLPE insulated conductors with a 100% coverage foil and an 85% coverage copper braided shield (with drain wire) surrounded by a PVC jacket. For detailed specifications and information on these installations, refer to Table 1.A on page 1-5.

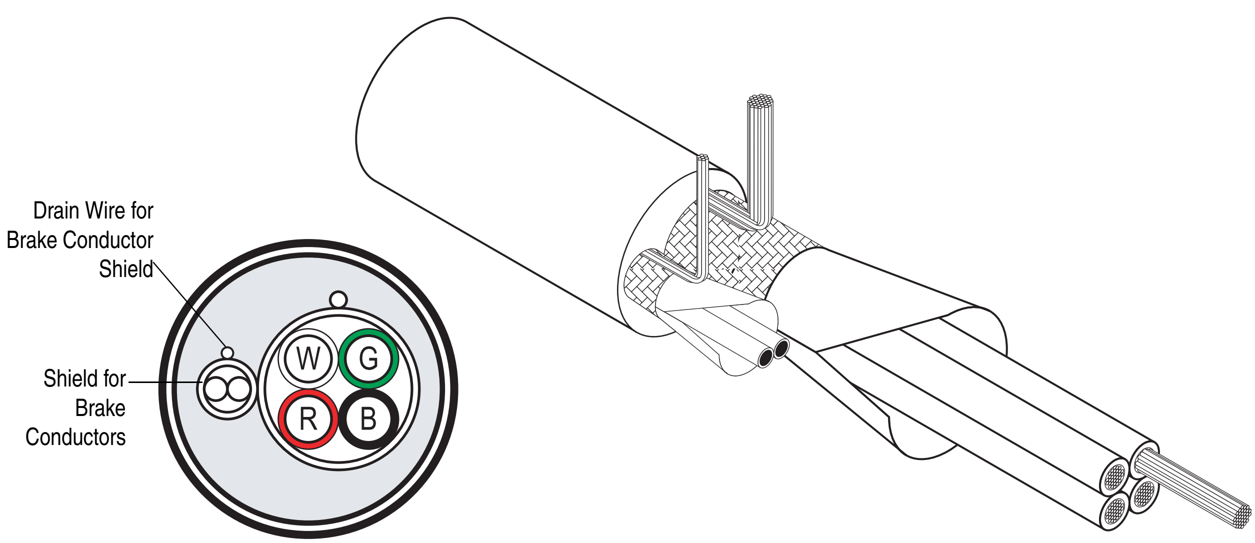
Figure 1.7 Type 1 Installation — Shielded Cable with Four Conductors



Type 2 Installation

A good example of acceptable shielded cable for Type 2 installation is Anixter OLF-7xxxxx. This is essentially the same cable as Type 1, plus one (1) shielded pair of brake conductors. For more information on this installation, refer to Table 1.A on page 1-5.

Figure 1.8 Type 2 Installation — Shielded Cable with Brake Conductors



Type 3 Installation

These cables have 3 XLPE insulated copper conductors, 25% minimal overlap with helical copper tape and three (3) bare copper grounds in PVC jacket.

TIP: Other types of shielded cable are available, but the selection of these types may limit the allowable cable length. Particularly, some of the newer cables twist 4 conductors of THHN wire and wrap them tightly with a foil shield. This construction can greatly increase the cable charging current required and reduce the overall drive performance. Unless specified in the individual distance tables as tested with the drive, these cables are not recommended and their performance against the lead length limits supplied is not known. For more information, about motor cable lead restrictions refer Appendix A, Conduit on page 4-13, Moisture on page 4-18 and Effects On Wire Types on page 5-1 on THHN wire.

Armored Cable

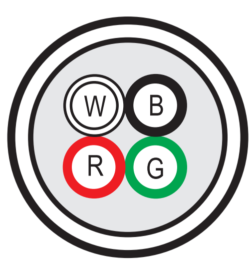
Cable with continuous aluminum armor is often recommended in drive system applications or specific industries. It offers most of the advantages of standard shielded cable and also combines considerable mechanical strength and resistance to moisture. It can be installed in concealed and exposed manners and removes the requirement for conduit (EMT) in the installation. It can also be directly buried or embedded in concrete.

Because noise containment can be affected by incidental grounding of the armor to building steel (see Chapter 2) when the cable is mounted, it is recommended the armored cable have an overall PVC jacket.

Interlocked armor is acceptable for shorter cable runs, but continuous welded armor is preferred.

Cable with a single ground conductor is sufficient for drive sizes up to and including 200 HP (150 kW). Cable with three ground conductors is recommended for drive sizes larger than 200 HP (150 kW). The ground conductors should be spaced symmetrically around the power conductors. The ground conductor(s) should be rated for full drive ampacity.

Cable with a Single Ground Conductor



Cable with Three Ground Conductors

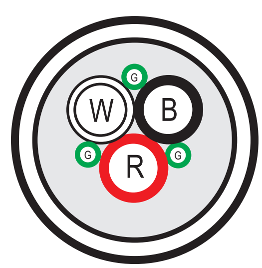
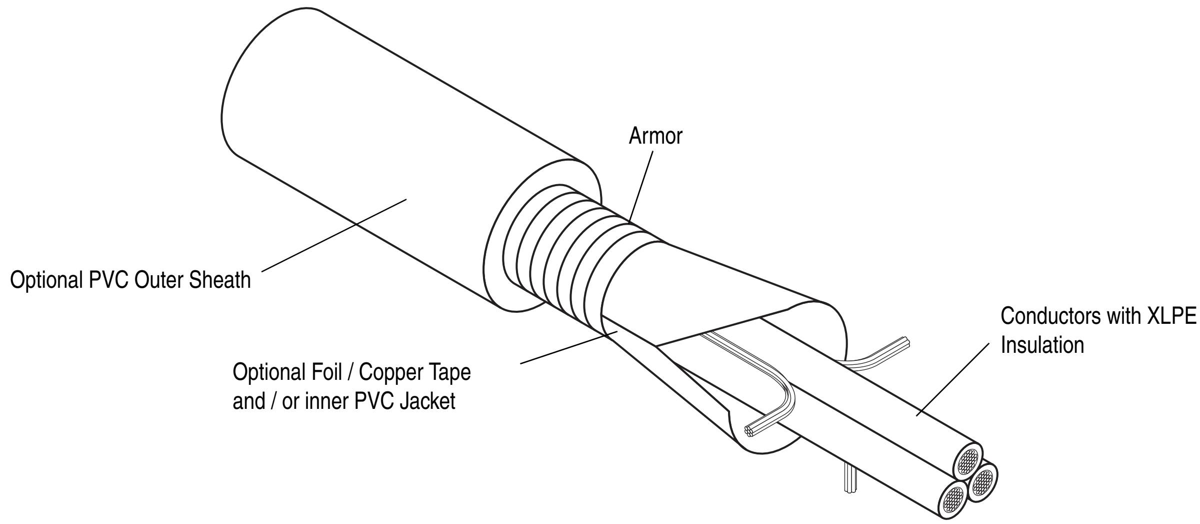


Figure 1.9 Armored Cable with Three Ground Conductors



A good example of acceptable cable for Type 5 installation is Anixter 7V-5003-3G, which has three (3) XLPE insulated copper conductors, 25% minimal overlap with the helical copper tape and three (3) bare copper grounds in PVC jacket. Please note that if a terminator network or output filter is used, connector insulation must be XLPE, not PVC.

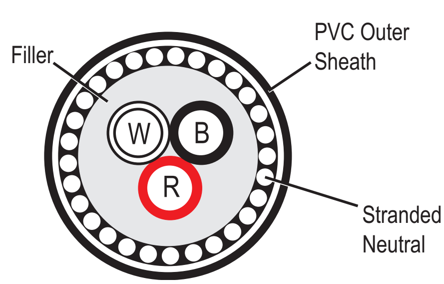
European Style Cable

Cable used in many installations in Europe should conform to the CE Low Voltage Directive 73/23/EEC. Generally recommended are flexible cables with a recommended bend radius of 20 times the cable diameter for movable cable and 6 times the cable diameter for fixed installations. The screen (shield) should be between 70 and 85% coverage. Insulation for both conductors and the outer sheath is PVC.

The number and color of individual conductors may vary, but the recommendation is for 3 phase conductors (customer preferred color) and one ground conductor (Green / Yellow)

Ölflex® Classic 100SY or Ölflex Classic 110CY are examples.

Figure 1.10 European Style Multi-Conductor Cable



Input Power Cables

In general, the selection of cable for AC input power to a drive has no special requirements. Some installations may suggest shielded cable to prevent coupling of noise onto the cable (see Chapter 2) and in some cases, shielded cable may be required to meet noise standards such as CE for Europe, C-Tick for Australia / New Zealand, and others. This may be especially true if an input filter is required to meet a standard. Each individual drive user manual will show the requirements for meeting these types of standards. Additionally, individual industries may have required standards due to environment or experience.

For AC variable frequency drive applications that must satisfy EMC standards for CE, C-Tick, FCC or other, Rockwell Automation may recommend that the same type of shielded cable specified for the AC motors be used between the drive and transformer. Check the individual user manuals or system schematic note sheets for specific additional requirements in these situations.

Motor Cables

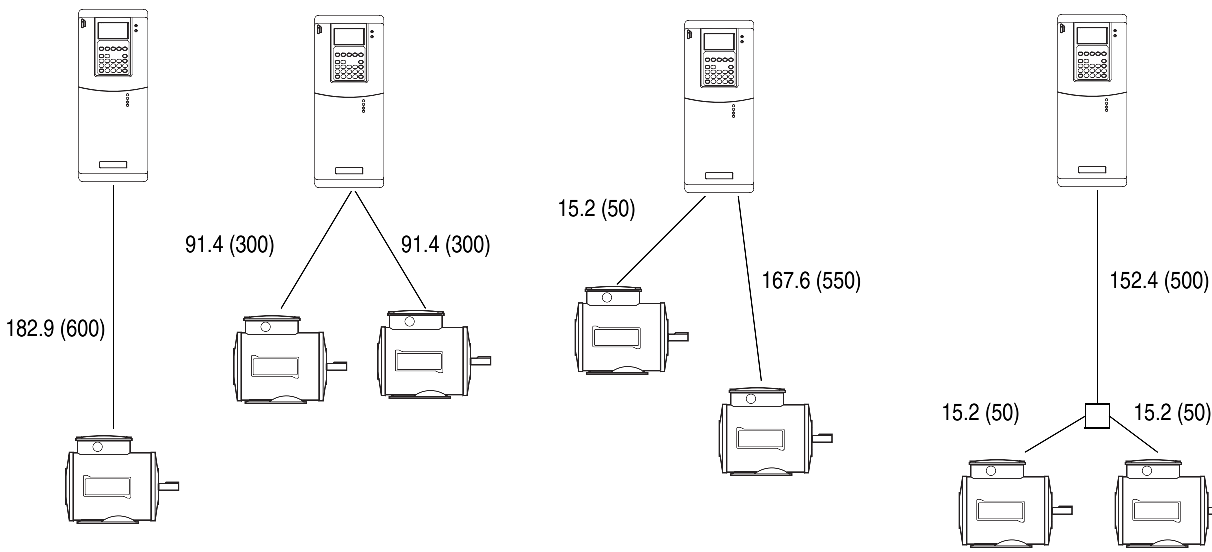
The majority of recommendations regarding drive cable address issues caused by the nature of the drive output. A PWM drive creates AC motor current by sending DC voltage pulses to the motor in a specific pattern. These pulses affect the wire insulation and can be a source of electrical noise. The rise time, amplitude, and frequency of these pulses must be considered when choosing a wire / cable type. The choice of cable must consider:

1. The effects of the drive output once the cable is installed
2. The need for the cable to contain noise caused by the drive output
3. The amount of cable charging current available from the drive
4. Possible voltage drop (and subsequent loss of torque) for long wire runs

Keep the motor cable lengths within the limits set by the drive's user manual. Various issues, including cable charging current and reflected wave voltage stress may exist. If the cable restriction is listed because of excessive coupling current, apply the methods to calculate total cable length, as shown in Figure 1.11 on page 1-11. If the restriction is due to voltage reflection and motor protection, tabular data is available. Refer to Appendix A for exact distances allowed.

Figure 1.11 Motor Cable Length

All examples represent motor cable length of 182.9 meters (600 feet)



Important: For multi motor applications review the installation carefully. Consult Rockwell Automation when considering a multi motor application with greater than two motors. In general most installations will have no issues. However high peak cable charging currents can cause drive over-currents or ground faults.

Cable for Discrete Drive I/O

Discrete I/O such as Start and Stop commands can be wired to the drive using a variety of cabling. Shielded cable is recommended, as it can help reduce cross-coupled noise from power cables. Standard individual conductors that meet the general requirements for type, temperature, gauge and applicable codes are acceptable if they are routed away from higher voltage cables to minimize noise coupling. However, multi-conductor cable may be less expensive to install. Control wires should be separated from power wires by at least 0.3 meters (1 foot)

Table 1.B Recommended Control Wire for Digital I/O

Type	Wire Type(s)	Description	Minimum Insulation Rating
Unshielded	Per US NEC or applicable national or local code	–	300V, 60° C (140 ° F)
Shielded	Multi-conductor shielded cable such as Belden 8770 (or equiv.)	0.750 mm^2 (18 AWG), 3 conductor, shielded.	

Analog Signal and Encoder Cable

Always use shielded cable with copper wire. Wire with insulation rating of 300V or greater is recommended. Analog signal wires should be separated from power wires by at least 0.3 meters (1 foot). It is recommended that encoder cables be run in a separate conduit. If signal cables must cross power cables, cross at right angles. Terminate the shield of the shielded cable as recommended by manufacturer of the encoder or analog signal device.

Table 1.C Recommended Signal Wire

Signal Type/ Where Used	Wire Type(s)		Description	Minimum Insulation Rating
Standard Analog I/O	Belden 8760/9460 (or equiv.)		0.750 mm^2 (18 AWG), twisted pair, 100% shield with drain[5].	300V, 75-90 °C (167-194 °F)
Remote Pot	Belden 8770 (or equiv.)		0.750 mm^2 (18 AWG), 3 cond., shielded	
Encoder/Pulse I/O Less 30.5 m (100 ft.)	Combined:	Belden 9730 (or equivalent) [1]	0.196 mm^2 (24 AWG), individually shielded.	
Encoder/Pulse I/O 30.5 m (100 ft.) to 152.4 m (500 ft.)	Signal:	Belden 9730/9728 (or equivalent) [1]	0.196 mm^2 (24 AWG), individually shielded.	
	Power:	Belden 8790 [2]	0.750 mm^2 (18 AWG)	
	Combined:	Belden 9892 [3]	0.330 mm^2 or 0.500 mm^2 [3]	
Encoder/Pulse I/O 152.4 m (500 ft.) to 259.1 m (850 ft.)	Signal:	Belden 9730/9728 (or equivalent) [1]	0.196 mm^2 (24 AWG), individually shielded.	
	Power:	Belden 8790 [2]	0.750 mm^2 (18 AWG)	
	Combined:	Belden 9773/9774 (or equivalent) [4]	0.750 mm^2 (18 AWG), individually shielded pair.	

(1) Belden 9730 is 3 individually shielded pairs (2 channel plus power). If 3 channel is required, use Belden 9728 (or equivalent).

(2) Belden 8790 is 1 shielded pair.

(3) Belden 9892 is 3 individually shielded pairs (3 channel), 0.33 mm^2 (22 AWG) plus 1 shielded pair 0.5 mm^2 (20 AWG) for power.

(4) Belden 9773 is 3 individually shielded pairs (2 channel plus power). If 3 channel is required, use Belden 9774 (or equivalent).

(5) If the wires are short and contained within a cabinet which has no sensitive circuits, the use of shielded wire may not be necessary, but is always recommended.

Communications

Serial (RS232/485)

Standard practices for serial communications wiring should be followed. Belden 3106A or equivalent that contains one twisted pair and one signal common is recommended for RS232. Recommended cable for RS485 is two individually shielded twisted pairs.

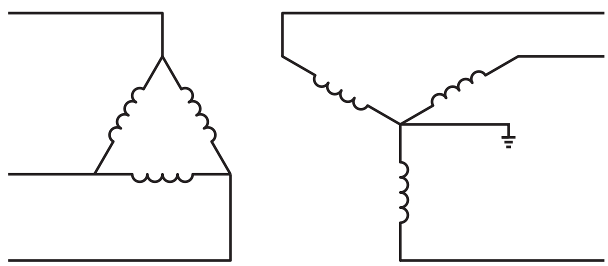
Power Distribution

This chapter discusses different power distribution schemes and factors which affect drive performance.

System Configurations

The type of transformer and the connection configuration feeding a drive plays an important role in its performance and safety. The following is a brief description of some of the more common configurations and a discussion of their virtues and shortcomings.

Delta / Wye with Grounded Wye Neutral

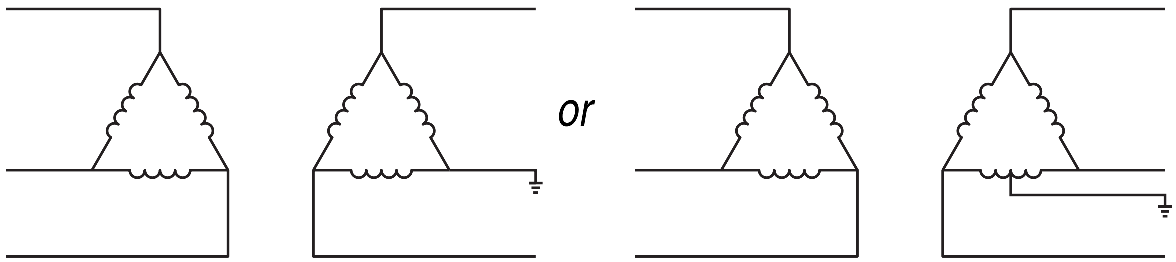


Delta / Wye with Grounded Wye Neutral is the most common type of distribution system. It provides re-balancing of unbalanced voltage with a 30-degree phase shift. The grounded neutral provides a direct path for common mode current caused by the drive output (see Chapter 3 and Chapter 6).

Rockwell Automation strongly recommends the use of grounded neutral systems for the following reasons:

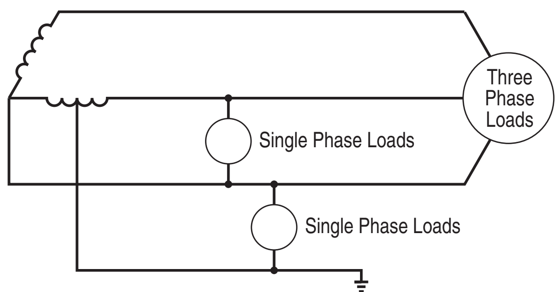
- Controlled path for common mode noise current
- Consistent line to ground voltage reference, which minimizes insulation stress
- Accommodation for system surge protection schemes

Delta / Delta with Grounded Leg or Four-Wire Connected Secondary Delta



Delta / Delta with Grounded Leg or Four-Wire Connected Secondary Delta is a common configuration providing voltage re-balancing with no phase shift between input and output. The grounded center tap provides a direct path for common mode current caused by the drive output.

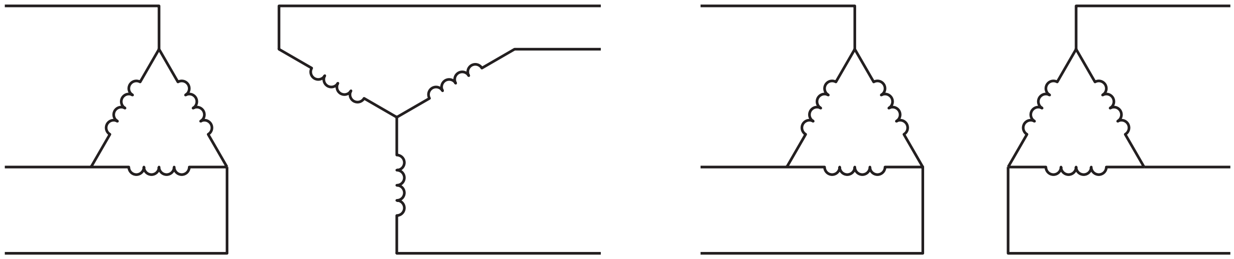
3-Phase Open Delta with 1-Phase Center Tapped



Three-Phase Open Delta with 1-Phase Center Tapped is a configuration providing a 3-phase delta transformer with one side tapped. This tap (the neutral) is connected to earth. The configuration is called the antiphase grounded (neutral) system.

The open delta transformer connection is limited to 58% of the 240V, single-phase transformer rating. Closing the delta with a third single-phase, 240V transformer allows full rating for the two single-phase, 240V transformers. The phase leg opposite the midpoint has an elevated voltage when compared to earth or neutral. The “hottest” high leg must be positively identified throughout the electrical system. It should be the center leg in any switch, motor control, three-phase panel board, etc. The NEC requires orange color tape to identify this leg.

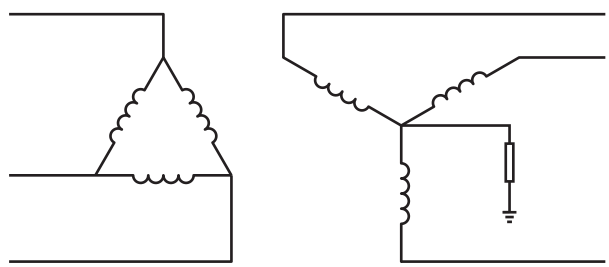
Ungrounded Secondary



Grounding the transformer secondary is essential to the safety of personnel and safe operation of the drive. Leaving the secondary floating allows dangerously high voltages between the chassis of the drive and the internal power structure components. Exceeding the voltage rating of the drive's input MOV (Metal Oxide Varistor) protection devices could cause a catastrophic failure. In all cases, the input power to the drive should be referenced to ground.

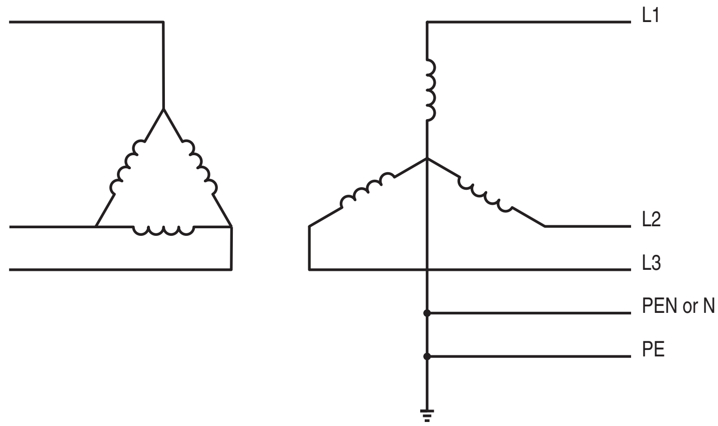
If the system is ungrounded, other general precautions such as a system level ground fault detector or system level line to ground suppressor may be necessary or an isolation transformer must be considered with the secondary of the transformer grounded. Refer to local codes regarding safety requirements. Also refer to Surge Protection MOVs and Common Mode Capacitors on page 2-10.

High Resistance Ground



Grounding the wye secondary neutral through a resistor is an acceptable method of grounding. Under a short circuit secondary condition, any of the output phases to ground will not exceed the normal line to line voltage. This is within the rating of the MOV input protection devices on the drive. The resistor is often used to detect ground current by monitoring the associated voltage drop. Since high frequency ground current can flow through this resistor, care should be taken to properly connect the drive motor leads using the recommended cables and methods. In some cases, multiple drives (that may have one or more internal references to ground) on one transformer can produce a cumulative ground current that can trigger the ground fault interrupt circuit. Refer to Surge Protection MOVs and Common Mode Capacitors on page 2-10.

TN-S Five-Wire System



TN-S five-wire distribution systems are common throughout Europe, with the exception of the United Kingdom and Germany. Leg to leg voltage (commonly at 400V) powers three-phase loads. Leg to neutral voltage (commonly at 230V) powers single-phase loads. Neutral is a current conducting wire, and connects through a circuit breaker. The fifth wire is a separate ground wire. There is a single connection between ground and neutral, typically in the distribution system. There should be no connections between ground and neutral within the system cabinets.

AC Line Voltage

In general all VTAC drives are tolerant to a wide swing of AC line voltage. Check the individual specification for the drives you are installing.

Incoming voltage imbalances greater than 2% can cause large unequal currents in a drive. An input line reactor may be necessary when line voltage imbalances are greater than 2%.

AC Line Impedance

To prevent excess current that may damage drives during events such as line disturbances or certain types of ground faults, drives should have a minimum amount of impedance in front of them. In many installations, this impedance comes from the supply transformer and the supply cables. In certain cases, an additional transformer or reactor is recommended. If any of the following conditions exist, serious consideration should be given to adding impedance (line reactor or transformer) in front of the drive:

A. Installation site has switched power factor correction capacitors.

B. Installation site has lightning strikes or voltage spikes in excess of 6000V Peak.

C. Installation site has power interruptions or voltage dips in excess of 200VAC.

D. The transformer is too large in comparison to the drive. See impedance recommendation tables Table 2.A on page 7 and Table 2.B on page 7 that are specific to each drive. **Using these tables will allow the largest transformer size for each product and rating based on specific differences in construction, and is the preferred method to follow.**

Otherwise, use one of the two following more conservative methods:

1. For drives without built-in inductors, add line impedance whenever the transformer kVA is more than 10 times larger than the drive kVA, or the percent source impedance relative to each drive is less than 0.5%.

2. For drives with built-in inductors, add line impedance whenever the transformer kVA is more than 20 times larger than the drive kVA, or the percent source impedance relative to each drive is less than 0.25%.

To identify drives with built-in inductors, see the product specific tables. The shaded rows identify products ratings without built-in inductors.

Use the following equations to calculate the impedance of the drive and transformer:

Drive Impedance (in ohms)

$$Z_{drive} = \frac{V_{line-line}}{\sqrt{3} \cdot I_{input-rating}}$$

Transformer Impedance (in ohms)

$$Z_{xfmr} = \frac{V_{line-line}}{\sqrt{3} \cdot I_{xfmr-rated}} \cdot \% \text{ Impedance}$$

or

$$Z_{xfmr} = \frac{(V_{line-line})^2}{VA} \cdot \% \text{ Impedance}$$

% Impedance is the nameplate impedance of the transformer

Typical values range from 0.03 (3%) to 0.06 (6%)

Transformer Impedance (in ohms)

$$Z_{xfmr} = \frac{V_{line-line}}{\sqrt{3} \cdot I_{xfmr-rated}} \cdot \% \text{ Impedance}$$

% Impedance is the nameplate impedance of the transformer

Typical values range from 0.03 (3%) to 0.06 (6%)

Example: The drive is rated 1 Hp, 480V, 2.7A input.
The supply transformer is rated 50,000 VA (50 kVA), 5% impedance.

$$Z_{drive} = \frac{V_{line\text{-}line}}{\sqrt{3} \quad I_{input \quad rating}} = \frac{480V}{\sqrt{3} \quad 2.7} = 102.6 \text{ ohms}$$

$$Z_{xfmr} = \frac{(V_{line\text{-}line})^2}{VA} \cdot \% \text{ Impedance} = \frac{480^2}{50{,}000} \cdot 0.05 = 0.2304 \text{ Ohms}$$

Note that the percent (%) impedance has to be in per unit (5% becomes 0.05) for the formula.

$$\frac{Z_{xfrmr}}{Z_{drive}} = \frac{0.2304}{102.6} = 0.00224 = 0.22\,\%$$

0.22% is less than 0.5%. Therefore, this transformer is too big for the drive and a line reactor should be added.

Note: Grouping multiple drives on one reactor is acceptable; however, the reactor percent impedance must be large enough when evaluated for each drive separately, not evaluated for all loads connected at once.

These recommendations are merely advisory and may not address all situations. Site specific conditions must be considered to assure a quality installation.

Table 2.A AC Line Impedance Recommendations for VTAC 9 Drives (Frames B, C, D, E)

	Drive Catalog #(1)	Volts	kW (hp)	Max Supply KVA (2)	3% Line Reactor Open Style 1321-	Reactor Inductance (mh)	Reactor Current Rating (Amps)
VTAC 9 (Frames B, C, D, E)	9VT201-007HTNNN	208	1.5 (2)	50	3R8-A	1.5	8
	9VT201-011HTNNN	208	2.2 (3)	50	3R12-A	1.25	12
	9VT201-017HTANN	208	4.0 (5)	200	3R18-A	0.8	18
	9VT201-025HTANN	208	5.5 (7.5)	250	3R25-A	0.5	25
	9VT201-032HTANN	208	7.5 (10)	300	3R35-A	0.4	35
	9VT201-062HTANN	208	15 (20)	1000	3R55-A	0.25	55
	9VT201-078HTANN	208	18.5 (25)	1000	3R80-A	0.2	80
	9VT401-005HTNNN	480	2.2 (3)	75	3R8-C	5	8
	9VT401-008HTNNN	480	3.7 (5)	100	3R8-B	3	8
	9VT401-011HTANN	480	5.5 (7.5)	250	3R12-B	2.5	12
	9VT401-014HTANN	480	7.5 (10)	250	3R18-B	1.5	18
	9VT401-022HTANN	480	11 (15)	300	3R25-B	1.2	25
	9VT401-027HTANN	480	15 (20)	400	3R35-B	0.8	35
	9VT401-034HTANN	480	18.5 (25)	750	3R35-B	0.8	35
	9VT401-040HTANN	480	22 (30)	1000	3R45-B	0.7	45
	9VT401-052HTANN	480	30 (40)	1000	3R55-B	0.5	55
	9VT401-065HTANN	480	37 (50)	1000	3R80-B	0.4	80

(1) Shaded rows identify drive ratings without built-in inductors

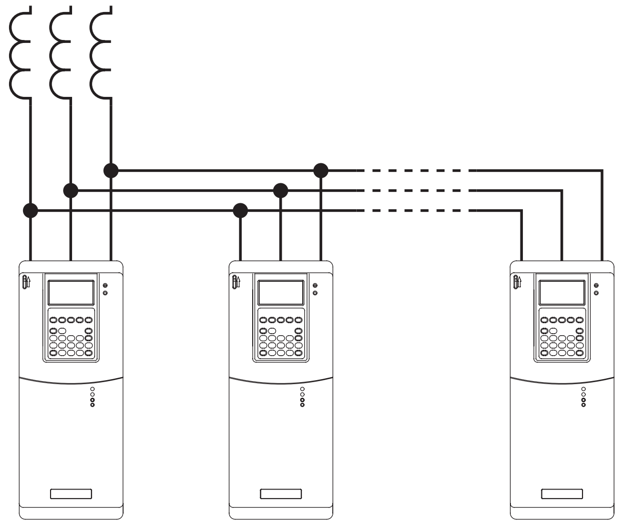
(2) Maximum suggested KVA supply without consideration for additional inductance

Table 2.B AC Line Impedance Recommendations for VTAC 9 Drives (Frames 2, 3, 4, 5, 6)

	Drive Catalog #	Volts	kW (hp)	Max Supply KVA (1)	3% Line Reactor Open Style 1321-	Reactor Inductance (mh)	Reactor Current Rating (Amps)
VTAC 9 (Frames 2, 3, 4, 5, 6)	9VT201-092HNANA	208	22 (30)	1000	3R100-A	0.15	100
	9VT201-120HNANA	208	30 (40)	1000	3R130-A	0.1	130
	9VT201-177HNANA	208	45 (60)	1000	3R160-A	0.075	160
	9VT201-221HNANA	208	55 (75)	1000	3R200-A	0.055	200
	9VT201-260HNANA	208	75 (100)	1000	3R320-A	0.04	320
	9VT401-034HTANA	480	18.5 (25)	1000	3R35-B	0.8	35
	9VT401-040HTANA	480	22 (30)	1000	3R45-B	0.7	45
	9VT401-052HTANA	480	30 (40)	1000	3R55-B	0.5	55
	9VT401-065HTANA	480	37 (50)	1000	3R80-B	0.4	80
	9VT401-077HNANA	480	45 (60)	1000	3R80-B	0.4	80
	9VT401-096HNANA	480	55 (75)	1000	3R100-B	0.3	100
	9VT401-125HNANA	480	75 (100)	1000	3R130-B	0.2	130
	9VT401-156HNANA	480	90 (125)	1500	3R160-B	0.15	160
	9VT401-180HNANA	480	110 (150)	1500	3R200-B	0.11	200

(1) Maximum suggested KVA supply without consideration for additional inductance

Multi-Drive Protection



Multiple drives on a common power line should each have their own line reactor. Individual line reactors provide filtering between each drive to provide optimum surge protection for each drive. However, if it is necessary to group more than one drive on a single AC line reactor, use the following process to verify that the AC line reactor provides a minimum amount of impedance:

1. In general, up to 5 drives can be grouped on one reactor.

2. Add the input currents of the drives in the group.

3. Multiply that sum by 125%.

4. Use publication 1321-2.0 to select a reactor with a maximum continuous current rating greater than the multiplied current.

5. Verify that the impedance of the selected reactor is more than 0.5% (0.25% for drives with internal inductors) of the smallest drive in the group by using the formulas below. If the impedance is too small, select a reactor with a larger inductance and same amperage, or regroup the drives into smaller groups and start over.

$$Z_{drive} = \frac{V_{line\text{-}line}}{\sqrt{3} \cdot I_{input\ \ rating}}$$

$$Z_{reactor} = L \cdot 2 \cdot \Pi \cdot f$$

L is the inductance of the reactor in henries and f is the AC line frequency

Example: There are 5 drives, each is rated 1 HP, 480V, 2.7 amps. These drives do <u>not</u> have internal inductors.

Total current = 5 * 2.7 amps = 13.5 amps

125% * Total current = 125% * 13.5 amps = 16.9 amps

From publication 1321-2.0, we selected the reactor 1321-3R12-C, which has a maximum continuous current rating of 18 amps and an inductance of 4.2 mh (0.0042 henries).

$$Z_{drive} = \frac{V_{line\text{-}line}}{\sqrt{3} \cdot I_{input\ \ rating}} = \frac{480}{\sqrt{3} \cdot 2.7} = 102.6\ \text{Ohms}$$

$$Z_{reactor} = L \cdot 2\Pi \cdot f = 0.0042 \cdot 2\,.\,\Pi \cdot 60 = 1.58\ \text{Ohms}$$

$$\frac{Z_{reactor}}{Z_{drive}} = \frac{1.58}{102.6} = 0.0154 = 1.54\,\%$$

1.54% is more than the 0.5% impedance recommended. The 1321-3R12-C can be used for the (5) 2.7 amp drives in this example.

Surge Protection MOVs and Common Mode Capacitors

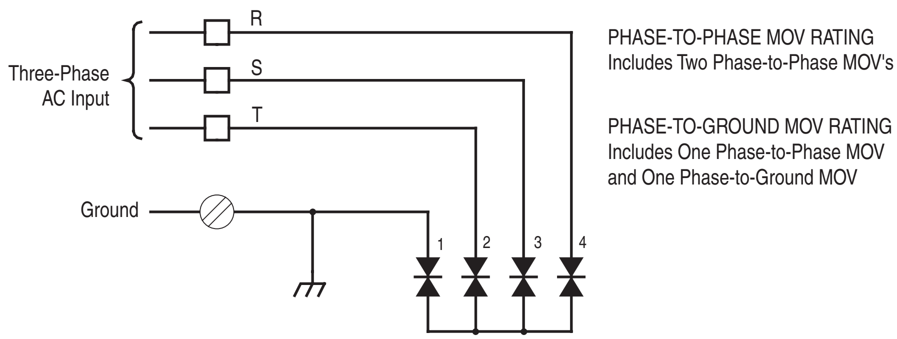
ATTENTION: When installing a drive on an ungrounded or high-resistance ground distribution system, disconnect the phase-to-ground MOV circuit and the common mode capacitors from ground.

Note: *In some drives, a single jumper connects both the phase-to-ground MOV and the common mode capacitors to ground.*

MOV Circuitry

Most drives are designed to operate on three-phase supply systems with symmetrical line voltages. To meet IEEE 587, these drives are equipped with MOVs that provide voltage surge protection as well as phase-to-phase and phase-to-ground protection. The MOV circuit is designed for surge suppression (transient line protection) only, not for continuous operation.

Figure 2.1 Typical MOV Configuration



With ungrounded distribution systems, the phase-to-ground MOV connection can become a continuous current path to ground. Exceeding the published phase-to-phase, phase-to-ground voltage or energy ratings may cause physical damage to the MOV.

Suitable isolation is required for the drive when there is potential for abnormally high phase-to-ground voltages (in excess of 125% of nominal line-to-line voltage), or when the supply ground is tied to another system or equipment that could cause the ground potential to vary with operation. An isolation transformer is strongly recommended when this condition exists.

Common Mode Capacitors

Many drives also contain common mode capacitors that are referenced to ground. In installations with ungrounded or high resistive grounded systems, the common mode capacitors can capture high frequency common mode or ground fault currents. This could cause over-voltage conditions, which could lead to damage or drive faults.

Grounding

This chapter discusses various grounding schemes for safety and noise reduction.

An effectively grounded scheme or product is one that is "intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages which may result in undue hazard to connected equipment or to persons" (as defined by the US National Electric Code NFPA70, Article 100B). Grounding of a drive or drive system is done for 2 basic reasons: safety (defined above) and noise containment or reduction. While the safety ground scheme and the noise current return circuit may sometimes share the same path and components, they should be considered different circuits with different requirements.

Grounding Safety Grounds

The object of safety grounding is to ensure that all metalwork is at the same ground (or Earth) potential at power frequencies. Impedance between the drive and the building scheme ground must conform to the requirements of national and local industrial safety regulations or electrical codes. These will vary based on country, type of distribution system and other factors. Periodically check the integrity of all ground connections.

General safety dictates that all metal parts are connected to earth with separate copper wire or wires of the appropriate gauge. Most equipment has specific provisions to connect a safety ground or PE (protective earth) directly to it.

Building Steel

If intentionally bonded at the service entrance, the incoming supply neutral or ground will be bonded to the building ground. Building steel is judged to be the best representation of ground or earth. The structural steel of a building is generally bonded together to provide a consistent ground potential. If other means of grounding are used, such as ground rods, the user should understand the voltage potential, between ground rods in different areas of the installation. Type of soil, ground water level and other environmental factors can greatly affect the voltage potential between ground points if they are not bonded to each other.

Grounding PE or Ground

The drive safety ground - PE must be connected to scheme or earth ground. This is the safety ground for the drive that is required by code. This point must be connected to adjacent building steel (girder, joist), a floor ground rod, bus bar or building ground grid. Grounding points must comply with national and local industrial safety regulations or electrical codes. Some codes may require redundant ground paths and periodic examination of connection integrity. Global Drive Systems requires the PE ground to be connected to the transformer ground feeding the drive system.

RFI Filter Grounding

Using an optional RFI filter may result in relatively high ground leakage currents. Therefore, the filter must only be used in installations with grounded AC supply systems and be permanently installed and solidly grounded to the building power distribution ground. Ensure the incoming supply neutral is solidly connected to the same building power distribution ground. Grounding must not rely on flexible cables or any plug or socket that may be accidentally disconnected. Some codes may require redundant ground connections. Periodically check the integrity of all connections. Refer to the instructions supplied with the filter.

Grounding Motors

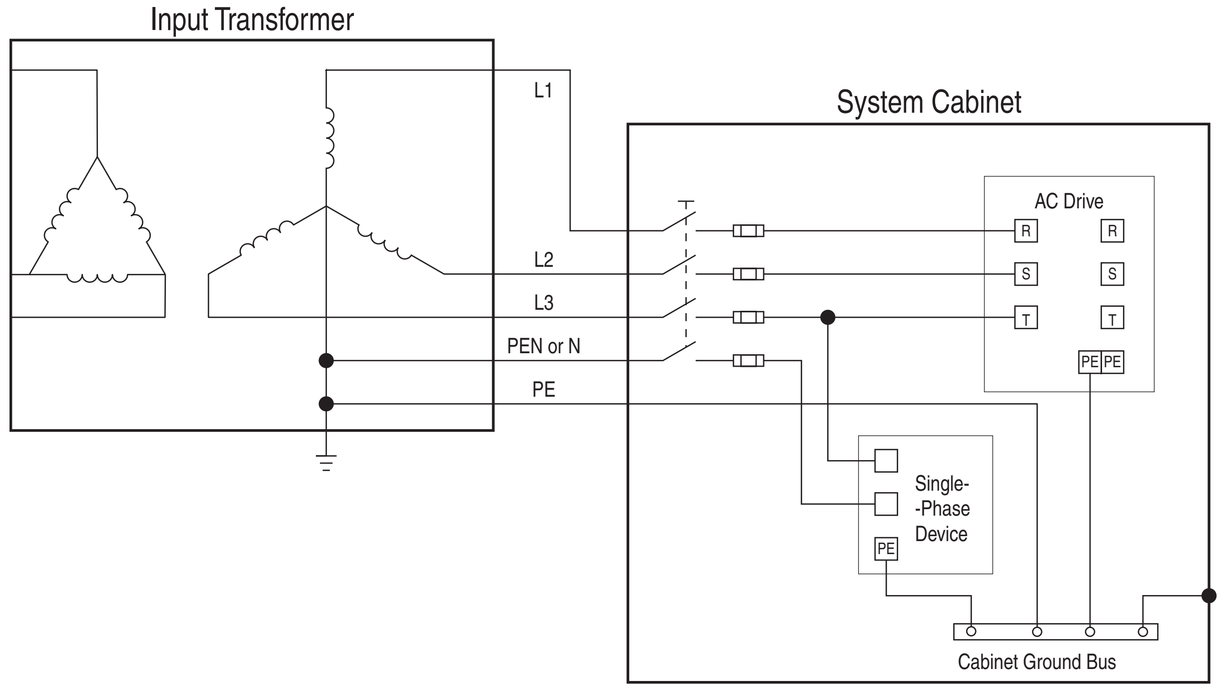
The motor frame or stator core must be connected directly to the drive PE connection with a separate ground conductor. It is recommended that each motor frame be grounded to building steel at the motor. Refer to Cable Trays in Chapter 4 for more information.

Grounding and TN-S Five-Wire Systems

Do not connect ground to neutral within a system cabinet, when using a TN-S five-wire distribution system. The neutral wire is a current conducting wire. There is a single connection between ground and neutral, typically in the distribution system.

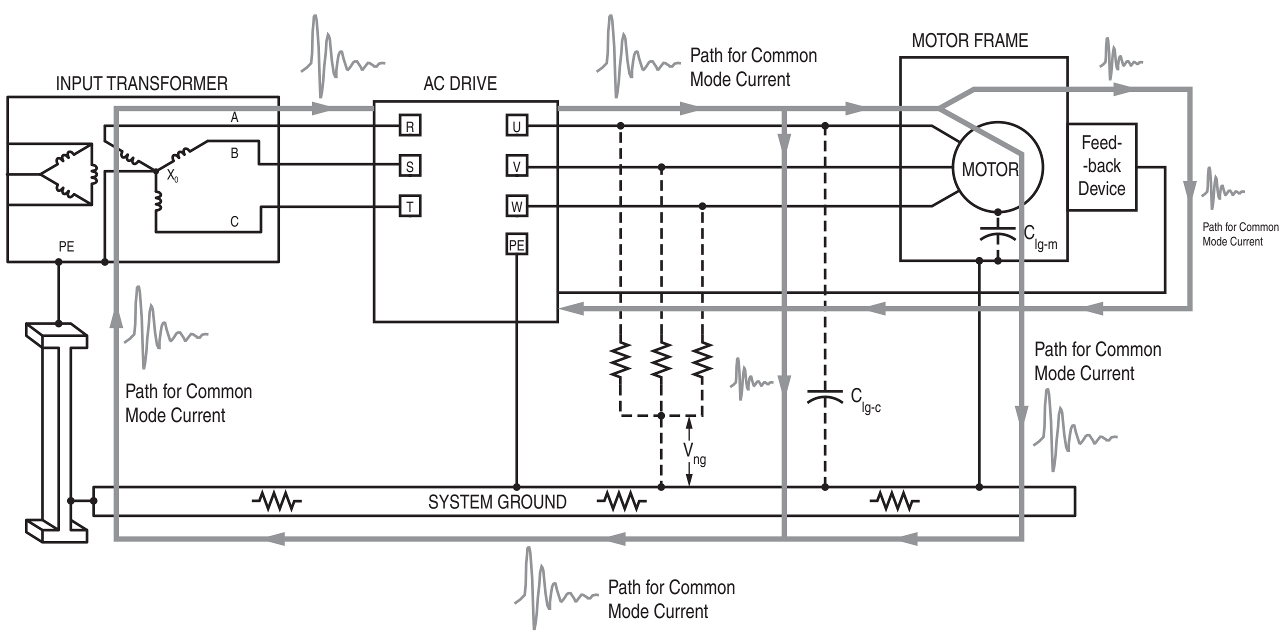
TN-S five-wire distribution systems are common throughout Europe, with the exception of the United Kingdom and Germany. Leg to leg voltage (commonly at 400V) powers three-phase loads. Leg to neutral voltage (commonly at 230V) powers single-phase loads.

Figure 3.1 Cabinet Grounding with a TN-S Five-Wire System



Noise Related Grounds

It is important to take care when installing PWM AC drives because output can produce high frequency common mode (coupled from output to ground) noise currents. These currents cause sensitive equipment to malfunction if they are allowed to propagate.

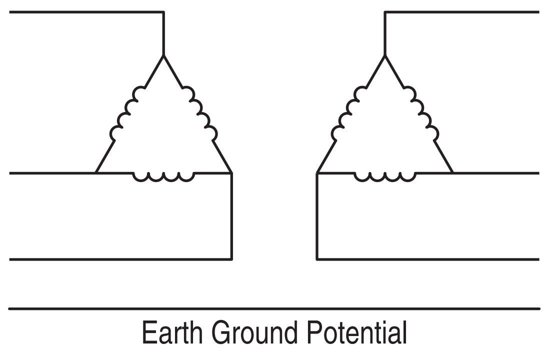


The grounding scheme can greatly affect the amount of noise and its impact on sensitive equipment. The power scheme is likely to be one of three types:

- Ungrounded Scheme
- Scheme with High Resistance Ground
- Fully Grounded Scheme

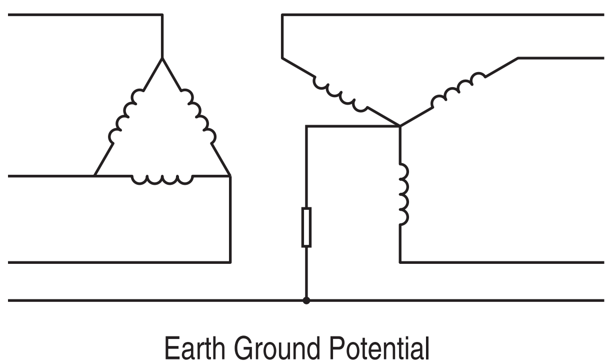
An ungrounded scheme, as shown in Figure 3.2, does not provide a direct path for the common mode noise current, causing it to seek other uncontrolled paths. This causes related noise issues.

Figure 3.2 Ungrounded Scheme



A scheme with a high resistance ground, shown in Figure 3.3, provides a direct path for common mode noise current, like a fully grounded scheme. Designers, who are concerned with minimizing ground fault currents, commonly choose high resistance ground schemes.

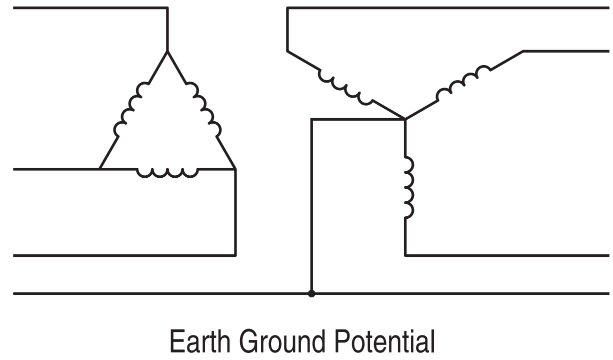
Figure 3.3 Scheme with High Resistance Ground



A fully grounded scheme, shown in Figure 3.4, provides a direct path for common mode noise currents. Rockwell Automation strongly recommends the use of grounded neutral systems for the following reasons:

- Controlled path for common mode noise current
- Consistent line to ground voltage reference, which minimizes insulation stress
- Accommodation for system surge protection schemes

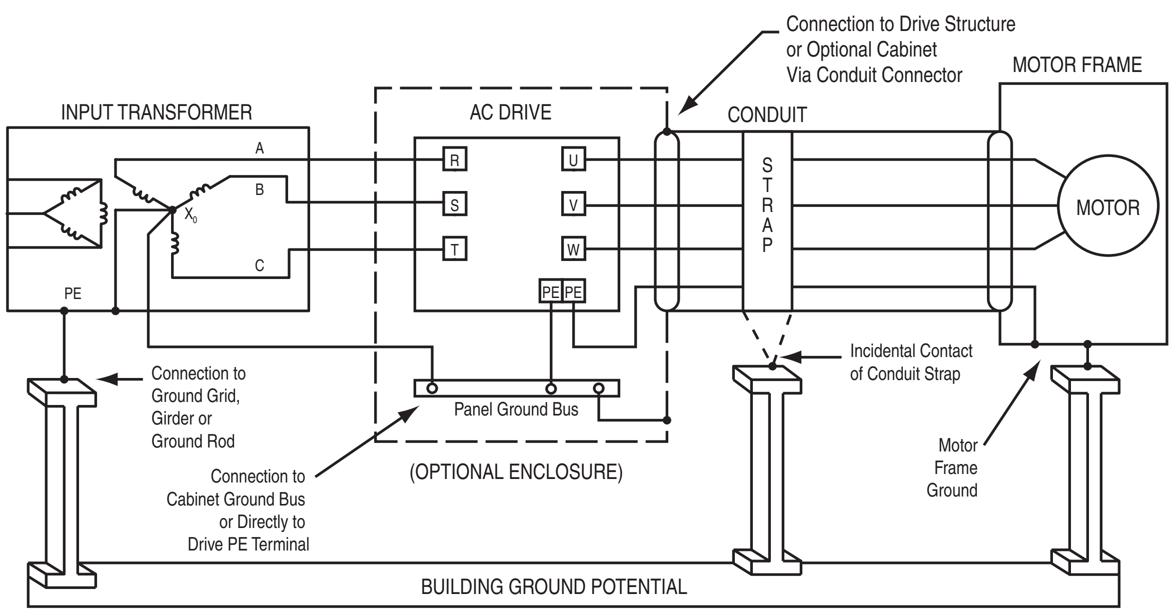
Figure 3.4 Fully Grounded Scheme



The installation and grounding practices to reduce common mode noise issues can be categorized into three ratings. The scheme used must weigh additional costs against the operating integrity of all scheme components. If no sensitive equipment is present and noise is not be an issue, the added cost of shielded cable and other components may not be justified.

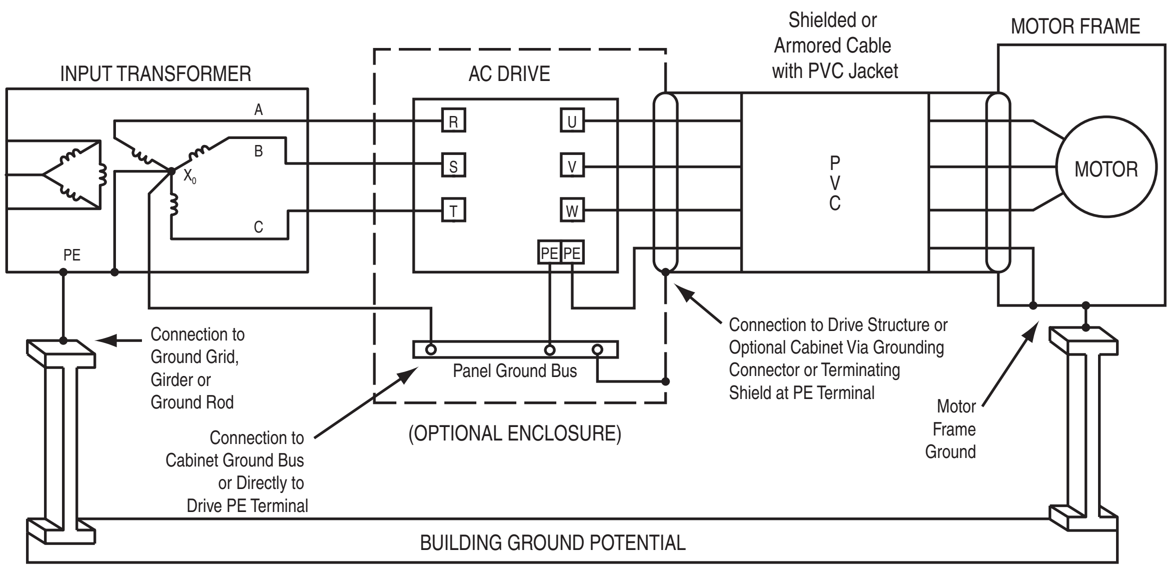
Acceptable Grounding Practices

The scheme shown below is an acceptable ground layout for a single drive installation. However, conduit may not offer the lowest impedance path for any high frequency noise. If the conduit is mounted so that it contacts the building steel, it is likely that the building steel will offer a lower impedance path and allow noise to inhabit the ground grid.



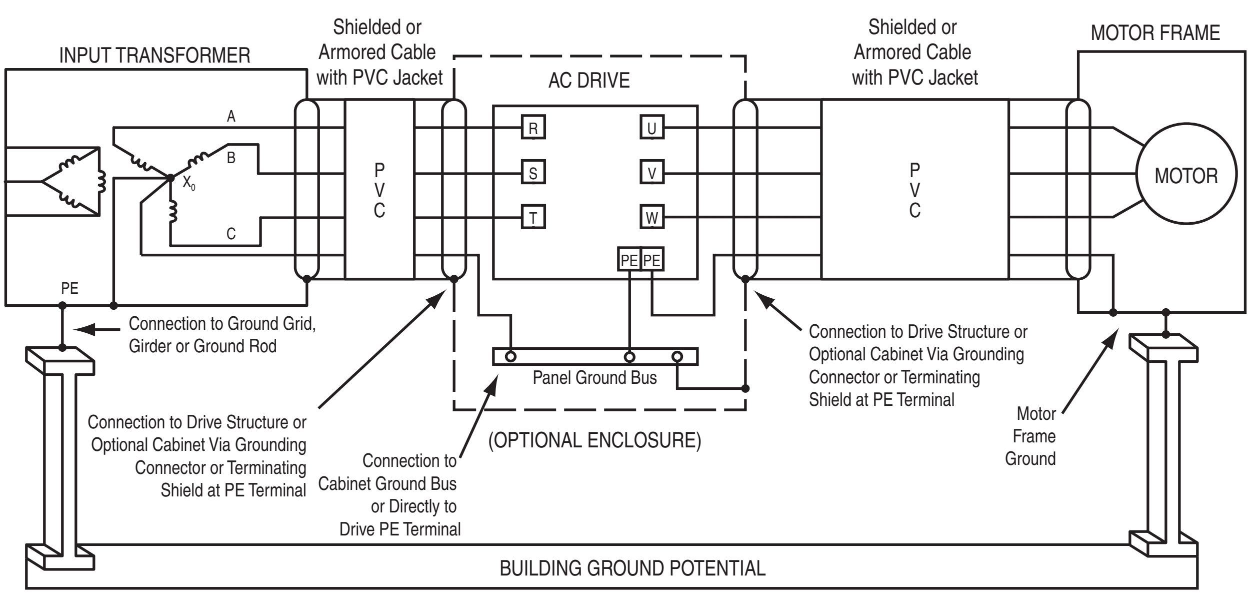
Effective Grounding Practices

This scheme replaces the conduit with shielded or armored cable that has a PVC exterior jacket. This PVC jacket prevents accidental contact with building steel and reduces the possibility that noise will enter the ground grid.



Optimal - Recommended Grounding Practices

The fully grounded scheme provides the best containment of common mode noise. It uses PVC jacketed, shielded cable on both the input and the output to the drive. This method also provides a contained noise path to the transformer to keep the ground grid as clean as possible.



Cable Shields

Motor and Input Cables

Shields of motor and input cables must be bonded at both ends to provide a continuous path for common mode noise current.

Control and Signal Cables

Shields of control cables should be connected at one end only. The other end should be cut back and insulated.

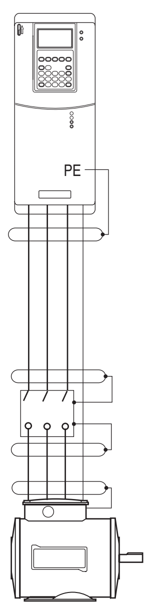
– The shield for a cable from one cabinet to another must be connected at the cabinet that contains the signal source.

– The shield for a cable from a cabinet to an external device must be connected at the cabinet end, unless specified by the manufacturer of the external device.

Never connect a shield to the common side of a logic circuit (this will introduce noise into the logic circuit). Connect the shield directly to a chassis ground.

Shield Splicing

Figure 3.5 Spliced Cable Using Shieldhead Connector



If the shielded cable needs to be stripped, it should be stripped back as little as possible to ensure that continuity of the shield is not interrupted. Avoid splicing motor power cables when ever possible. Ideally, motor cables should run continuously between the drive and motor terminals. The most common reason for interrupted cable/shield is to incorporate an “at the motor” disconnect switch. In these cases, the preferred method of splicing is to use fully shielded bulkhead connectors.

Single Point

A single safety ground point or ground bus bar should be directly connected to the building steel for cabinet installations. All circuits including the AC input ground conductor should be grounded independently and directly to this point/bar.

Isolated Inputs

If the drive’s analog inputs are from isolated devices and the output signal is not referenced to the ground, the drive’s inputs do not need to be isolated. An isolated input is recommended to reduce the possibility of induced noise if the transducer’s signal is referenced to ground and the ground potentials are varied (Refer to Noise Related Grounds on page 3-3). An external isolator can be installed if the drive does not provide input isolation.

Notes:

Practices

This chapter discusses various installation practices.

Mounting

Standard Installations

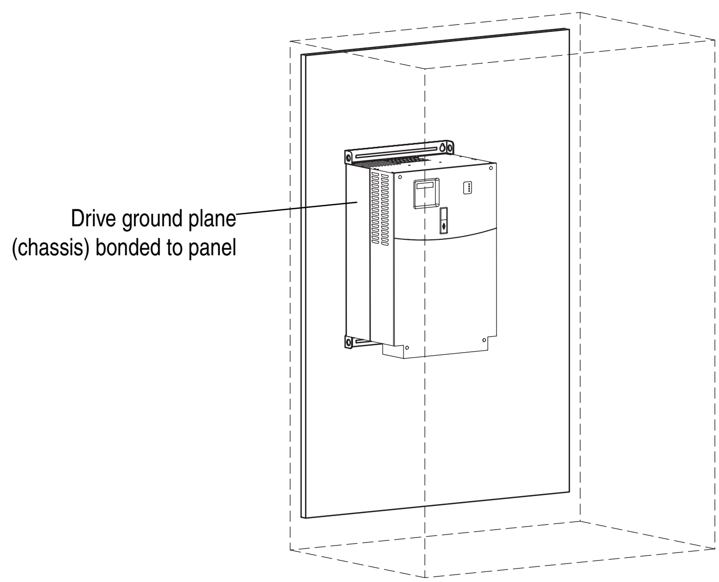
There are many criteria in determining the appropriate enclosure. Some of these include:

- Environment
- EMC Compatibility/Compliance
- Available Space
- Access/Wiring
- Safety Guidelines

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 4.1 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.

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 should be made of zinc-plated mild steel. If painted, remove the paint at each mounting and grounding point.

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 to remove the paint, is the difficulty in making quality control checks to verify if the paint has been properly removed, and any future corrosion of the unprotected mild steel may 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 applicable, a plated cabinet frame is also highly desirable since it makes a high frequency bond between panel and cabinet sections more reliable.

Doors

For doors 2 m (78 in.) in height, ground the door to the cabinet with two or three braided straps.

EMC seals are not normally required for industrial systems.

EMC Specific Installations

A steel enclosure is recommended. A steel enclosure can help guard against radiated noise to meet EMC standards. If the enclosure door has a viewing window, it should be a laminated screen or a conductive optical substrate to block EMC.

Do not rely on the hinge for electrical contact between the door and the enclosure - install a grounding wire. For doors 2 m (78 in.) in height, two or three braided grounding straps between the door and the cabinet should be used. EMC gaskets are not normally required for industrial systems.

Layout

Plan the cabinet layout so that drives are separated from sensitive equipment. Choose conduit entry points that allow any common mode noise to remain away from PLCs and other equipment that may be susceptible to noise. Refer to Moisture on page 4-18 for additional information.

Hardware

You can mount the drive and/or mounting panel with either bolts or welded studs.

Figure 4.2 Stud Mounting of Ground Bus or Chassis to Back Panel

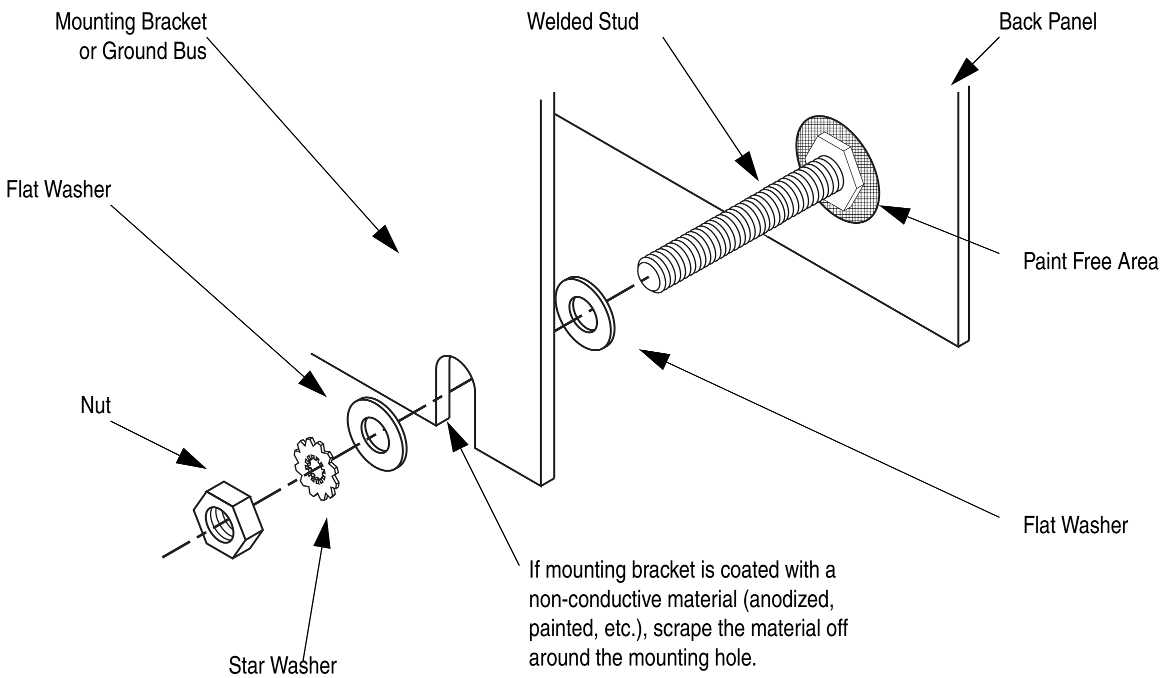
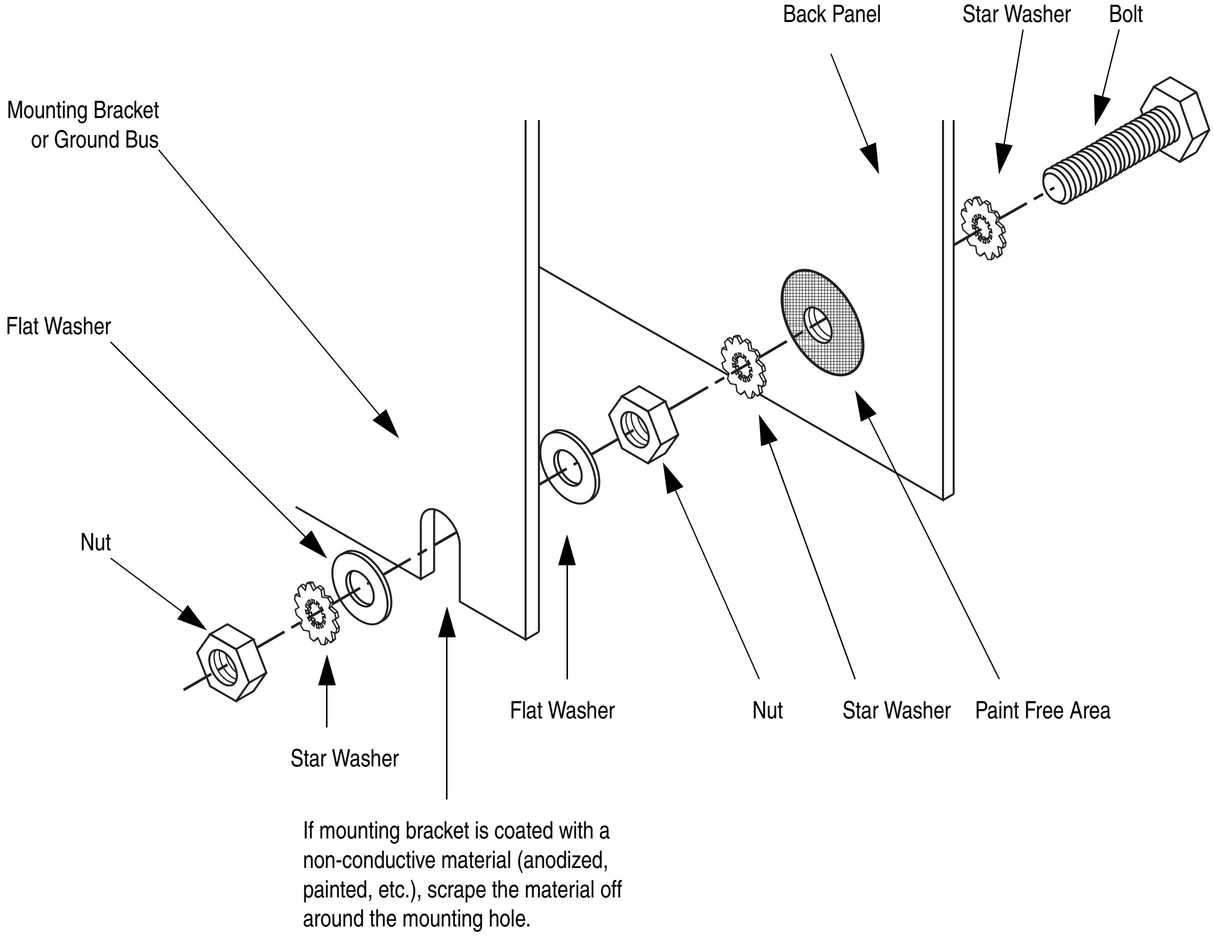


Figure 4.3 Bolt Mounting of Ground Bus or Chassis to Back Panel



If the drive chassis does not lay flat before the nuts / bolts are tightened, use additional washers as shims so that the chassis does not bend when you tighten the nuts.

Conduit Entry

Entry Plates

In most cases, the conduit entry plate will be a paint-free conductive material. The surface of the plate should be clean of oil or contaminants. If the plate is painted, use a connector that cuts through the paint and makes a high quality connection to the plate material

Or

Remove the paint around the holes to the bare metal one inch in from the edge of the plate. Grind down the paint on the top and bottom surfaces. Use a high quality joint compound when reassembling to avoid corrosion.

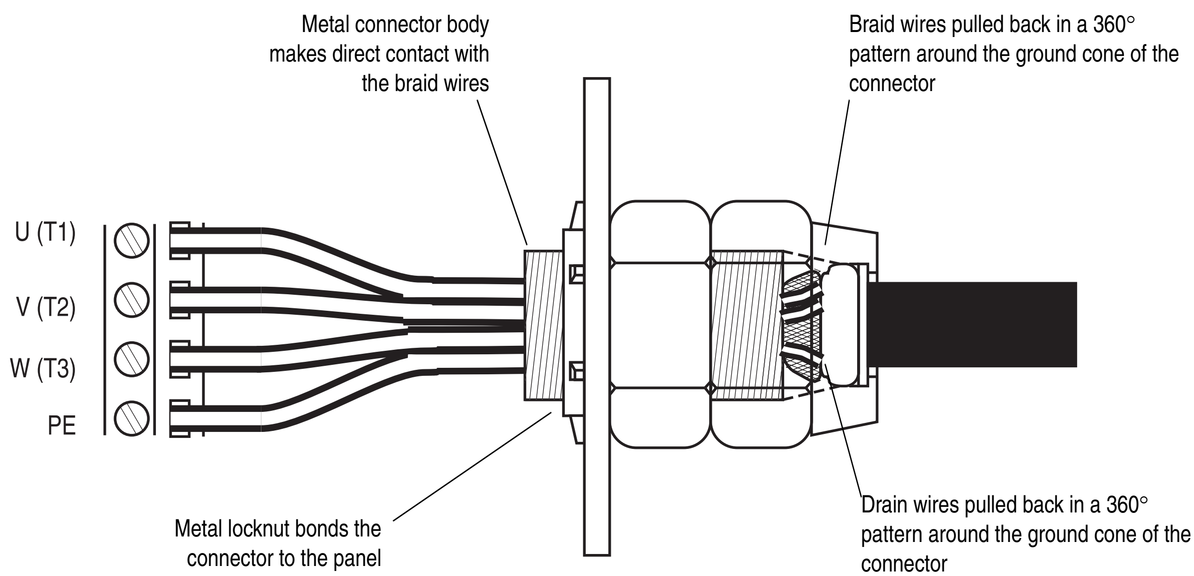
Cable Connectors / Glands

Choose cable connectors or glands that offer the best cable protection, shield termination and ground contact. Refer to Shield Termination on page 4-15 for more information.

Shield terminating connectors

The cable connector selected must provide good 360° contact and low transfer impedance from the shield or armor of the cable to the conduit entry plate at both the motor and the drive or drive cabinet for electrical bonding. SKINTOP® MS-SC/MS-SCL cable grounding connectors and NPT/PG adapters from LAPPUSA are good examples of this type of shield terminating gland. Use a connector with 3 ground bushings when using a cable with 3 ground conductors.

Figure 4.4 Terminating the Shield with a Connector

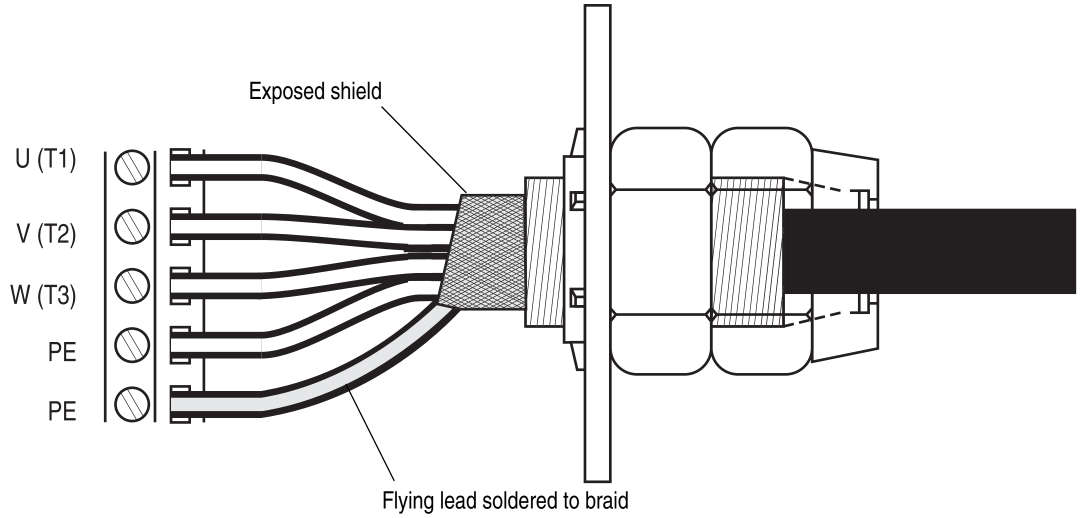


Important: This is mandatory for CE compliant installations, to meet requirements for containing radiated electromagnetic emissions

Shield termination via Pigtail (Lead)

If a shield terminating connector is not available, the ground conductors or shields must be terminated to the appropriate ground terminal. If necessary, use a compression fitting for ground conductor(s) and/or shields together as they leave the cable fitting.

Figure 4.5 Terminating the Shield with a Pigtail Lead



Important: This is an acceptable industry practice for most installations.
to minimize stray common mode currents

Pigtail termination is the least effective method of noise containment.

It is not recommended if:

- the cable length is greater than 1 m (39 in.) or extends beyond the panel
- in very noisy areas
- the cables are for very noise sensitive signals (for example, registration or encoder cables)
- strain relief is required

If a pigtail is used, pull and twist the exposed shield after separation from the conductors. Solder a flying lead to the braid to extend its length.

Ground Connections

Ground conductors should be connected with care to assure safe and adequate connections.

For individual ground connections, star washers and ring lugs should be used to make connections to mounting plates or other flat surfaces that do not provide proper compression lugs.

If a ground bus system is used in a cabinet, follow the bus bar mounting diagrams.

Figure 4.6 Connections to Ground Bus

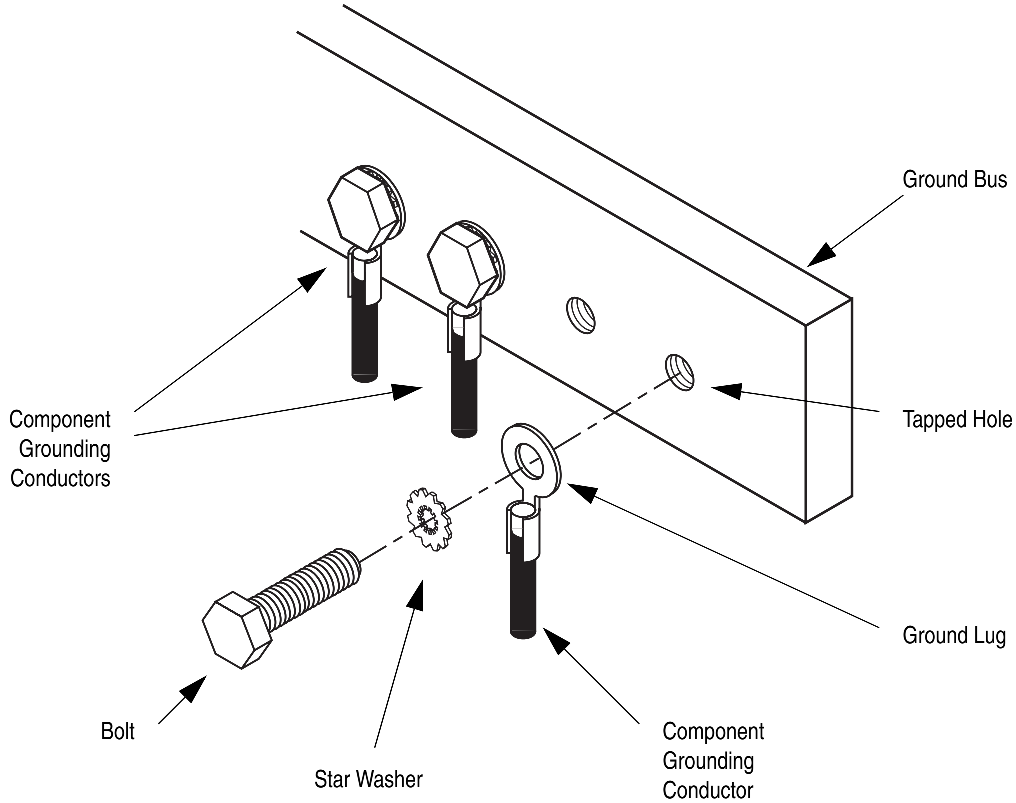
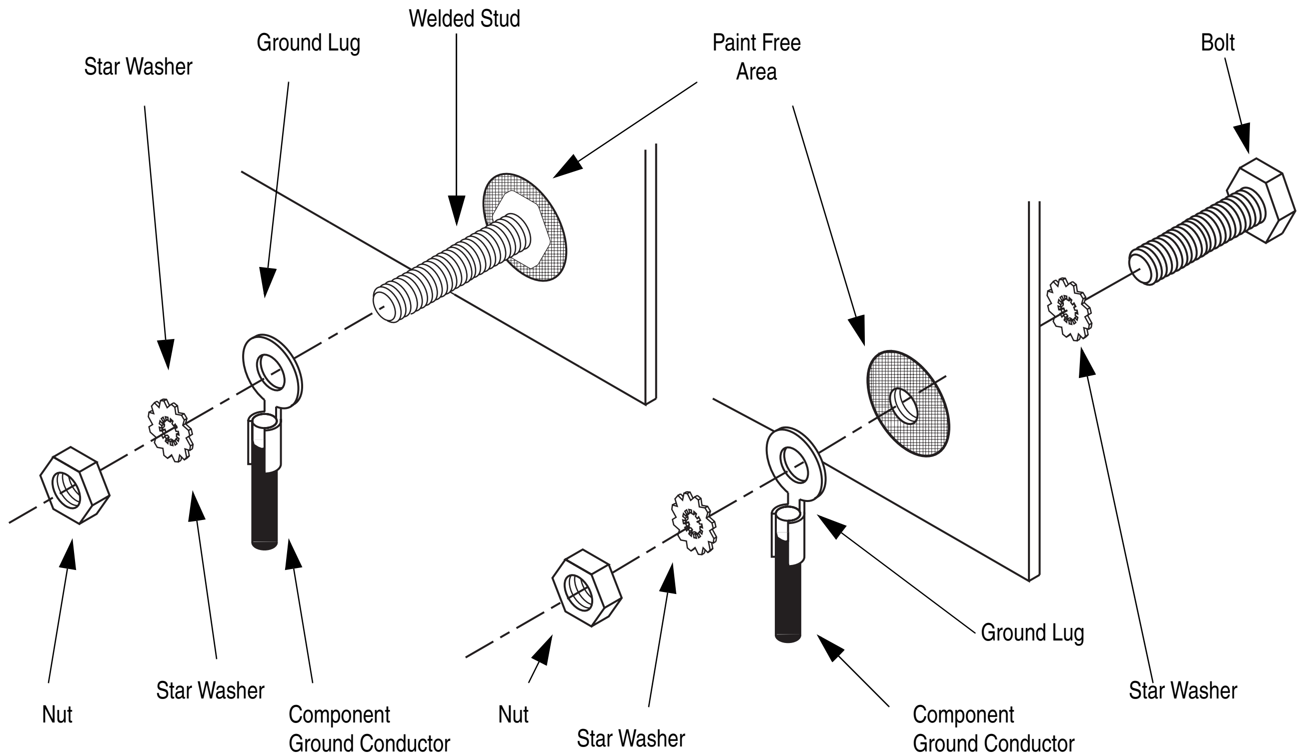
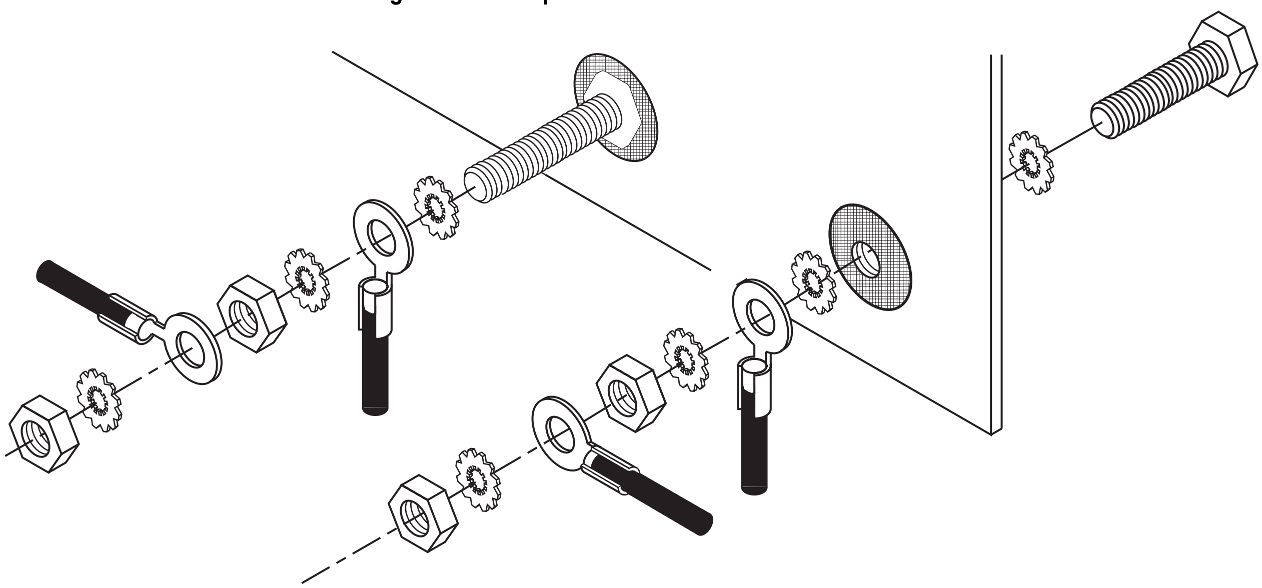


Figure 4.7 Ground Connections to Enclosure Wall



Do not lay one ground lug directly on top of the other. This type of connection can become loose due to compression of the metal lugs. Sandwich the first lug between a star washer and a nut with another star washer following. After tightening the nut, sandwich the second lug between the first nut and a second nut with a captive star washer.

Figure 4.8 Multiple Connections to Ground Stud or Bolts



Wire Routing

General

When routing wiring to a drive, separate high voltage power and motor leads from I/O and signal leads. To maintain separate routes, route these in separate conduit or use tray dividers.

Table 4.A Cable and Wiring Recommendations

Category	Wiring Level	Signal Definition	Signal Examples	Minimum Spacing (in inches) between Levels in Steel Conduits (Cable Trays)					Spacing Notes
				1	2/3/4	5/6	7/8	9/10/11	
Power	1	AC Power (600V or greater)	2.3kV 3-Ph AC Lines	0	3 (9)	3 (9)	3 (18)	Refer to Spacing Note 6	Refer to Spacing Notes 1, 2 and 5
	2	AC Power (less than 600V)	460V 3-Ph AC Lines	3 (9)	0	3 (6)	3 (12)	Refer to Spacing Note 6	Refer to Spacing Notes 1, 2 and 5
	3	AC Power	AC Motor						
	4	Dynamic Brake Cables	Refer to Spacing Note 7						
Control	5	115V ac/dc Logic	Relay Logic/PLC I/O Motor Thermostat	3 (9)	3 (6)	0	3 (9)	Refer to Spacing Note 6	Refer to Spacing Notes 1, 2 and 5
		115V ac Power	Power Supplies, Instruments						
	6	24V ac/dc Logic	PLC I/O						
Signal (Process)	7	Analog Signals, DC Supplies	Reference/Feedback Signal, 5 to 24V DC	3 (18)	3 (12)	3 (9)	0	1 (3)	Refer to Spacing Notes 2, 3, 4 and 5
		Digital (Low Speed)	TTK						
	8	Digital (High Speed)	I/O, Encoder, Counter Pulse Tach						
Signal (Comm)	9	Serial Communication	RS-232, 422 to Terminals/Printers	Refer to Spacing Note 6			1 (3)	0	
	11	Serial Communication (greater than 20k total)	ControlNet, DeviceNet, Remote I/O, Data Highway						

Example: Spacing relationship between 480V ac incoming power leads and 24V dc logic leads.

- 480V ac leads are Level 2; 24V dc leads are Level 6.
- For separate steel conduits, the conduits must be 3 inches (76 mm apart).
- In a cable tray, the two groups of leads must be 6 inches (152 mm) apart.

Spacing Notes:

1. Both outgoing and return current carrying conductors are pulled in the same conduit or laid adjacent in tray.
2. The following cable levels can be grouped together:

   A.Level 1: Equal to or above 601V.

   B.Levels 2, 3, & 4 may have respective circuits pulled in the same conduit or layered in the same tray.

   C.Levels 5 & 6 may have respective circuits pulled in the same conduit or layered in the same tray. **Note**: Bundle may not exceed conditions of NEC 310.

   D.Levels 7 & 8 may have respective circuits pulled in the same conduit or layered in the same tray. **Note**: Encoder cables run in a bundle may experience some amount of EMI coupling. The circuit application may dictate separate spacing.

   E.Levels 9, 10 & 11 may have respective circuits pulled in the same conduit or layered in the same tray. **Note**: Communication cables run in a bundle may experience some amount of EMI coupling and corresponding communication faults. The application may dictate separate spacing.
3. Level 7 through Level 11 wires must be shielded per recommendations.
4. In cable trays, steel separators are advisable between the class groupings.
5. If conduit is used, it must be continuous and composed of magnetic steel.
6. Spacing of Communication cables Levels 2 through 6 is the following:

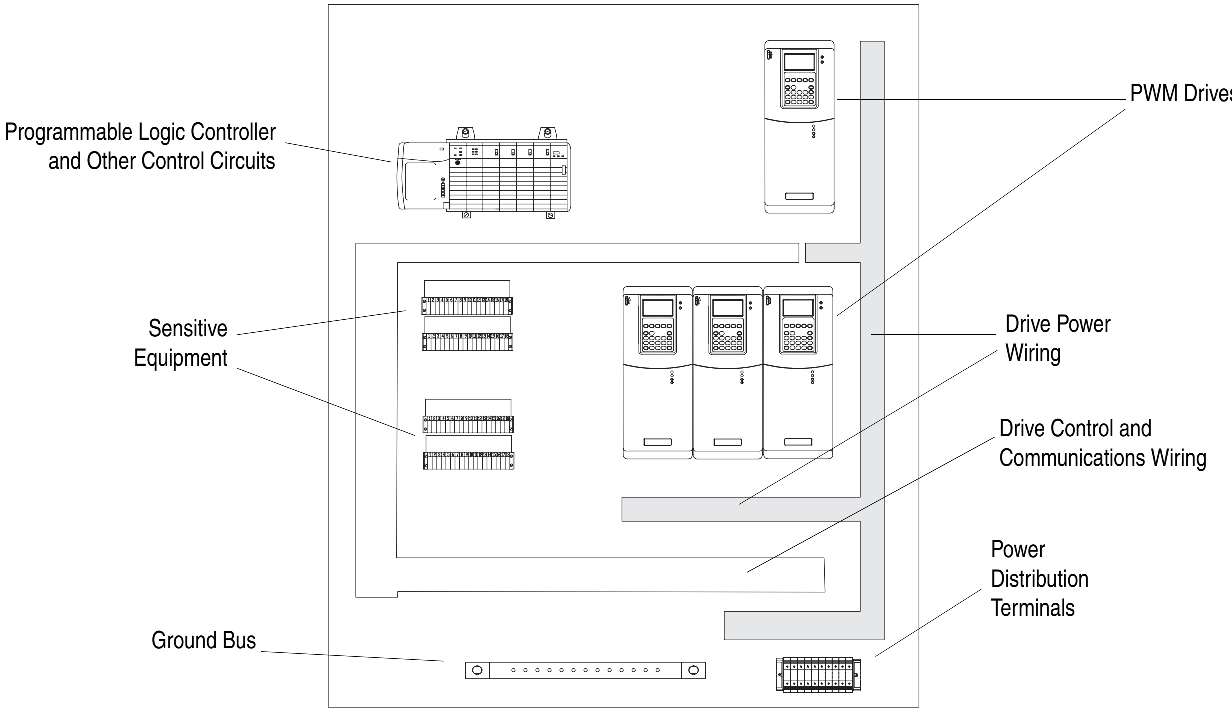
Conduit Spacing	Through Air Spacing
115V = 1 inch	115V = 2 inches
230V = 1.5 inches	230V = 4 inches
460/575V = 3 inches	460/575V = 8 inches
575 volts = proportional to 6 inches Per 1000V	575V proportional to 12 inches Per 1000V

7. If more than one brake module is required, the first module must be mounted within 3.0 m (10 ft.) of the drive. Each remaining brake module can be a maximum distance of 1.5 m (5 ft.) from the previous module. Resistors must be located within 30 m (100 ft.) of the chopper module.

Within A Cabinet

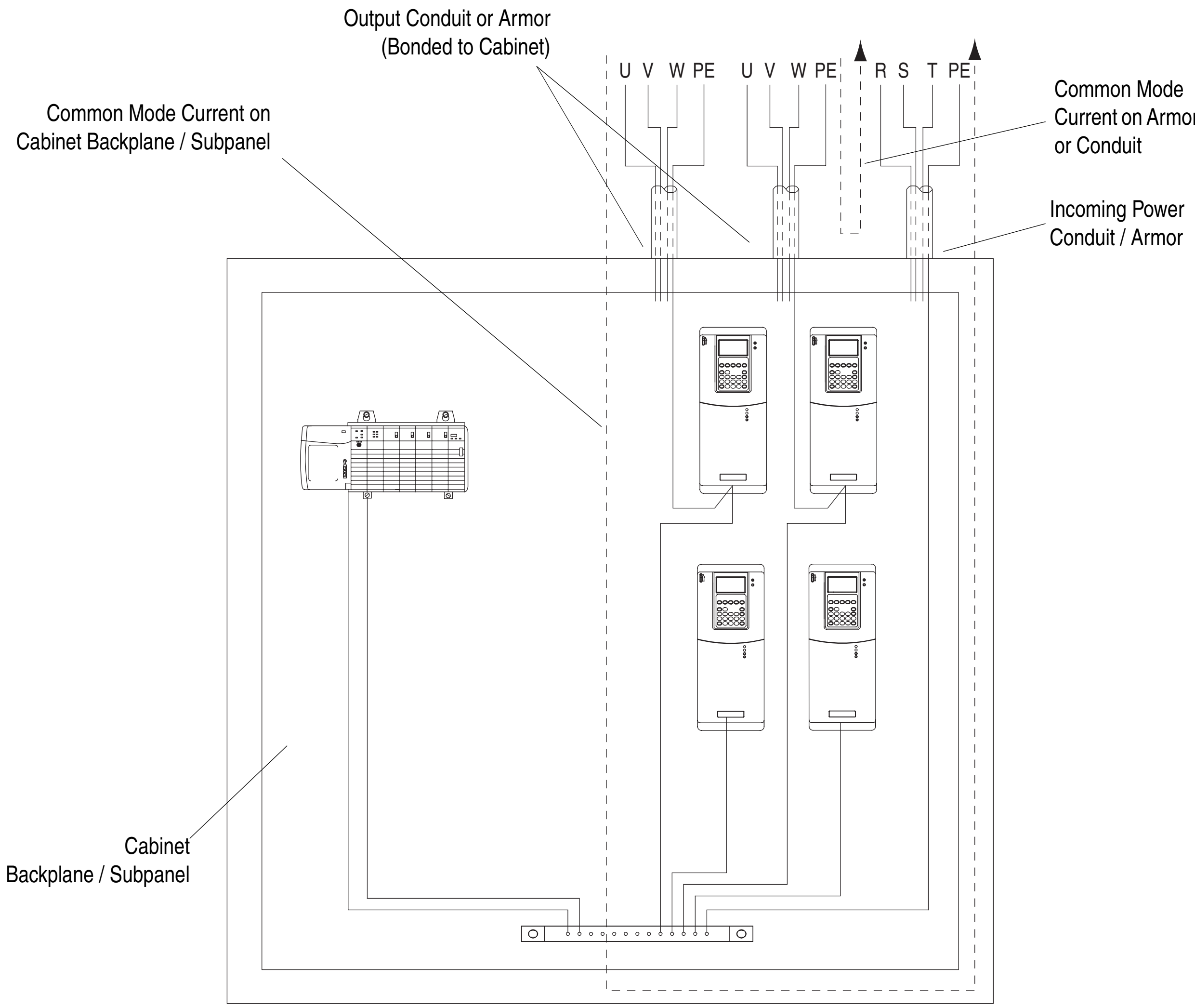
When multiple equipment is mounted in a common enclosure, group the input and output conduit/armor to one side of the cabinet as shown in Separating Susceptible Circuits on page 4-11. Separating any Programmable Logic Controller (PLC) or other susceptible equipment cabling to the opposite side will minimize many effects of drive induced noise currents.

Figure 4.9 Separating Susceptible Circuits



Common mode noise current returning on the output conduit, shielding or armor can flow into the cabinet bond and most likely exit through the adjacent input conduit/armor bond near the cabinet top, well away from sensitive equipment (such as the PLC). Common mode current on the return ground wire from the motor will flow to the copper PE bus and back up the input PE ground wire, also away from sensitive equipment (Refer to Proper Cabinet Ground - Drives & Susceptible Equipment on page 4-12). If a cabinet PE ground wire is run it should be connected from the same side of the cabinet as the conduit/armor connections. This keeps the common mode noise shunted away from the PLC backplane.

Figure 4.10 Proper Cabinet Ground - Drives & Susceptible Equipment



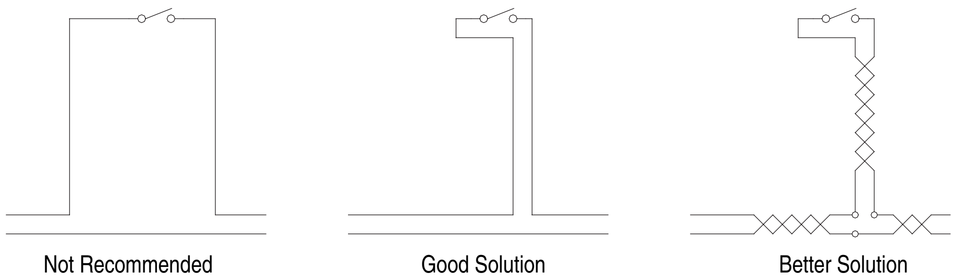
Within Conduit

Do not route more than 3 sets of motor leads (3 drives) in the same conduit. Maintain fill rates per applicable electrical codes. **Do not** run power or motor cables and control or communications cables in the same conduit. If possible, avoid running incoming power leads and motor leads in the same conduit for long runs.

Loops, Antennas and Noise

When routing signal or communications wires, avoid routes that produce loops. Wires that form a loop can form an efficient antenna. Antennas work well in both receive and transmit modes, these loops can be responsible for noise received into the system and noise radiated from the system. Run feed and return wires together rather than allow a loop to form. Twisting the pair together further reduces the antenna effects. Refer to Avoiding Loops in Wiring on page 4-13.

Figure 4.11 Avoiding Loops in Wiring



Conduit

Magnetic steel conduit is preferred. This type of conduit provides the best magnetic shielding. However not all applications allow the use of magnetic steel conduit. Stainless steel or PVC may be required. Conduit other than magnetic steel will not provide the same level of shielding for magnetic fields induced by the motor and input power currents.

Conduit must be installed so as to provide a continuous electrical path through the conduit itself. This path can become important in the containment of high frequency noise.

To avoid nicking, use caution when pulling the wire. Insulation damage can occur when nylon coated wiring such as THHN or THWN is pulled through conduit, particularly 90º bends. Nicking can significantly reduce or remove the insulation. Use great care when pulling nylon coated. Do not use water based lubricants with nylon coated wire such as THHN.

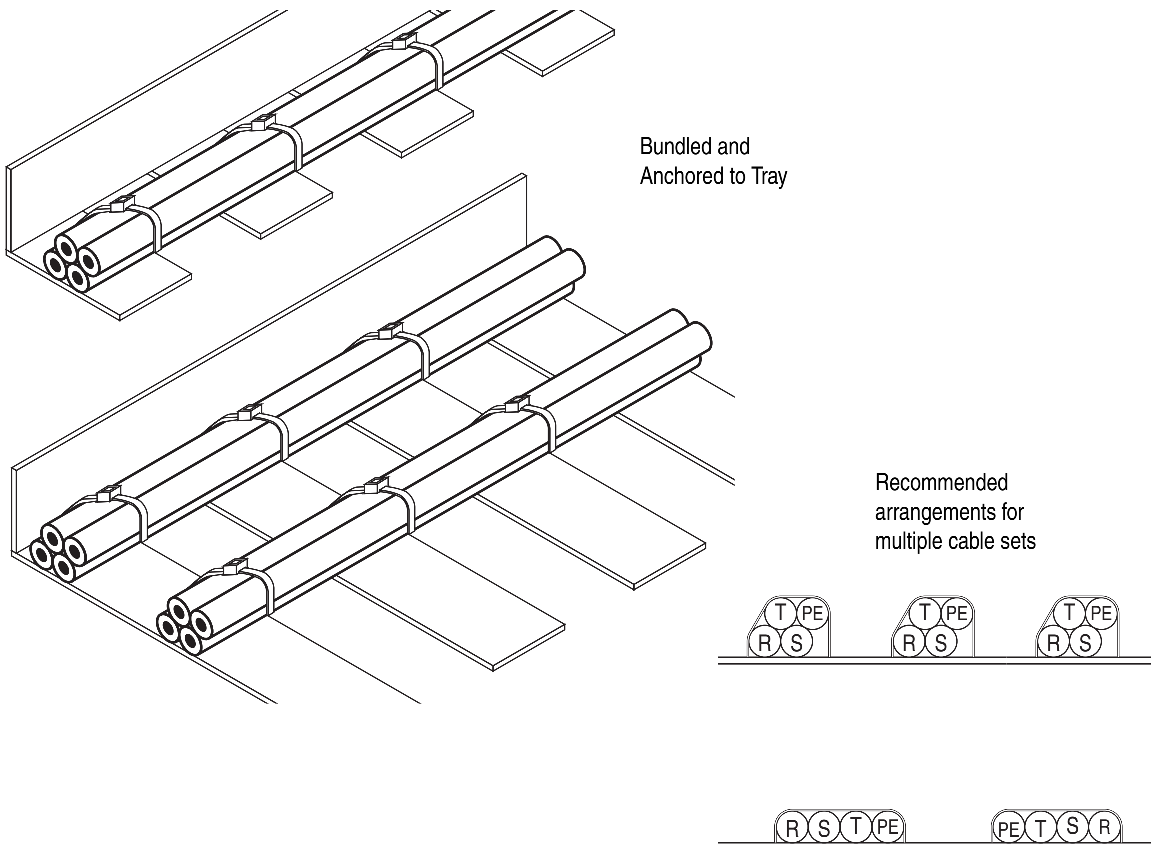
Do not route more than 3 sets of motor cables in one conduit. Maintain the proper fill rates per the applicable electrical codes.

Do not rely on the conduit as the ground return for a short circuit. Route a separate ground wire inside the conduit with the motor or input power wires.

Cable Trays

When laying cable in cable trays, do not randomly distribute them. Power cables for each drive should be bundled together and anchored to the tray. A minimum separation of one cable width should be maintained between bundles to reduce overheating and cross-coupling. Current flowing in one set of cables can induce a hazardous voltage and / or excessive noise on the cable set of another drive, even when no power is applied to the second drive.

Figure 4.12 Recommended Cable Tray Practices



Carefully arrange the geometry of multiple cable sets. Keep conductors within each group bundled. Arrange the order of the conductors to minimize the current which induced between sets and to balance the currents. This is critical on drives with power ratings of 200 hp (150 kW) and higher.

Maintain separation between power and control cables. When laying out cable tray for large drives make sure that cable tray or conduit containing signal wiring is separated from the conduit or trays containing power or motor wiring by 3 feet or more. Electromagnetic fields from power or motor currents can induce currents in the signal cables. Dividers also provide excellent separation.

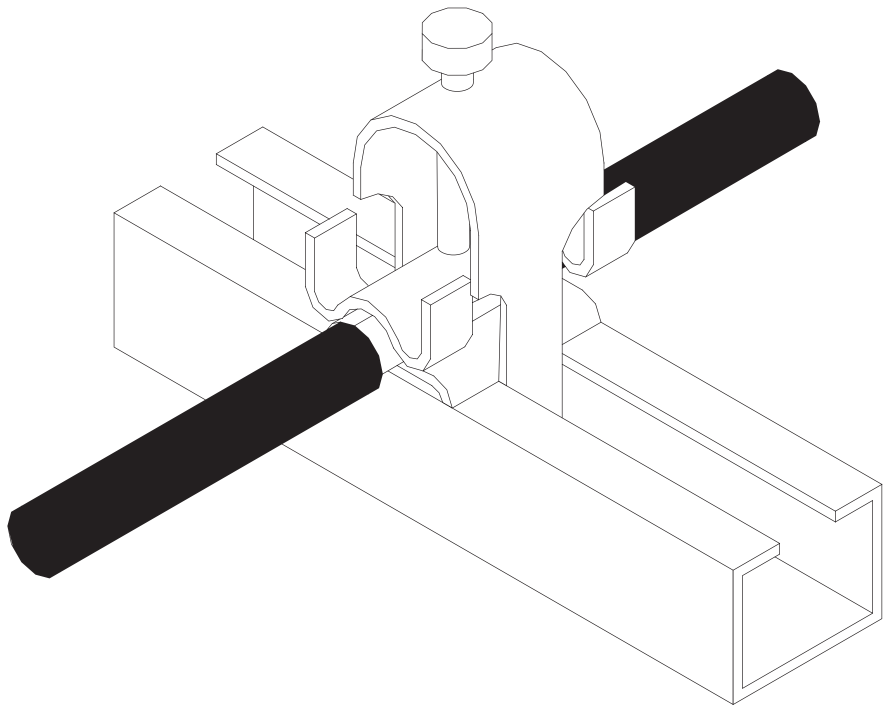
Shield Termination

Refer to Shield Splicing on page 3-7 to splice shielded cables. The following methods are acceptable if the shield connection to the ground is not accomplished by the gland or connector. Refer to the table associated with each type of clamp for advantages and disadvantages.

Termination via circular clamp

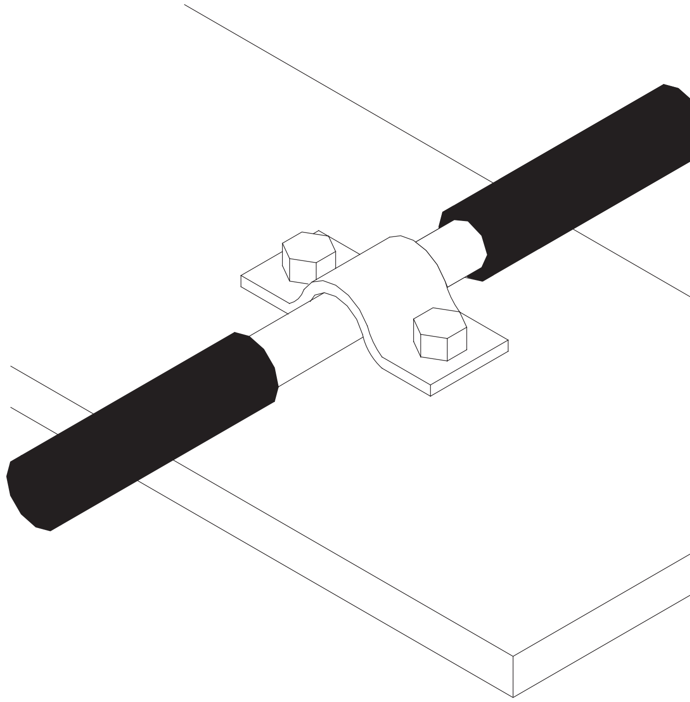
Clamp the cable to the main panel closest to the shield terminal using the circular section clamping method. The preferred method for grounding cable shields is clamping the circular section of 360º bonding, as shown in Commercial Cable Clamp (Heavy Duty) on page 4-15. It has the advantage of covering a wide variety of cable diameters and drilling / mounting is not required. Its disadvantages are cost and availability in all areas.

Figure 4.13 Commercial Cable Clamp (Heavy Duty)



Plain copper saddle clamps, as shown in Figure 4.14 on page 4-16, are sold in many areas for plumbing purposes, but are very effective and available in a range of sizes. They are low cost and offer good strain relief as well. You must drill mounting holes to use them.

Figure 4.14 Plain Copper Saddle Clamp



Shield Termination via Pigtail (Lead)

If a shield terminating connector is not available, the ground conductors and/or shields must be terminated to the appropriate ground terminal. If necessary, use a compression fitting on the ground conductor(s) or shield together as they leave the cable fitting.

Pigtail termination is the least effective method of noise containment.

It is not recommended if:

- the cable length is greater than 1 m (39 in.) or extends beyond the panel.
- being used in very noisy areas
- the cables are for very noise sensitive signals (for example, registration or encoder cables)
- strain relief is required

If a pigtail is used, pull and twist the exposed shield after separation from the conductors. To extend the length, solder a flying lead to the braid.

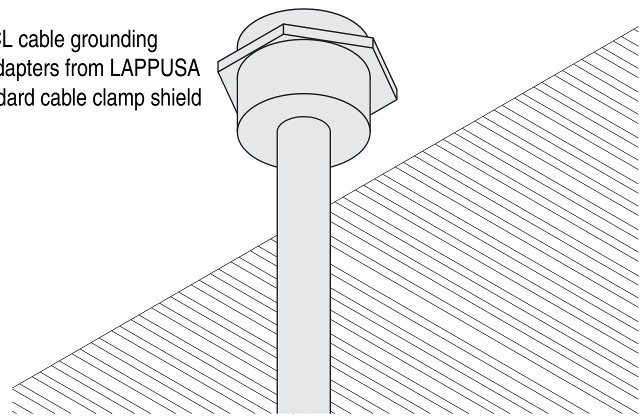
Shield Termination via Cable Clamp

Standard Cable

Grounding Cable glands are a simple and effective method for terminating shields while offering excellent strain relief. They are only applicable when entry is through a cabinet surface or bulkhead.

The cable connector selected must provide good 360^{o} contact and low transfer impedance from the shield or armor of the cable to the conduit entry plate at both the motor and the drive or drive cabinet for electrical bonding.

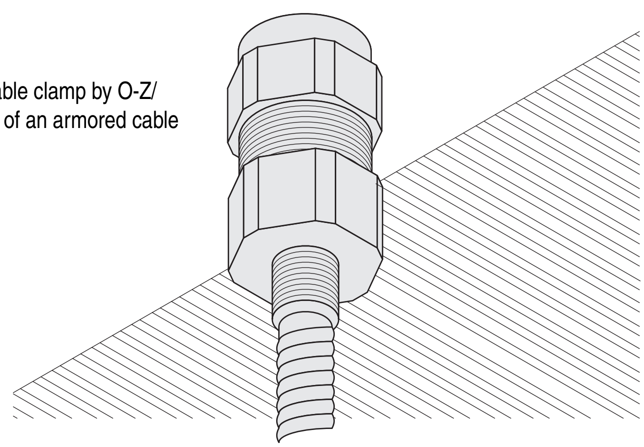
SKINTOP® MS-SC/MS-SCL cable grounding connectors and NPT/PG adapters from LAPPUSA are good examples of standard cable clamp shield terminating gland.



Armored Cable

Armored cable can be terminated in a similar manner to standard cable.

The Tek-Mate™ Fast-Fit cable clamp by O-Z/Gedney is a good example of an armored cable terminator.



Conductor Termination

Terminate power, motor and control connections to the drive terminal blocks. User manuals list minimum and maximum wire gauges, tightening torque for terminals and recommended lug types if stud connections are provided. Use a connector with 3 ground bushings when using a cable with 3 ground conductors. Bending radii minimums per the applicable electrical code should be followed.

Power TB

Power terminals are normally fixed (non-pull apart) and can be cage clamps, barrier strips or studs for ring type crimp lugs depending on the drive style and rating. Cage clamp styles may require a non-standard screwdriver. Crimp lugs will require a crimping tool. On smaller sizes, a stripping gauge may be provided on the drive to assist in the amount of insulation to remove. Normally the three phase input is not phase sensitive. That is, the sequence of A,B,C phases has no effect on the operation of the drive or the direction of motor rotation.

Control TB

Control terminal blocks are either pull apart or fixed (non pull apart). Terminals will be either spring clamp type or barrier strip. A stripping gauge may be provided on the drive to assist in the amount of insulation to remove. Some control connections, such as analog input and output signals, are polarity sensitive. Consult the applicable user manual for correct connection.

Signal TB

If an encoder or tachometer feedback is used, a separate terminal block or blocks may be provided. Consult the user manual for these phase sensitive connections. Improper wiring could lead to incorrect drive operation.

Cables terminated here are typically shielded and the signals being carried are generally more sensitive to noise. Carefully check the user manual for recommendations on shield termination. Some shields can be terminated at the terminal block and others will be terminated at the entry point.

Moisture

Refer to NEC Article 100 for definitions of Damp, Dry and Wet locations. The U.S. NEC permits the use of heat-resistant thermoplastic wire in both dry and damp applications (Table 310-13). However, PVC insulation material is more susceptible to absorbing moisture than XLPE (Cross Linked polyethylene) insulation material (XHHW-2) identified for use in wet locations. Because the PVC insulating material absorbs moisture, the corona inception voltage (CIV) insulation capability of the “damp” or “wet” THHN was found to be less than ½ of the same wire when “dry.” For this reason, certain industries where water is prevalent in the environment have refrained from using THHN wire with IGBT drives.

Belden 29500 style cable is a PVC jacketed, shielded type TC with XLPE conductor insulation designed to meet NEC code designation XHHW-2 (use in wet locations per the U.S. NEC, Table 310-13). Based on Rockwell Automation research, tests have determined this cable is notably superior to loose wires in dry, damp and wet applications and can significantly reduce capacitive coupling and common mode noise. Other cable types for wet locations include continuous welded armor cables or CLX designation.

Notes:

Reflected Wave

This chapter discusses the reflected wave phenomenon and its impact on drive systems.

Description

The inverter section of a drive does not produce sinusoidal voltage, but rather a series of voltage pulses created from the DC bus. These pulses travel down the motor cables to the motor. The pulses are then reflected back to the drive. The reflection is dependent on the rise time of the drive output voltage, cable characteristics, cable length and motor impedance. If the voltage reflection is combined with another, subsequent pulse, peak voltages can be at a destructive level. A single IGBT drive output may have reflected wave transient voltage stresses of up to twice (2 pu or per unit) the DC bus voltage between its own output wires. Multiple drive output wires in a single conduit or wire tray further increase output wire voltage stress between multi-drive output wires that are touching. Drive #1 may have a (+) 2 pu stress while drive #2 may simultaneously have a (-) 2 pu stress.

Effects On Wire Types

Wires with dielectric constants greater than 4 cause the voltage stress to shift to the air gap between the wires that are barely touching. This electric field may be high enough to ionize the air surrounding the wire insulation and cause a partial discharge mechanism (corona) to occur. The electric field distribution between wires increases the possibility for corona and greater ozone production. This ozone attacks the PVC insulation and produces carbon tracking, leading to the possibility of insulation breakdown.

Based on field and internal testing, Rockwell Automation has determined conductors manufactured with Poly-Vinyl Chloride (PVC) wire insulation are subject to a variety of manufacturing inconsistencies which can lead to premature insulation degradation when used with IGBT drives. Flame-retardant heat-resistant thermoplastic insulation is the type of insulation listed in the NEC code for the THHN wire designation. This type of insulation is commonly referred to as PVC. In addition to manufacturing inconsistencies, the physical properties of the cable can change due to environment, installation and operation, which can also lead to premature insulation degradation. The following is a summary of our findings:

Due to inconsistencies in manufacturing processes or wire pulling, air voids can also occur in the THHN wire between the nylon jacket and PVC insulation. Because the dielectric constant of air is much lower than the dielectric constant of the insulating material, the transient reflected wave voltage might appear across these voids. If the corona inception voltage

(CIV) for the air void is reached, ozone is produced. Ozone attacks the PVC insulation leading to a breakdown in cable insulation.

Asymmetrical construction of the insulation has also been observed for some manufacturers of PVC wire. A wire with a 15 mil specification was observed to have an insulation thickness of 10 mil at some points. The smaller the insulation thickness, the less voltage the wire can withstand.

THHN jacket material has a relatively brittle nylon that lends itself to damage (i.e. nicks and cuts) when pulled through conduit on long wire runs. This issue is of even greater concern when the wire is being pulled through multiple 90º bends in the conduit. These nicks may be a starting point for CIV leading to insulation degradation.

During operation, the conductor heats up and a “coldflow” condition may occur with PVC insulation at points where the unsupported weight of the wire may stretch the insulation. This has been observed at 90º bends where wire is dropped down to equipment from an above wireway. This “coldflow” condition produces thin spots in the insulation which lowers the cable's voltage withstand capability.

Refer to NEC Article 100 for definitions of Damp, Dry and Wet locations. The U.S. NEC permits the use of heat-resistant thermoplastic wire in both dry and damp applications (Table 310-13). However, PVC insulation material is more susceptible to absorbing moisture than XLPE (Cross Linked polyethylene) insulation material (XHHN-2) identified for use in wet locations. Because the PVC insulating material absorbs moisture, the Corona Inception Voltage insulation capability of the “damp” or “wet” THHN was found to be less than ½ of the same wire when “dry.” For this reason, certain industries where water is prevalent in the environment have refrained from using THHN wire with IGBT drives. Rockwell Automation strongly suggests the use of XLPE insulation for wet areas.

Length Restrictions For Motor Protection

To protect the motor from reflected waves, limit the length of the motor cables from the drive to the motor. Each drive's user manual lists the lead length limitations based on drive size and the quality of the insulation system in the chosen motor.

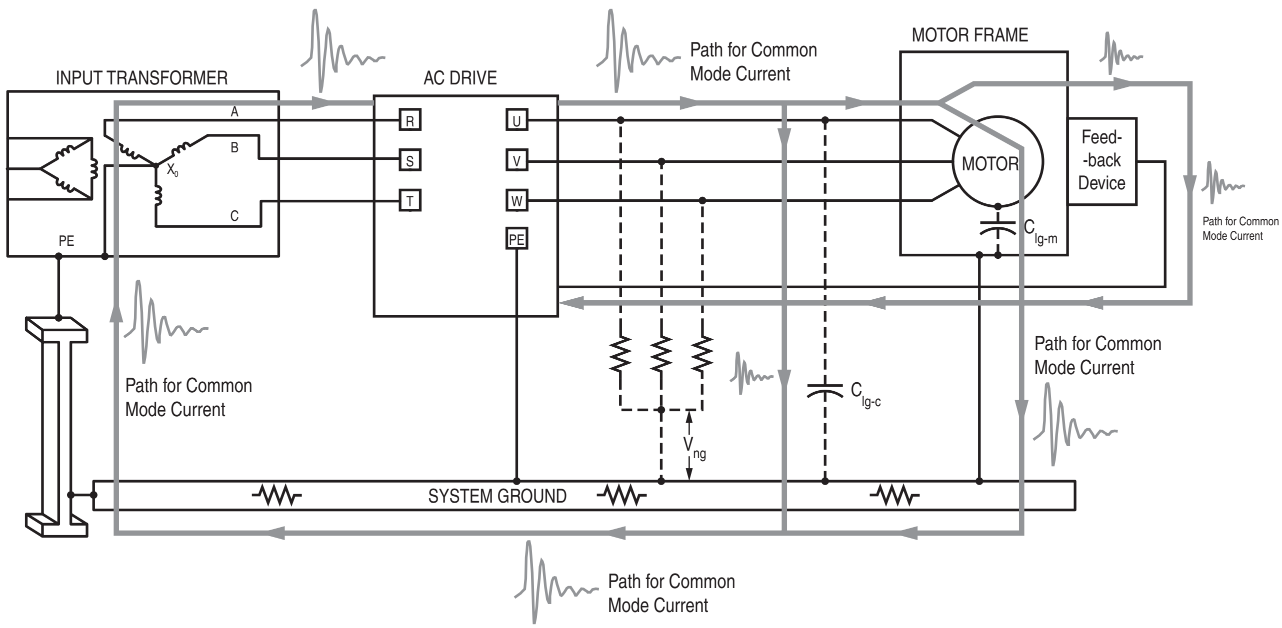
If the distance between drive and motor must exceed these limits, contact the local office or factory for analysis and advice. Refer to Appendix A for complete tables.

Electromagnetic Interference

This chapter discusses types of electromagnetic interference and its impact on drive systems.

What Causes Common Mode Noise

Faster output dv/dt transitions of IGBT drives increase the possibility for increased Common Mode (CM) electrical noise. Common Mode Noise is a type of electrical noise induced on signals with respect to ground.



There is a possibility for electrical noise from drive operation to interfere with adjacent sensitive electronic equipment, especially in areas where many drives are concentrated. Generating common mode currents by varying frequency inverters is similar to the common mode currents that occur with DC drives. Although AC drives produce a much higher frequency then DC drives (250 kHz - 6MHz). Inverters have a greater potential for exciting circuit resonance because of very fast turn on switches causing common mode currents to look for the lowest impedance path back to the inverter. The dv/dt and di/dt from the circulating ground currents can couple into the signal and logic circuits, causing improper operation and possible circuit damage. When conventional grounding techniques do not work you must use high frequency bonding techniques. If installers do not use these techniques, motor bearing currents increase and system circuit boards have the potential to fail prematurely. Currents in the ground system may cause problems with computer systems and distributed control systems.

Containing Common Mode Noise With Cabling

Cable type has a great effect on the ability to contain common mode noise in a system that incorporates a drive.

Conduit

The combination of a ground conductor and conduit contains most capacitive current and returns it to the drive without polluting the ground grid. A conduit may still have unintended contact with grid ground structure due to straps, support, etc. The AC resistance characteristics of earth are generally variable and unpredictable, making it difficult to predict how noise current will divide between wire, conduit or the ground grid.

Shielded or Armored Power Cable

The predominant return path for common mode noise is the shield/armor itself when using shielded or armored power cables. Unlike conduit, the shield/armor is isolated from accidental contact with grounds by a PVC outer coating. Making the majority of noise current flow in the controlled path and very little high frequency noise flows into the ground grid.

Noise current returning on the shield or safety ground wire is routed to the drive PE terminal, down to the cabinet PE ground bus, and then directly to the grounded neutral of the drive source transformer. Take care when bonding the armor or shield to the drive PE. A low impedance cable or strap is recommended when making this connection, as opposed to the smaller gauge ground wire either supplied as part of the motor cable or supplied separately. Otherwise, the higher frequencies associated with the common mode noise will find this cable impedance higher and look for a lower impedance path. The cable’s radiated emissions are minimal because the armor completely covers the noisy power wires. Also, the armor prevents EMI coupling to other signal cables that might be routed in the same cable tray.

Another effective method of reducing common mode noise is to attenuate it before it can reach the ground grid. Installing a common mode ferrite core on the output cables can reduce the amplitude of the noise to a level that makes it relatively harmless to sensitive equipment or circuits. Common mode cores are most effective when multiple drives are located in a relatively small area. For more information see the *1321-M Common Mode Chokes Instructions*, publication 1321-5.0.

As a general rule:

IF the distance between the drive and motor or the distance between drive and input transformer is greater than 75 feet.

AND

IF sensitive circuits with leads greater then 75 feet such as: encoders, analog, or capacitive sensors are routed, in or out of the cabinet, near the drive or transformer

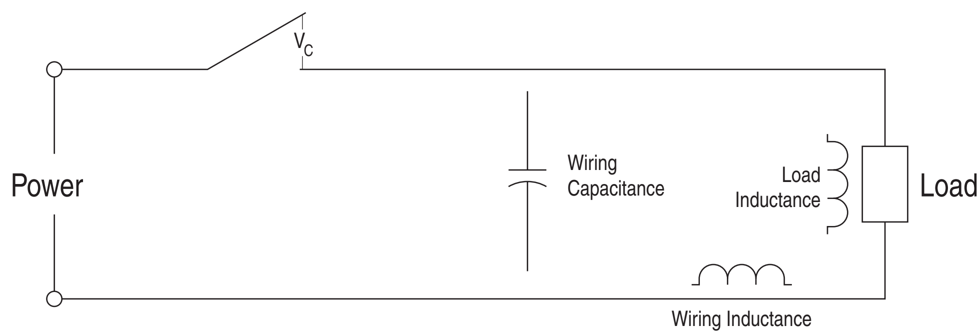
THEN

Common mode chokes should be installed.

How Electromechanical Switches Cause Transient Interference

Electromechanical contacts cause transient interference when switching inductive loads such as relays, solenoids, motor starters, or motors. Drives, as well as other devices having electronic logic circuits, are susceptible to this type of interference.

Examine the following circuit model for a switch controlling an inductive load. Both the load and the wiring have inductance, which prevents the current from stopping instantly when the switch contacts open. There is also stray capacitance in the wiring.

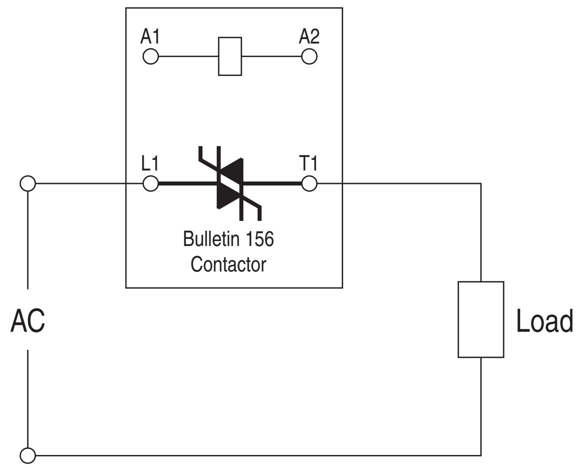


Interference occurs when the switch opens while it is carrying current. Load and cable inductance prevents the current from immediately stopping. The current continues to flow, and charges the capacitance in the circuit. The voltage across the switch contacts (VC) rises, as the capacitance charges. This voltage can reach very high levels. When the voltage exceeds the breakdown voltage for the space between the contacts, an arc occurs and the voltage returns to zero. Charging and arcing continues until the distance between the contacts is sufficient to provide insulation. The arcing radiates noise at an energy levels and frequencies that disturb logic and communication circuits.

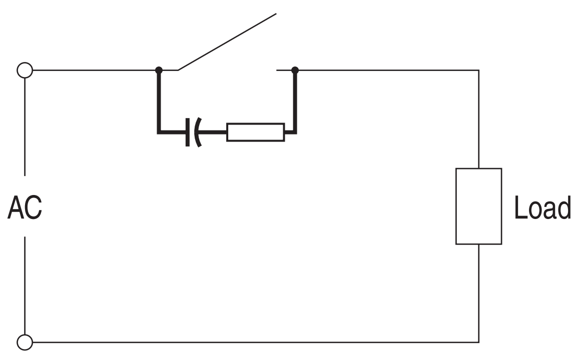
If the power source is periodic (like AC power), you can reduce the interference by opening the contact when the current waveform crosses zero. Opening the circuit farther from zero elevates the energy level and creates more interference.

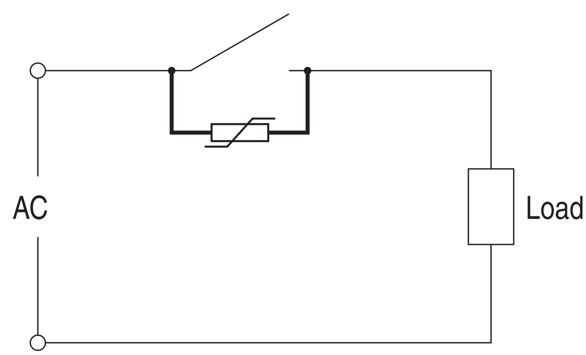
How to Prevent or Mitigate Transient Interference from Electromechanical Switches

The most effective way to avoid this type of transient interference, is to use a device like an Allen-Bradley Bulletin 156 contactor to switch inductive AC loads. These devices feature “zero cross” switching.

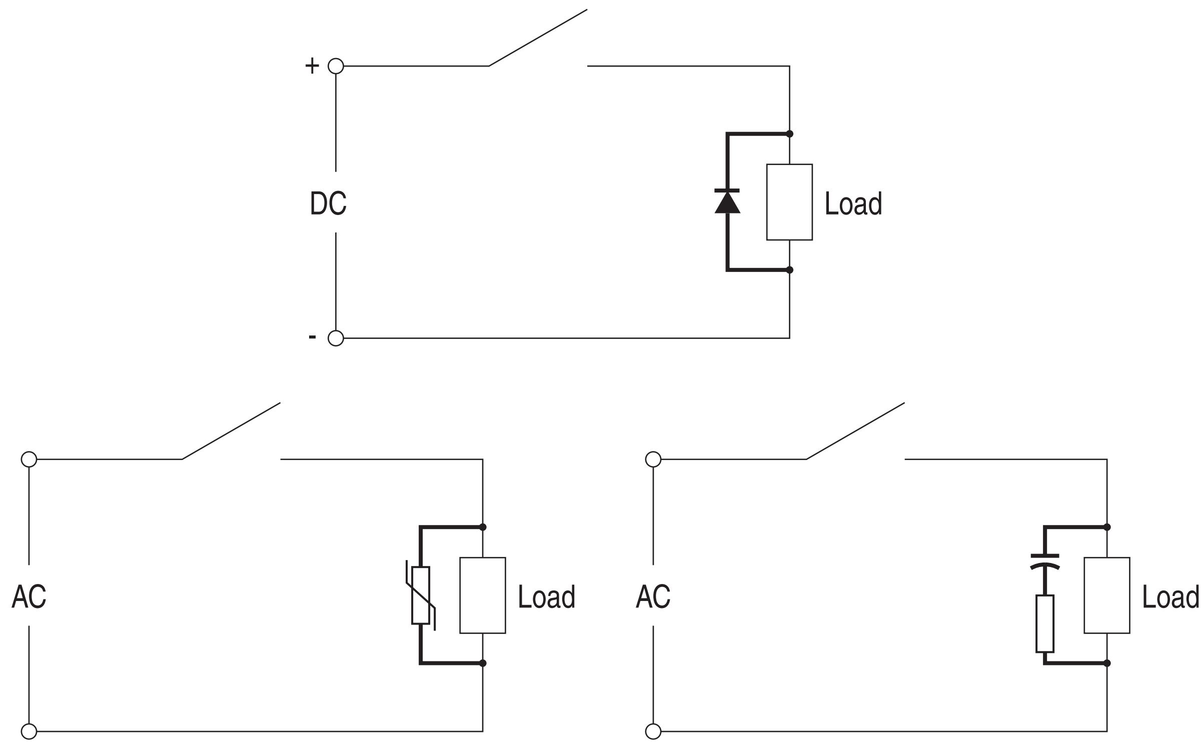


Putting Resistive-Capacitive (RC) networks or Voltage Dependant Resistors (Varistors) across contacts will mitigate transient interference. Make sure to select components rated to withstand the voltage, power and frequency of switching for your application.

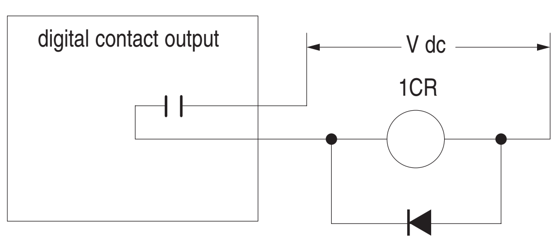




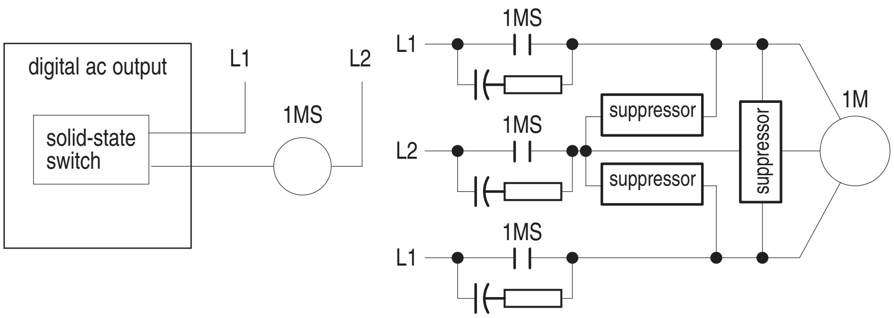
A common method for mitigating transient interference is to put a diode in parallel with an inductive DC load or a suppressor in parallel with an inductive AC load. Again, make sure to select components rated to withstand the voltage, power and frequency of switching for your application. These methods are not totally effective, because they do not entirely eliminate arcing at the contacts.



The following table contains examples which illustrate methods for mitigating transient interference.

Examples of Transient Interference Mitigation	
	**Example 1:** A contact output controls a dc control relay. The relay coil requires a suppressor (blocking diode) because it is an inductive device controlled by a dry contact.

Examples of Transient Interference Mitigation

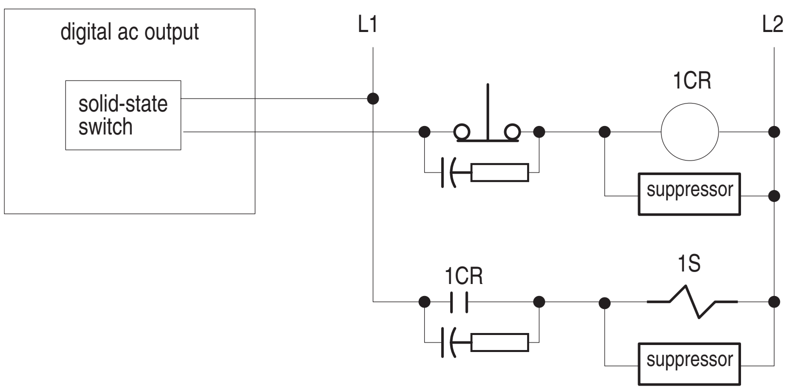


Example 2:
An ac output controls a motor starter, contacts on the starter control a motor.

The contacts require RC networks or Varistors.

The motor requires suppressors because it is an inductive device.

An inductive device controlled by a solid state switching device (like the starter coil in this example) typically does not require a suppressor.

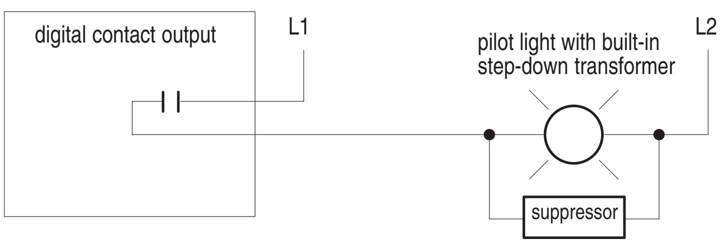


Example 3:
An ac output controls an interposing relay, but the circuit can be opened by dry contacts. Relay contacts control a solenoid coil.

The contacts require RC networks or Varistors.

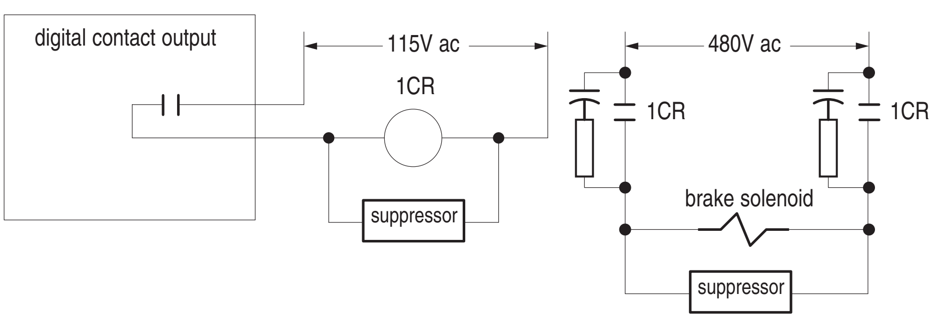
The relay coil requires a suppressor because it is an inductive device controlled by dry contacts.

The solenoid coil also requires a suppressor because it is an inductive device controlled by dry contacts.



Example 4:
A contact output controls a pilot light with a built in step-down transformer.

The pilot light requires a suppressor because its transformer is an inductive device controlled by a dry contact.



Example 5:
A contact output controls a relay, which controls a brake solenoid.

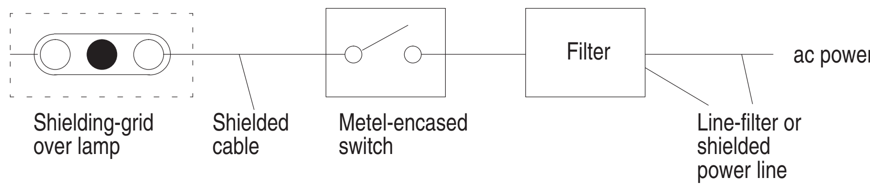
The contacts require RC networks or Varistors.

Both the relay and the brake solenoid require suppressors because they are both inductive devices controlled by dry contacts.

Enclosure Lighting

Fluorescent lamps are also sources of EMI. If you must use fluorescent lamps inside an enclosure, the following precautions may help guard against EMI problems from this source as shown in the figure below:

- install a shielding grid over the lamp
- use shielded cable between the lamp and its switch
- use a metal-encased switch
- install a filter between the switch and the power line, or shield the power-line cable



Notes:

Motor Cable Length Restrictions Tables

The distances listed in each table are valid only for specific cable constructions and may not be accurate for lesser cable designs, particularly if the length restriction is due to cable charging current (indicated in tables by shading). When choosing the proper cable, note the following definitions:

Unshielded Cable

- Tray cable - fixed geometry without foil or braided shield but including an exterior cover
- Individual wires not routed in metallic conduit

Definition Shielded Cable

- Individual conductors routed in metallic conduit
- Fixed geometry cables with foil or braided shield of at least 75% coverage
- Belden 295xx or Alcatel C1202 needed, as indicated by individual table for specific drive
- Continuous weld or interlocked armored cables with no twist in the conductors (may have and optional foil shield)

Important: Certain shielded cable constructions may cause excessive cable charging currents and may interfere with proper application performance, particularly on smaller drive ratings. Shielded cables that do not maintain a fixed geometry, but rather twist the conductors and tightly wrap the bundle with a foil shield may cause unnecessary drive tripping. Unless specifically stated in the table, the distances listed ARE NOT applicable to this type of cable. Actual distances for this cable type may be considerably less.

Type A Motor

- No phase paper or misplaced phase paper
- Lower quality insulation systems
- Corona inception voltages between 850 and 1000 volts

Type B Motor

- Properly placed phase paper
- Medium quality insulation systems
- Corona inception voltages between 1000 and 1200 volts

1488V Motor

- Meets NEMA MG 1-1998 section 31 standard
- Insulation can withstand voltage spikes of 3.1 times rated motor voltage due to inverter operation.

Reliance Electric Inverter Rated Motor

- Motor designed to meet or exceed the requirements of the Federal Energy Act of 1992.
- Optimized for variable speed operation and include premium inverter grade insulation systems, which meet or exceed NEMA MG1 (Part 31.40.4.2).

Table A.A VTAC 9 Drives, 480V, No External Devices - *Feet (Meters)*[1]

		Type A			Type B			1488V Motor			Reliance Electric Inverter Rated Motor		
HP	kHz	*Shld* [3]	*Shld* [2]	*Unshld*	*Shld* [3]	*Shld* [2]	*Unshld*	*Shld* [3]	*Shld* [2]	*Unshld*	*Shld* [3]	*Shld* [2]	*Unshld*
3 [4]	2		21.3 (70)	12.2 (40)		67.1 (220)	22.9 (75)		129.5 (425)	182.9 (600)		129.6 (425)	182.9 (600)
	4		21.3 (70)	12.2 (40)		67.1 (220)	22.9 (75)		121.9 (400)	158.5 (520)		121.9 (400)	182.9 (600)
	6		21.3 (70)	12.2 (40)		67.1 (220)	22.9 (75)		129.5 (425)	158.5 (520)		129.6 (425)	182.9 (600)
	8		21.3 (70)	12.2 (40)		67.1 (220)	22.9 (75)		121.9 (400)	115.8 (380)		121.9 (400)	176.8 (580)
	10		21.3 (70)	12.2 (40)		67.1 (220)	22.9 (75)		121.9 (400)	115.8 (380)		121.9 (400)	167.6 (550)
5 [4]	2		24.4 (80)	12.2 (40)		85.3 (280)	24.4 (80)		137.2 (450)	182.9 (600)		137.2 (450)	182.9 (600)
	4		24.4 (80)	12.2 (40)		85.3 (280)	24.4 (80)		121.9 (400)	182.9 (600)		121.9 (400)	182.9 (600)
	6		24.4 (80)	12.2 (40)		85.3 (280)	24.4 (80)		121.9 (400)	170.7 (560)		121.9 (400)	182.9 (600)
	8		24.4 (80)	12.2 (40)		85.3 (280)	24.4 (80)		91.4 (300)	121.9 (400)		91.4 (300)	182.9 (600)
	10		24.4 (80)	12.2 (40)		85.3 (280)	24.4 (80)		91.4 (300)	109.7 (360)		91.4 (300)	176.8 (580)
7.5 [4]	2		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	182.9 (600)		121.9 (400)	182.9 (600)
	4		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	182.9 (600)		121.9 (400)	182.9 (600)
	6		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	158.5 (520)		121.9 (400)	182.9 (600)
	8		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	121.9 (400)		121.9 (400)	170.7 (560)
	10		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		91.4 (300)	97.5 (320)		91.4 (300)	152.4 (500)
10 [4]	2		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	182.9 (600)		121.9 (400)	182.9 (600)
	4		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	182.9 (600)		121.9 (400)	182.9 (600)
	6	NA	15.2 (50)	12.2 (40)	NA	91.4 (300)	18.3 (60)	NA	121.9 (400)	170.7 (560)	NA	121.9 (400)	182.9 (600)
	8		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		121.9 (400)	134.1 (440)		121.9 (400)	170.7 (560)
	10		15.2 (50)	12.2 (40)		91.4 (300)	18.3 (60)		91.4 (300)	115.8 (380)		91.4 (300)	158.5 (520)
15	2		24.4 (80)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		24.4 (80)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		24.4 (80)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		24.4 (80)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	152.4 (500)		182.9 (600)	182.9 (600)
	10		24.4 (80)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	121.9 (400)		182.9 (600)	146.3 (480)
20	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
25	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)

Table A.A VTAC 9 Drives, 480V, No External Devices - *Feet (Meters)*❶

		Type A			**Type B**			**1488V Motor**			**Reliance Electric Inverter Rated Motor**		
HP	**kHz**	*Shld* ❸	*Shld* ❷	*Unshld*	*Shld* ❸	*Shld* ❷	*Unshld*	*Shld* ❸	*Shld* ❷	*Unshld*	*Shld* ❸	*Shld* ❷	*Unshld*
30	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
40	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
50	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
60	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6	NA	21.3 (70)	15.2 (50)	NA	61.0 (200)	24.4 (80)	NA	182.9 (600)	182.9 (600)	NA	182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
75	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	8		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	10		21.3 (70)	15.2 (50)		48.8 (160)	24.4 (80)		182.9 (600)	103.6 (340)		182.9 (600)	182.9 (600)
100	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		21.3 (70)	15.2 (50)		121.9 (400)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	6		21.3 (70)	15.2 (50)		61.0 (200)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
125	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		NA	NA		NA	NA		NA	NA		NA	NA
	6		NA	NA		NA	NA		NA	NA		NA	NA
150	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		NA	NA		NA	NA		NA	NA		NA	NA
200	2		21.3 (70)	15.2 (50)		182.9 (600)	24.4 (80)		182.9 (600)	182.9 (600)		182.9 (600)	182.9 (600)
	4		NA	NA		NA	NA		NA	NA		NA	NA

❶ You can extend cable lengths by installing reactors at the drive end or other reflected wave mitigation devices (RWRs or Terminators) at the motor end. Consult factory for recommendations.
❷ Cable is Alcatel C1202 or equivalent. Shielded cable with twisted conductors and no filler.
❸ Cable is Belden 295xx series or equivalent.
❹ Cable length restrictions at these ratings are partially attributed to cable charging current.
NR = Not Recommended
NA = Not Available at time of printing

Table A.B VTAC 9 Drives, 460V with Reactor - *Meters (Feet)*

		Type A Motor			Type B Motor			1488 Volt motor			Reliance Electric Inverter Rated Motor		
HP	**kHz**	*Shld* ❷	*Shld* ❶	*Unshld*	*Shld* ❷	*Shld* ❶	*Unshld*	*Shld* ❷	*Shld* ❶	*Unshld*	*Shld* ❷	*Shld* ❶	*Unshld*
3-20	2-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

❶ Cable is Alcatel C1202 or equivalent. Shielded cable with twisted conductors and no filler.
❷ Cable is Belden 295xx series or equivalent
NR = Not Recommended
NA = Not Available at time of printing

Table A.C VTAC 9 Drives, 460V with RWR or Eliminator - *Meters (Feet)*

<table>
<tr><th rowspan="2">HP</th><th rowspan="2">kHz</th><th colspan="3">Type A Motor</th><th colspan="3">Type B Motor</th><th colspan="3">1488 V Motor</th><th colspan="3">Reliance Electric Inverter Rated Motor</th></tr>
<tr><th>Shld ❷</th><th>Shld ❶</th><th>Unshld</th><th>Shld ❷</th><th>Shld ❶</th><th>Unshld</th><th>Shld ❷</th><th>Shld ❶</th><th>Unshld</th><th>Shld ❷</th><th>Shld ❶</th><th>Unshld</th></tr>
<tr><td rowspan="3">3</td><td>2</td><td rowspan="15">NA</td><td rowspan="15">NA</td><td>NA</td><td rowspan="15">NA</td><td rowspan="15">NA</td><td>NA</td><td colspan="3" rowspan="15">NA</td><td colspan="3" rowspan="15">NA</td></tr>
<tr><td>4</td><td>182.9 (600)</td><td>182.9 (600)</td></tr>
<tr><td>6-10</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">5</td><td>2</td><td>NA</td><td>NA</td></tr>
<tr><td>4</td><td>182.9 (600)</td><td>182.9 (600)</td></tr>
<tr><td>6-10</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">7.5</td><td>2</td><td>NA</td><td>NA</td></tr>
<tr><td>4</td><td>61.0 (200)</td><td>182.9 (600)</td></tr>
<tr><td>6-10</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="3">10</td><td>2</td><td>NA</td><td>NA</td></tr>
<tr><td>4</td><td>61.0 (200)</td><td>182.9 (600)</td></tr>
<tr><td>6-10</td><td rowspan="3">NA</td><td rowspan="3">NA</td></tr>
<tr><td>15</td><td>2-10</td></tr>
<tr><td>20</td><td>2-10</td></tr>
</table>

❶ Cable is Alcatel C1202 Or equivalent. Shielded cable with twisted conductors and no filler
❷ Cable is Belden 295xx series or equivalent
NR = Not Recommended
NA = Not Available at time of printing

Ambient Air

Air around any equipment cabinet.
See surrounding air for more detail.

Armored

A fixed geometry cable that has a protective "sheath" of continuous metal

Capacitive Coupling

Current or voltage that is induced on one circuit by another because of their close physical proximity. For drive installations it is generally seen in two areas:

1. Coupling between motor leads of two drives, such that the operating drive induces voltage onto the motor leads (and thus the motor) of a non-operating drive.

2. Coupling between the conductors /or shields of motor leads that creates a requirement for more current than the motor itself would demand.

CIV (Corona Inception Voltage)

The amplitude of voltage on a motor or other electrical winding that produces corona (ionization of air to ozone). CIV is increased by adding phase paper, placing windings in the proper pattern and reducing or eliminating air bubbles (voids) in the varnish applied.

Common Mode Core

A ferrite bead or core that can be used to pass control, communications or motor leads through to attenuate high frequency noise. Catalog Number/ Part Number 1321-Mxxx

Common Mode Noise

Electrical noise, typically high frequency, that is imposed on the ground grid, carriers in an electrical system

Conduit

Conductive ferrous electrical metal tubing used to contain and protect individual wires

Damp

Wet locations per U.S. NEC or local code

Discrete

Individual, hard-wired inputs or outputs, typically used for control of the drive (Start, Stop, etc.)

Dry

Dry locations per Per NEC Article 100 or local code

dv/dt

The rate of change of voltage over time

Fill Rates

The maximum number of conductors allowed in a conduit, as determined by local, state or national electrical code.

Fixed Geometry

Cable whose construction fixes the physical position of each conductor within the overall coating, usually with filler material that prevents individual conductors from moving.

IGBT

Insulated Gate Bi-Polar Transistor. The typical power semi conductor device used in most PWM AC drives today

mil

0.001 inches

MOV

Metal Oxide Varistor

NEC

United States National Electric Code NFPA70

Peak Cable Charging Current

The current required to charge capacitance in motor cable. This capacitance has various components:

- conductor to shield or conduit
- conductor to conductor
- motor stator to motor frame

PVC

Polyvinyl Chloride (typically thermoplastic)

RWR

Reflected Waver Reducer, an RL network mounted at or near the drive, used to reduce the amplitude and rise time of the reflected wave pulses. Cat No 1204-RWR2-09-B or 1204-RWR2-09-C

Shielded

Cable containing a foil or braided metal shield surrounding the conductors. Usually found in multi-conductor cable. Shield coverage should be at least 75%.

Signal

Individual hard wired analog inputs or outputs, typically used to issue reference commands or process information to or from the drive.

Surrounding Air Temperature

The temperature of the air around the drive. If the drive is free standing or wall mounted, the surrounding air temperature is room temperature. If the drive is mounted inside another cabinet, the surrounding air temperature is the interior temperature of that cabinet

Terminator

An RC network mounted at or near the motor, used to reduce the amplitude and rise time of the reflected wave pulses. Catalog Number 1204-TFxx

THHN / THWN

U.S. designations for individual conductor wire, typically 75º C or 90ºC rated and with PVC insulation and nylon coating.

Unshielded

Cable containing no braided or foil sheath surrounding the conductors. Can be multi-conductor cable or individual conductors.

Wet

Locations with moisture present - see Damp

XLPE

Cross Linked Polyethylene

UL

Underwriters Laboratories

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