Designing for EMC

Installation Guidelines
For Electromagnetic Compatibility

Revision 1.1

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Manual Revision History

Revision	Date	Description
1.0	Sep 20, 2002	Initial release
1.1	Apr 20, 2009	Added reference to latest EMC Directive revision 2004/108/EEC

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Prologue

This document is provided to help users install PMC's motion controllers so as to minimize the emission of electromagnetic interference (EMI) and maximize immunity to EMI generated by external devices and mechanisms.

CE Compliance – EMC Directive – 2004/108/EEC (formerly 89/336/EEC)

Components designed, manufactured and intended for incorporation into "apparatus" or a machines by professional manufacturers, installers or assemblers – components such as PMC motion controllers – are ***not*** required to be CE marked for the purposes of the EMC Directive (2004/108/EEC). However, the EMC Directive requires that relevant instructions for use must be provided by the component's manufacturer to help the manufacturer or assembler of the final apparatus solve foreseeable EMC problems within the final apparatus. This document is provided for this purpose.

Chapter

1

EMI Reduction

Motion control cards contain digital and microprocessor circuitry that because of their low-voltage and low-current characteristics can be adversely affected by electromagnetic interference (EMI). While these low-power circuits are very susceptible to EMI, because of their low power they generate very little EMI. Therefore, from the motion control card's perspective, the primary concern for properly wiring a machine should be placed on preventing noise from reaching it.

Once the motion control card has been placed inside a computer chassis, the amount of noise reaching the card should be minimal due to the metal shielding of the computer. However, any wire connected to the card will act as an antenna likely to capture unwanted signals if proper precautions are not taken. Although proper shielding of wires connected to the controller will reduce the amount of noise reaching the servo control loop, minimizing unnecessarily generated noise must also be considered a priority.

The largest source of EMI generally comes from amplifiers used to drive motors controlled by the motion control card. Switching amplifiers are capable of generating significant EMI at frequencies from 10kHz to 300MHz. This noise can interfere with the proper operation of the servo system as well as with any other electrical equipment in the immediate vicinity. Like the motion control card, any wire connected to the servo amplifier will act as an antenna, but in this case the servo amplifier is generating the noise which is propagated from the wires attached. Proper shielding of wires connected to the servo amplifier will reduce the amount of propagated noise.

When designing a system, the system integrator should think about possible background noise where the servo system may be installed. A typical servo system can be rather noisy, however, designing the system just to deal with the inherent noise can be underestimating potential problems. Debugging and troubleshooting a system in a lab may be far easier than on a factory floor rich with EMI.

Careful attention to EMI reduction will help minimize startup costs and help prevent future operating problems in any installation.

Grounding

Electrical codes require grounding equipment primarily for safety reasons. By electrically connecting the chassis of a piece of a equipment to earth ground, electrical faults in contact to the chassis should be safely dissipated until protection devices respond. Since electrical codes differs by location and are constantly evolving, this document only intends to cover general concepts.

If there is a conflict between recommendations in this document and electrical codes, safety requirements must be followed. The user is responsible for conforming to all applicable local, national and international codes.

Many grounding systems incorporate a copper rod which is driven into the Earth as a grounding electrode to achieve a connection to earth ground. A grounding electrode conductor then connects the grounding electrode to a ground bar in the electrical service box. The neutral wire (in a typical signal phase system) as well as the safety-ground wire typically connect to the same ground bar. In theory, they should both be at the same potential.

Just as the neutral wire and safety-ground wire should not be interchanged, all points of a safety-ground wire cannot be assumed to be at earth ground potential. Even though all safety-ground wires provide a path to earth ground, the inherent resistance in the wire and the possibility of a large fault current passing through the wire can present a potential voltage difference between two points of the same wire which otherwise should be at earth ground potential.

For safety reasons as well as EMI reasons, all devices should be connected to a single point ground. A single point ground tied to earth ground insures that each device has only one path to ground such that no ground loops are created.

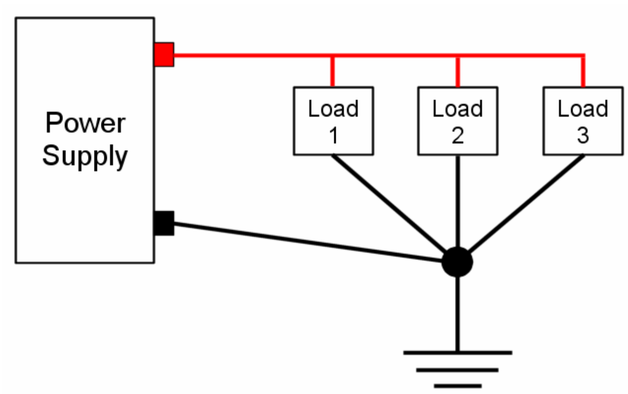

Figure 1. Single Point Grounding

Single-point grounding helps avoid creating ground loops.

Although connecting all grounds to a single point may seem simple enough, putting this method to practice will quickly show its limitations. Returning a large number of rather large gauge wires to a single point can be difficult if not impractical. A ground bus provides a very reasonable and convenient alternative. A ground bus constructed of a copper bar of low resistance rated to handle large currents provides an alternative to the single point ground. Given a low resistance, even carrying a large current, the voltage between one end of the bar and the other should be extremely close to zero.

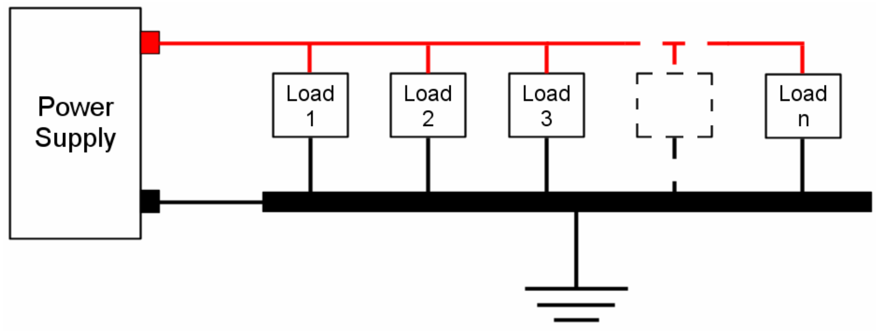

Figure 2. Ground Bus

Taking the concept of a ground bus one step further, an electrical enclosure can be used in a similar manner. Once the enclosure is properly connected to physical earth ground by an appropriately sized ground conductor (for safety considerations and not necessarily EMI), the entire metal enclosure is at earth ground potential and may be used as a ground plane. By removing enough paint from the enclosure to expose the metal, a device may be grounded by providing a good electrical connection between the metal housing of the device and the bare metal of the enclosure. By using an enclosure with the door properly grounded to the enclosure using a ground strap, the entire structure can prevent radiated noise from entering or exiting. While a rack or panel may be acceptable for a given application, a properly grounded enclosure can provide the best noise immunity. Thus, the rest of this document will refer to using an enclosure instead of a rack or panel. As enclosure design is beyond the scope of this document, please refer to the selected references for a thorough discussion of enclosure design issues.

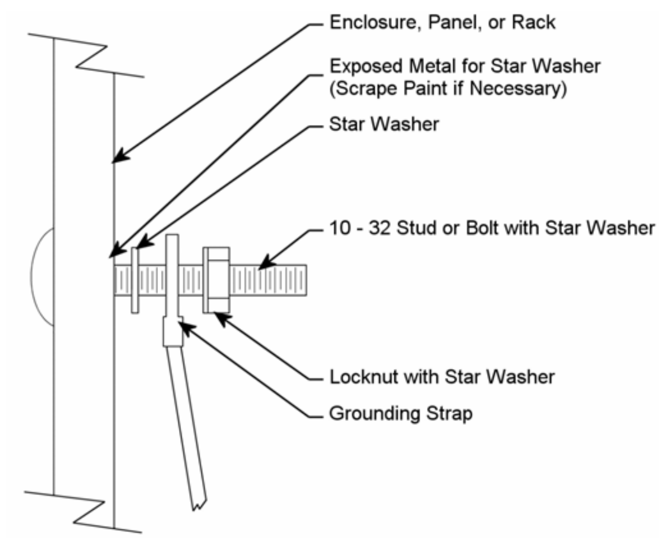

Figure 3. Recommended Ground Strap Mounting Technique

To assure a low-resistance path to ground, be sure to remove any non-conductive coating (paint, anodizing, grease, etc.) from the device and the mounting surface to obtain metal-to-metal contact. Use a serrated washer (star washer) between the metal housing of the device and the bare metal of the enclosure to improve the electrical connection. If in doubt use a ground strap to ensure a good connection between the device and the enclosure.

When mounting components which require grounding, be sure to remove non-conductive coatings from the component and the mounting surface to obtain metal-to-metal contact.

Ground straps should be short and relatively wide. While ordinary wire may provide a safe, low-resistance path for fault currents, the impedance will be too great to provide a path to ground for high-frequency noise. The ratio of length to width affects the inductance. Keeping the width 1/5 of the length or greater provides a relatively low-inductance path to ground for higher-frequency noise. Copper-tubular braid provides an excellent, low-resistance ground path with a relatively large width to maintain low impedance at high frequencies.

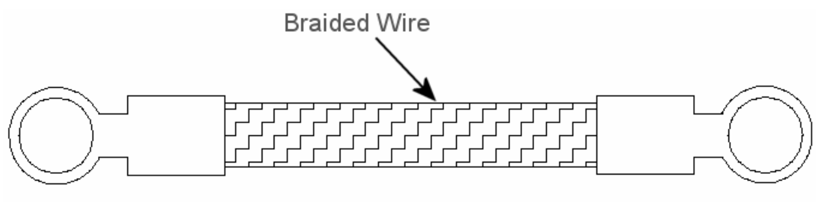

Figure 4. Recommended Ground Strap

Ground straps must be relatively wide to provide a low-impedance path for high-frequency noise.

The following table shows several sizes of tubular braid manufactured by Alpha Wire Company. This reference provides only a sample of their product line. Please refer to the wire manufacturer for specific details and recommendations for appropriate sized grounding straps for each application.

Tubular Braid References

Alpha P/N	ID
2172	3/8in (9.35mm)
2174	1/2in (12.7mm)
2177	7/8in (22.23mm)
2178	1in (25.40mm)

Alpha Wire Company (www.alphawire.com)

Where electrical codes call for the typical green safety-ground wires, use them **in addition** to any ground strap suggested in this guide.

Avoiding Ground Loops

Another point that should be emphasized is the avoidance of ground loops. Ground loops are a major concern when wiring any electrical system. While avoiding them is simple in theory, in practice they are surprisingly all too common. Erratic behavior caused by ground loops may at best be regarded as a nuisance. Unfortunately, they can cause relatively large, destructive currents and have in some cases have even caused death.

By grounding all devices to a single point, ground loops are easily avoided. However, the temptation to wire the grounds of different devices together still exists. The following examples show what could happen when different grounds or commons are wired together.

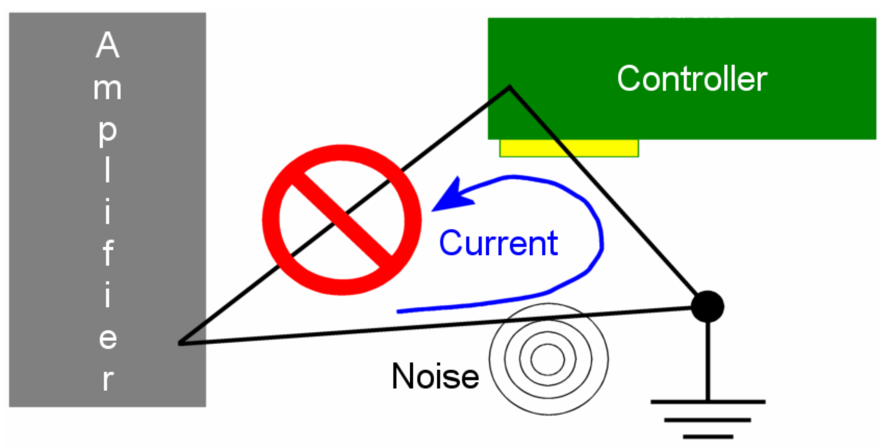

Figure 5. Unwanted Antenna

Figure 5 shows one example of a ground loop. While the controller and the amplifier should each be tied to earth ground, wiring the ground of the controller to the ground of the amplifier can cause serious problems. The triangle of ground wires forms an antenna which will unfortunately receive unwanted noise. Once received, the radiated noise will induce a current which will create a voltage difference between the earth ground and the ground of the device due to the inherent impedance in wire. Depending on the magnitude of the current and the path presented through the devices, the induced current can possibly disrupt normal operation or even cause damage.

Just as noise can induce current in a ground loop, different ground potentials can cause rather large currents when connected by a low-resistance path. For instance, an electrical fault can place a large current on a safety ground. While the safety ground is used to safely dissipate fault currents, this should not be confused with assuring a ground potential at the site of the fault. A large current combined with the inherent resistance in wire will create a potential difference from earth ground.

> When powering equipment from different sources, be careful of different grounding potentials.

Take a large office building which divides three-phase electrical power into three single-phase circuits in a building. Two outlets only feet apart may be on two different circuits. Now consider a device connected to one of these outlets has an electrical fault sending a large current through a safety-ground wire which is several hundred feet long. Before the protection device breaks the circuit, there will be a voltage difference between the safety grounds of the two circuits. Though it may be brief, this difference could be all it takes to cause problems.

Continuing with the example, a motion control card resides in a computer powered by single-phase outlet. The servo amplifier uses an outlet six feet away that is single-phase outlet as well. These two outlets are on two separate circuits. For safety reasons, the computer chassis is connected to safety ground through its outlet, and the amplifier is connected to safety ground through its outlet. Now consider that a wire connects the ground of the controller to the ground of the amplifier. The potential for disaster now exists. The following figure shows what can happen if one of the safety grounds should change with respect to the other.

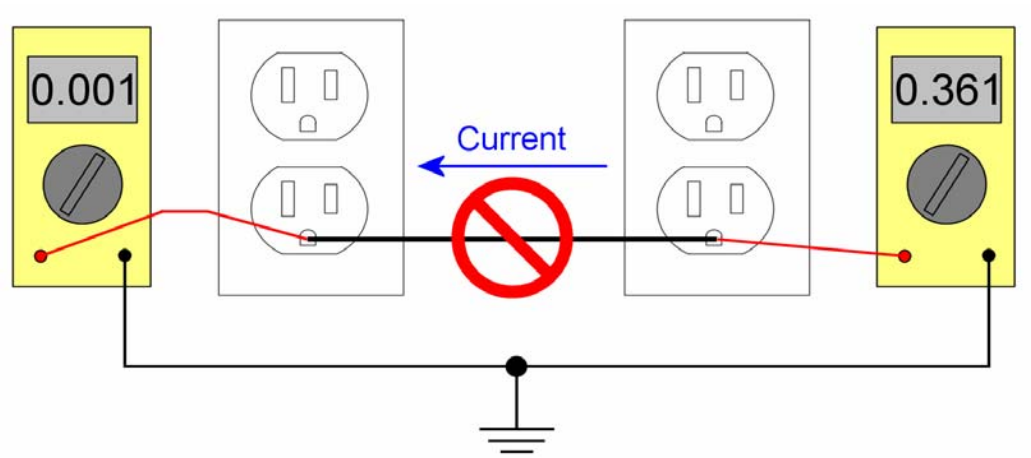

Figure 6. Different Ground Potential

To make figure 6 more meaningful, the following numerical example should clarify what can happen.

Assume the following conditions:

- 10ft of 22AWG copper wire (nominal resistance of 18Ω per 1000ft)
- $R = 10ft * 18\Omega/1000ft = 0.18\Omega$
- $V = (0.361V - 0.001V) = 0.36V$

$$I = V / R = 0.36V / 0.18\Omega = 2A$$

What the 2 Amps of current passes through could cause a rather short-lived problem with very permanent consequences. Thinking about what paths ground connections set up will help prevent potential problems related to different ground potentials. In some cases, the ground loop may exist with little effect on the overall system, however, the ground loop should be broken to ensure that system will function reliably.

The analog ±10V signal is an industry standard for torque or velocity control. The analog reference input of the amplifier connects to the motion controller ground and DAC output. Using a differential amplifier is important because there may be potential differences between the amplifier and controller grounds. The differential amplifier construction rejects these differences and measures the controller output relative to ground at the controller.

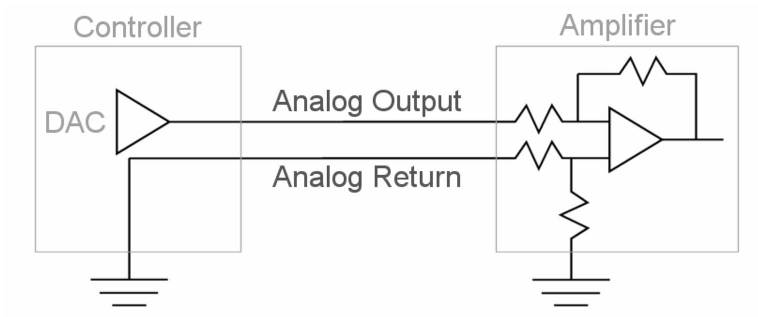

Figure 7. Standard Amplifier

If the amplifer provides a direct path to ground, any difference between ground potentials could lead to the amplifier causing motion when not so commanded. Test with an ohm meter to see that a direct path (0 ohms) exits between the analog return input and the chasis ground of the amplifier.

Verify that the amplifier's analog common for the analog ±10V signal does not have a direct path to ground.

Grounding Shields

Not all noise in a servo system can be eliminated, however, properly shielding wires will reduce the effects of noise. While any wire carrying current has the potential to create EMI, attention needs to be focused on which wires can cause the most havoc and which wires will be most affected. Wires carrying high amounts of power will generate the most EMI. Wires carrying low amounts of power will be most greatly affected by EMI. With this in mind, properly shielding wires will help reduce the amount of noise radiated from the high-power wiring and reduce the amount of noise entering the low-power wiring.

For cables that are shielded, how the shield is grounded critically determines the effectiveness. To reduce the effects of high-frequency noise, the cable must be terminated to ground on both ends to prevent the shield from acting as an antenna. As you have probably already deduced, by grounding both ends of the cable, a ground loop is formed. Unfortunately, this sets up the possibility for low-frequency currents to be carried by the shield which can be rather large. Ground loops can also inject low-frequency noise into the conductors within the shield. Thus the debate over whether or not to ground both ends begins. The length of a cable determines what frequencies will be suppressed and which will create standing waves thus acting as an antenna. Single-point grounding will be effective if the cable is less than 1/20 the wavelength of the highest frequency which can affect the system.

When using metal conduits, do not allow the shield to touch the conduit. The shield could carry high currents as a result of a ground loop.

To determine the proper grounding method, the highest frequency of concern must be calculated for each cable. In the case of control signal cable, the maximum bandwidth of the amplifier determines the highest frequency. In the case of the feedback cable, the greatest bandwidth of all the connected encoder processing circuitry determines the maximum frequency of concern. In the case of the motor cable, the chopping frequency of the pulse width modulated amplifier does not determine the highest frequency of concern as higher-order harmonics are also created.

Consider encoder receiving circuitry that accepts up to 10MHz. The highest frequency that can be recieved is 10MHz, while anything above this frequency will not even be noticed. Noise subjected to the shield of the cable at 10MHz and below may affect the encoder signal. Next, calculate the wavelength of concern to determine whether single-point grounding will be effective.

Determine the wavelength of concern by dividing the velocity of propagation (V_p) on the cable in question by the frequency of concern. Use the following formula to calculate the wavelength of the highest frequency of concern for each case. Remember that problems may occur for cables 1/20 of this wavelength or longer.

$$\lambda = V_p/f$$

The velocity of propagation is roughly the speed of light (299,792,458 m/s in a vacuum) for that of a wire in air, but can drop to around half of the speed of light for cables with plastic sheathing. Please consult the cable manufacture for the velocity of propagation for the cable being used.

Continuting with the example of the encoder cable, assume you are using the Belden 8108 cable with a normal velocity of propigation of 78% that of the speed of light.

$\lambda = V_p/f$
λ = 78% * 299,792,458 m/s / 10MHz
λ = 23.4 meters

Maximum Recommend Length for Single-Point Grounding

λ / 20 = 1.2 meters (3.9 feet)

Remember that a cable in length 1/20 of this wavelength or greater could pick up 10MHz noise on the shield. Which means an encoder cable that is 1.2 meters (3.9 feet) or longer should have its shield grounded at both ends to prevent possible signal corruption.

When high-frequency noise could present a problem despite concerns of forming a ground loop, the cable must be grounded on both ends. Fortunately, there is a solution. By properly grounding the cable shield at one end, preferably at the source end for a culprit cable and at the receiver end for a victim cable, the opposite end should be terminated to ground through a capacitor with a low value, typically 0.01 - 0.1 µF, and very short leads.

> ⚠ Connecting both ends of a shield to ground can induce large low-frequency currents. When necessary, properly ground one end to chassis ground and the other end to chassis ground through a capacitor.

Obviously, the shield should provide coverage for as much of the cable as possible, but it need not be grounded at the very end of the cable to be effective. One of the best places to ground the shield of a cable is generally as it leaves or enters an enclosure. The ideal connection makes a 360 degree contact with the cable's shield. If absolutely necessary, a short, flat grounding strap is preferred over a long wire which will present too much impedance at high frequencies to provide an effective path to ground. A fairly simple, acceptable method to achieve a good shield ground is by using a 'P' clamp to mechanically mount the cable to the enclosure case. Ensure a good metal-to-metal connection to provide a solid electrical ground.

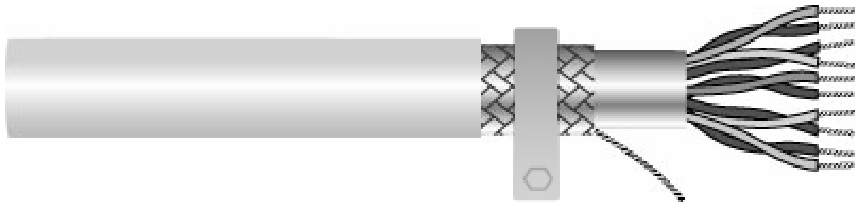

Figure 8. 'P' Clamp Cable Shield to Enclosure

Even inside a well grounded, shielded enclosure, all feedback wiring should be shielded throughout the entire length of their runs. At some point, however, the shielding will need to be removed to access individual wires. The unshielded length of the twisted pairs should not exceed 2 inches (50 mm) to avoid injected noise. If necessary to run wires greater than 2 inches (50 mm) from the shielded cable, use another section of shielded cable electrically connected to the shield of the original cable using a low impedance path such as a flat ground strap or properly ground the new cable's shield. If a cable contains more conductors than required by the application, remove unused pairs or ground them at only one end to avoid creating a ground loop inside of the shield.

Ground shields to an appropriate grounding point with a 'P' clamp. Avoid using ground pins through devices as the circuit path to ground may have too high of an impedance at problematic frequencies.

Designing Cables

All low-power signals interfacing to the motion control system should be wired with twisted cable, with at least one twist per inch (2.5 cm), to minimize noise coupling. In particular, feedback wiring should be wired with individually twisted, shielded pairs, using low-capacitance cable. All cables should be designed with like power signals within the shield to avoid cross talk corrupting lower-power signals.

Due to the low-voltage, high-frequency characteristics of the feedback cable, special consideration must be given to its construction. Capacitance loading of the encoder will affect the rise and fall times of otherwise square-shaped signals. Cables with a given capacitance per unit length will increasingly load the encoder output as a function of length. At relatively low speeds, the encoder output waveform may not be greatly distorted. However, as speeds increase, the time constant (product of the load's resistance and capacitance) becomes more of an issue. The following figure shows the difference between a relatively low-capacitance load and a relatively high-capacitance load on the encoder output.

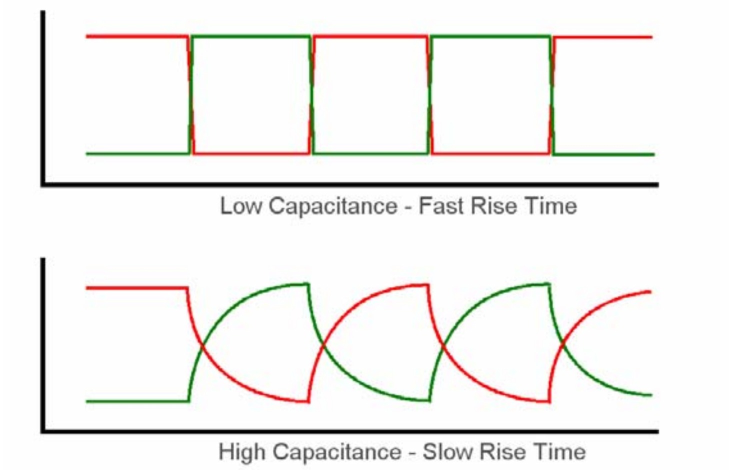

Figure 9. Effects of Capacitance

While the second graph exhibits a slower rise time than the first, this may still be acceptable. A differential encoder, which is recommended for better noise immunity, allows the use of a differential receiver. When using a differential receiver based on the RS-485 specification, only a difference of +/-200mV between the channel and its compliment defines a high or low state. This allows the signal to be reshaped into more of a square wave which can be interpreted by the digital processor of the controller. When the signals are within 200mV of each other, the output of the differential receiver is undefined. Within and near this region problems will more likely occur. As the time constant gets larger, the time to rise or fall to the appropriate voltage may become so large relative to the duration of the high or low state that the signal may be easily corrupted by noise or not even transition states. Rise times must be acceptable. Using low-capacitance cable on the order of 40pF/ft (12pF/m), such as found in the following table, helps reduce the rise time and fall time.

Low-capacitance cable allows longer feedback cables with higher bandwidth.

Recommended Cables

Manufacturer & P/N	Description
Alpha 5482C OR Belden 8302	22 AWG, 2 Pair, Shield & Drain
Alpha 5483C OR Belden 8303	22 AWG, 3 Pair, Shield & Drain
Alpha 6222C OR Belden 8102	24 AWG, 2 Pair, Shield & Drain, Low Capacitance
Alpha 6224C OR Belden 8104	24 AWG, 4 Pair, Shield & Drain, Low Capacitance
Alpha 6228C OR Belden 8108	24 AWG, 8 Pair, Shield & Drain, Low Capacitance
Alpha 3492C OR Belden 8132	28 AWG, 2 Pair, Shield & Drain, Low Capacitance
Alpha 3494C OR Belden 8134	28 AWG, 4 Pair, Shield & Drain, Low Capacitance
Alpha 3498C OR Belden 8138	28 AWG, 8 Pair, Shield & Drain, Low Capacitance

Alpha Wire Company (www.alphawire.com)

Belden Electronics Division (www.belden.com)

Due to the variables involved, one cannot determine the maximum cable length for every application. Consult your encoder manufacturer to discuss the maximum advisable cable length for your application. However, to give you an idea of what type of encoder output you should at least consider, the following table lists typical maximum lengths for feedback cables. This is a compilation or range of recommendations from several encoder manufacturers and has little to do with the controller. Please note that the TTL single-ended encoder is listed, but not recommended for noisy environments. If faced with such a situation, US Digital offers products to convert single-ended outputs to differential signals. Also due to loading when connecting the encoder to multiple devices (amplifier, controller, etc.), using a differential line driver is highly recommended.

Maximum Length Recommendations

Encoder Output	Typical Maximum Length
TTL Single-ended	20 - 30ft (6 - 9m)
TTL Open Collector (Differential)	30 - 50ft (9 -15m)
Line Driver (Differential)	100ft + (30m +)

Consult the encoder manufacturer to determine advisable cable lengths for your application.

When dealing with environments rich with EMI, consider using a 12V encoder. Some companies produce higher voltage encoders that help reduce the signal to noise ratio compared to that of a 5V encoder. The 12V option also reduces the time spent in the transistion region since the rise and fall time for a capacitive load is proportional to the voltage applied. However, note that ultimately the line driver device will affect the rise and fall time. For example, two commonly used ICs are the ET7272 and the OL7272 with operating frequencies of 800kHz and 4MHz respectively. Obviously, the latter device will allow faster encoder speeds which are comparable to a 5V differential line driver. Consult your encoder manufacturer for recommendations regarding environments which should use higher voltage encoders and the maximum frequency at which they can be run.

Proper termination of the encoder cable improves the received signal in all cases. In situations where the encoder cable becomes relatively long or when both the controller and amplifier require feedback, termination becomes more critical. For both 5V and 12V encoders using differential line drivers, proper termination should be used at the receiver end of the cable to reduce reflections due to improper impedance matching.

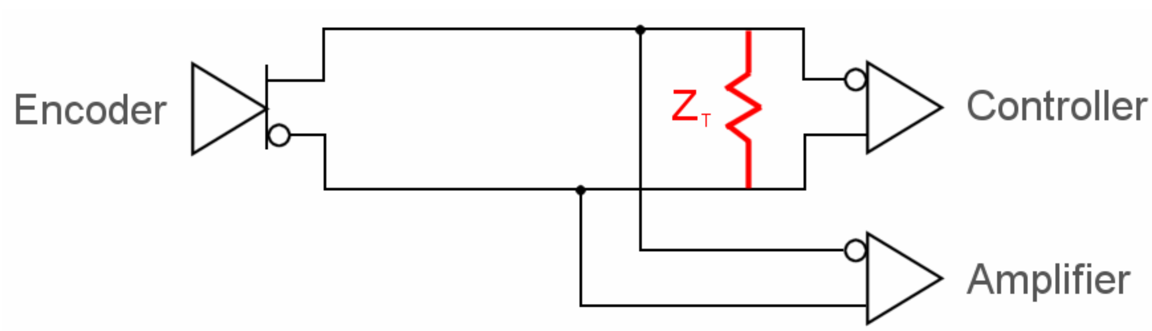

Figure 10. Proper Encoder Cable Termination

The terminating resistor Z_T should match the impedance of the cable to prevent reflections. Consult your cable manufacturer to determine the nominal impedance. For the low-capcitance cables listed in the cable recommendation table above which have a nominal impedance of 100Ω, a resistor of 100Ω should be used for a 5V encoder. Note that using a resistor of 100Ω with a 12V encoder may draw too much current for the encoder to function properly. For 12V encoders, consult your encoder manufacture to determine an acceptable compromise between loading and reflections.

When designing cables greater than 100ft (30m) that use the controller or amplifier to power the encoder, check the voltage reaching the encoder. The inherent resistance in the cable can drop the voltage reaching the encoder to a level that will cause the encoder to malfunction. In this situation, place the encoder power supply at the encoder end of the cable. Bear in mind that unshielded lengths of power cable have the potential for picking up noise and injecting it into the feedback system.

The motor side of both the feedback cable and the motor cable need to be properly strain relieved. Especially for motors that move with stages, at least two securing points (several cable diameters apart) must attach the cable to the moving portion of the stage. Providing only one will allow the cable to move on both sides of the securing point allowing damage to be done to the shield, wires, and connectors.

> The motor wiring must be properly strain relieved to ensure interconnects, wiring and terminal connections do not become damaged.

Designing the Enclosure

When designing the enclosure keep in mind that a motion control system will be most affected by primarily two inherent problems: heat generation and electrical noise. With these two items in mind, how components are placed in an enclosure will greatly determine the success or failure of a motion control system. Problems can range from intermittent failures to destroyed components, all of which will require time and money to solve. A few simple precautions can minimize the effort required to debug a new system, or even more importantly, a system placed in the field where EMI is not always as low as where the machine was tested.

The enclosure must be grounded to earth ground for safety reasons. The conductor that connects the enclosure to earth ground should be sized according to all relevant electrical codes. Devices installed in the enclosure must also be grounded to the enclosure for safety reasons, but remember here the goal is to reduce the effects of noise as well. While there must be a low resistance path for electrical faults to be safely dissipated, there must be a low-impedance path for high-frequency noise to prevent the device from raising or lowering its ground potential with respect to the ground plane created by the enclosure. Remember that an enclosure's door must also have a low-impedance path to the rest of the enclosure. When in doubt, an appropriate ground strap should be used.

While shielding will reduce the amount of noise generated or received by the cable, all cabling should be run in like groups within the enclosure. Low-power wiring (digital and analog signals) entering or leaving the enclosure in which the control system is mounted should run in separate metallic conduits or wire race ways from AC power, motor power conductors, or other power equipment circuits. Maintain a minimum distance of 12 inches (305 mm) between parallel runs of low-power cables and high-power cables.

> High-power wiring and low-power wiring within the enclosure should be separated by a minimum of 12 inches (305 mm) for parallel runs. If their paths must cross, they should do so only at right angles to each other.

Low-power cables should be routed as far away as possible from sources of EMI. The three largest sources to avoid are the switching power supplies in the amplifiers, the motor power cables (which act as antennae for the switching power supplies) and the AC supply line providing power for components in the enclosure. Similarly, group all high-power wiring and high-power devices (such as circuit breakers, contactors, fuses, etc.) in an area separate from the low-power wiring and low-power devices. Route control signal wiring and feedback wiring away from the amplifier such that the distance between them and the motor power cabling is maximized.

> Route low-power cabling as far away from any EMI noise sources and other transient noise sources as possible.

The separation of components should also allow for proper airflow in the enclosure. Without proper airflow, heat generating components such as integrated circuits will have a tendency towards thermal runaway. Which simply means that the hotter the integrated circuit gets, the more power it will require for the same operation. The power required in excess of normal operation dissipates as heat bringing the component to a higher temperature. This vicious cycle can easily continue until component destruction occurs.

> Allow a minimum distance of 3 inches (78 mm) above and below each amplifier and a minimum of 3 inches (78 mm) on each side to eliminate the potential problems of heat generation and electrical noise.

The largest sources of heat generating devices are typically amplifiers and regen resistors. Mount amplifiers in the enclosure following the manufacturers recommendations for orientation and spacing. No heat generating devices, such as transformers, inductors, braking resistors, etc., should be mounted directly below thermally sensitive devices, such as amplifiers. If possible, mount them outside of the enclosure with a protective mesh cage. Large regen resistors should be mounted external to the enclosure as they can generate massive amounts of heat.

> Consider mounting heat-generating devices outside the cabinet inside a protective enclosure.

Machine builders concerned with CE marking their machines should install components into an industrial grade enclosure and observe the following figure as to general layout recommendations.

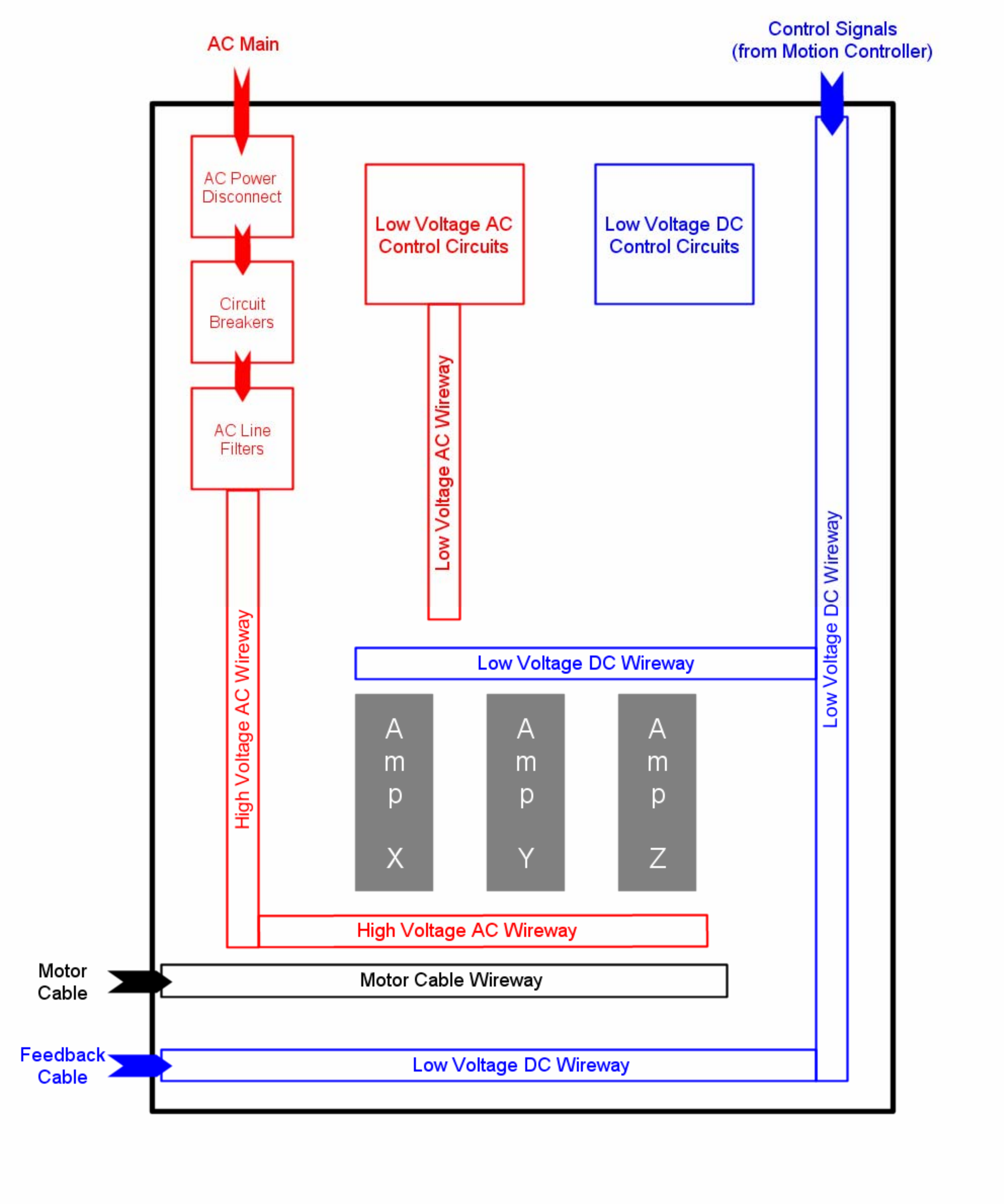

Figure 11. Enclosure Layout

Observing Noise

While a well designed product should reject noise, the integration of several products from different manufactures can present many subtle problems. Not all products have been designed with noise immunity a priority, and wiring several components together presents multiple paths for noise to enter a system. Detecting where noise enters a system can be rather challenging. Reducing the effects of noise to a tolerable level can be an art form in itself. However, the first step is to determine if there is a problem. Most easily affected are the low-power signals, though, the results may be hard to detect and may take time to accumulate enough error that the problem is apparent.

Noise injected into the feedback cable of a closed-loop system can cause "extra" encoder counts to be received by the controller. This is most easily noticed by the mechanics physically moving short of the commanded target even though the position calculated by the controller is correct. Unfortunately, many "extra" encoder counts may have to accumulate before the system will be obviously out of alignment. This may exhibit itself as "drift" in the system or that mechanics do not return to the same position to which it was originally homed. More obvious will be a brushless motor with a sinusoidal digital amplifier that loses torque due to the electrical commutation angle no longer aligning with the mechanical commutation angle. Given enough "extra" encoder counts, the controller will command full torque, but no motion will result because the commutation angle in the amplifier will be out of phase. Please note that related problems can occur when operating a motor at a velocity which exceeds the bandwidth of the controller or amplifier. However, in this case encoder counts are "lost."

Noise in the motion control card's analog command signal may be observed when the motor dithers while it should be remaining stationary. (Please note that poor tuning, a relatively high resolution encoder, or mechanical play between the motor and the mechanics may all account for or exacerbate the situation.) While torque and velocity ripple will similarly occur because of this noise, though, these two items can also be caused by too low of resolution in the analog signal, current loop, or encoder.

In the case of an open-loop stepper motor, noise induced in the motion control card's digital signal, step and direction or clockwise and counter clockwise, may be observed as the motor moving an extra distance at a faster speed than commanded, or the motor may move when not commanded. As there is no feedback signal to compare the distance traveled, the mechanics must be observed. Over time the "extra" steps will cause the system to "drift" such that the system will not return to where it was originally homed. Please note that a stepper motor could lose synchronization during the transition through its resonant frequencies and operating near the maximum speed/torque curve, which would also cause the system to lose positional alignment.

Reducing Noise

Not all noise in a servo system can be eliminated. However, a prudent integrator will attempt to reduce as much noise as possible. Relays and contactor coils can produce a large amount of unwanted and unnecessary noise. For example, a 12VDC relay may generate a voltage of 1000 to 1500 volts as the magnetic field collapses. This magnitude of voltage can not only create EMI, but can destroy semiconductor devices as well as damage switches. Noise suppressors can be purchased locally and are an effective, inexpensive method of eliminating potential noise problems in the system.

Inductive loads in a DC circuit may make use of a high-speed flyback diode for noise suppression. When the switch in the circuit is opened, there is a large amount of energy stored in the inductor that must be dissipated. By connecting a diode across the inductive load with its polarity reversed and when the switch is opened, the diode will allow the current to decay more quietly. For maximum noise suppression, the diode should be located as close to the inductive load as possible. The diode must be rated accordingly to handle the energy stored in the inductive load. Being the most simple and cost effective, this method remains fairly common. Please note that this may not be an acceptable solution in all stituations. Please refer to the application note "Application of Relay Coil Suppression with DC Relays" listed in the reference section of this document.

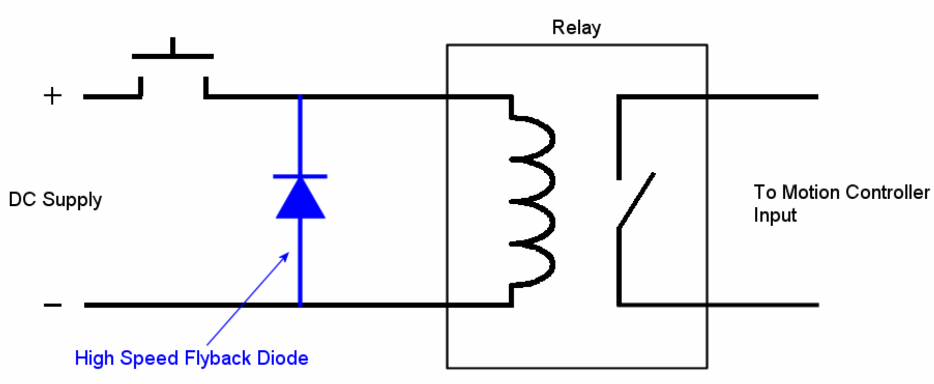

Figure 12. Noise Suppression - DC Relay

Similarly, an inductive load in an AC circuit needs to have noise suppression. Two common methods that may be used for noise suppresion of an AC relay or DC relay are the resistor-capacitor circuit (snubber circuit) and the metal oxide varistor (MOV). Generally, an RC snubber (4.7kΩ resistor in series with a 0.1 μf capacitor) will provide better noise suppression than the MOV, and the MOV will tend to degrade over time. However, an acceptable MOV will generally have a lower cost than the snubber circuit. In either case, each device must be rated to handle the energy stored in the inductive load.

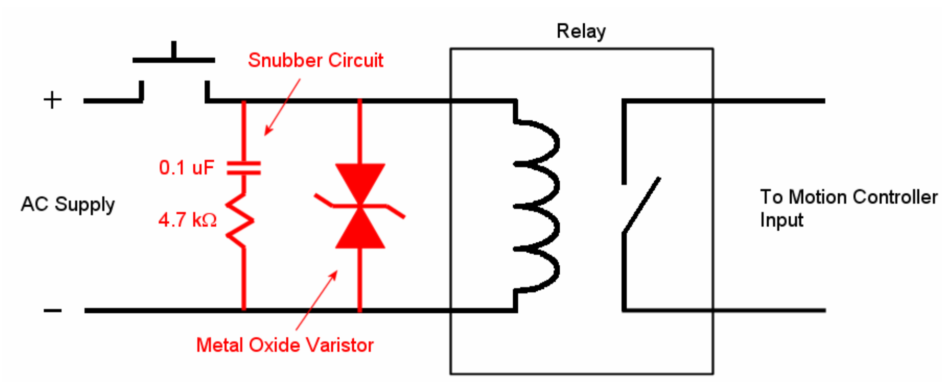

Figure 13. Noise Suppression - AC Relay

In both the DC and AC case, the suppression device must be properly rated to prevent a degradation in performance. Choose a device with an acceptable safety margin to dissipate the energy stored in the inductive load. To determine the energy stored in an inductive load for either case, use the following equation to determine the energy or power. (Determining the inductance of a coil is beyond the scope of this document. Consult the relay manufacturer or refer to the application note "Determining Relay Coil Inductance" listed in the reference section of this document.)

$$P = L * I^2 / 2$$

For example, consider a relay coil with an inductance of 40mH that has 5A of current in the coil before the switch is disconnected.

$$P = L * I^2 / 2$$

$$P = 40mH * (5A)^2 / 2$$
$$P = 0.5\ W$$

The noise suppression device chosen must be able to safely dissapate one half watt of energy.

While not generating radiated noise, solid-state inputs that are driven from solid-state outputs may require a bleeder resistor across the input. Especially for high-speed inputs, precisely capturing the instant that the state transitions from high to low requires a relatively low-resistance path to ground to drain the stored charge. However, the bleeder resistor must be of sufficient resistance to activate the input when the output is high. Using Ohms Law (R = V / I), the resistance should be greater than the voltage required to turn on the input divided by the current produced from the output when it is in its high state.

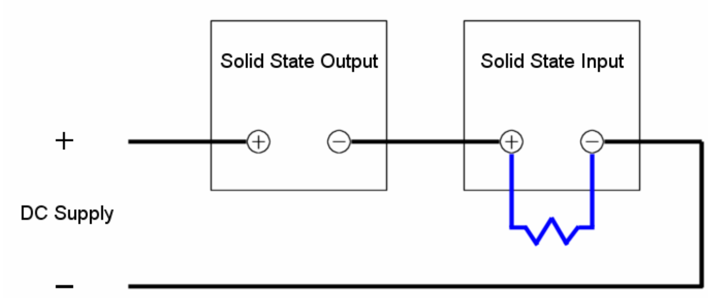

Figure 14. Noise Suppression - Solid State Relay

For example, consider using a 5V optical sensor with a TTL input. The following specifications refer to the optical sensor.

On State: 120 mA max at 5V
Off State: 50 µA max

$$R = V / I$$
$$R = 5V / 120\ mA$$
$$R = 42\Omega \text{ (minimum resistance)}$$

By using a 50Ω resistor the sensor will not be loaded to its maximum current output, the TTL input will still see 5V while the sensor is on, and there will be a relatively low resistance path to drain the leakage current while the optical sensor turns off.

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