Chapter 13

System Grounding, Noise Control, and Safety Considerations

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System Grounding and Noise Control

Once the construction of a motion control system or any other computer controlled system has been completed, the first step in the startup process is to ensure that the system grounds are working and that radiated or other types of electrical interference (electromagnetic noise) have been suppressed below a qualified signal-to-noise ratio.

In this chapter, references to certain specifics are taken from the National Electrical Code handbook. The NEC manual should be used to guide the design in safety, and functionality of grounding and suppression methods.

Noise and Grounding Terminology

Earth/Ground –	A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to earth, or to some conducting body of relatively large extent that serves in place of the earth (ground plane). A rod used for grounding purposes driven at least ten feet into the ground should register under 25 ohms when measured with respect to another (qualified) earth (refer to the NEC). Also referred to as ground is: power ground (not to be confused with power common), frame ground, and chassis ground.
Ground Bus –	A conducting bus structure to which the grounds from individual pieces of equipment or circuits are connected, and which, in turn, is connected to ground *at a single point*.
Ground Plane –	An assumed plane of *true ground* or *zero potential*. The ground plane can be constructed as a wire grid or a single sheet of metal larger than the equipment or circuits being protected.
Noise –	Unwanted electrical signals superimposed upon and tending to mask the desired signal.

Basic Solutions to Eliminating Noise

In general, four techniques are used to prevent or reduce signal degradation in electrical systems:

- Electrical grounding of certain power points.
- Suppression of electrical spikes using RLC filter networks, surge suppressors, or other types of blocking devices, such as power conditioners.
- Shielding of cables or areas within an electrical enclosure from radiated noise.
- In cases of critical equipment, UPS systems and isolation transformers are used to isolate the equipment from the actual power source.

Any or all of the four techniques listed above can be used to control noise. The key is not to misapply them. A single ground loop or undersized suppressor can cause more problems than it solves.

The Purpose of Grounding and Safety

Note that grounding is used for a multitude of reasons, the most important is *safety*. The challenge is to make the product installation as safe as possible; and yet, satisfy all practical noise emission and susceptibility requirements. Applying proper grounding, suppression, and shielding techniques will allow the safe interconnection of different voltage level equipment in a given system without sacrificing operator, control, or machine safety requirements.

Note again that even if the manufacturer's equipment grounding rules are followed to the letter, electrical noise can still cause problems that may cost hours (or days) to resolve—especially if you have never encountered these types of problems before. It is extremely important that, as a system designer, you take the time to ensure that your system includes the best suppression techniques available.

Some of the basic purposes for equipment grounding are:

- **Personal safety –** Ground straps connected to system equipment cabinet frames are intended to limit the touch 0voltages (to people) to safe levels in the event of insulation or component failure within the system.
- **Equipment Safety –** In the event of electrical failure, properly grounding system electronic components will prevent catastrophic failure to major system parts.
- **Zero Reference and Voltage Equalization –** Failure to provide a qualified signal return path simply means that the signal will find its own way home. This then becomes *noise* picked up by other circuits. Properly grounding high and low voltage systems will eliminate this condition. It is not always possible or practical to commonly ground system equipment together. Under these circumstances, the use of differential or specially isolated interfaces (i.e., optical) should be used.

- **Shielding –** It would be easy enough to recommend that all signal shields should be tied to *earth ground*. However, this would not be correct. In my experience, I have found that some signal shields work better when tied directly to their respective power supply commons, and others work better when tied to *earth ground*.

To prevent this statement from sounding like a *copout*, I must add that I generally do not connect my low voltage power supply commons (under 24VDC) to *earth ground* as a rule. If I did, and a high voltage AC power wire found a low resistance path to a low voltage circuit, the high AC current would find its way back to ground via the low voltage electronics, possibly destroying everything in its path. Instead, I *float* the low voltage electronics at the onset of the debug and check to see if the grounding of that supply is proper. If not, I provide fault detection to shut down the system in the event of a ground fault occurance.

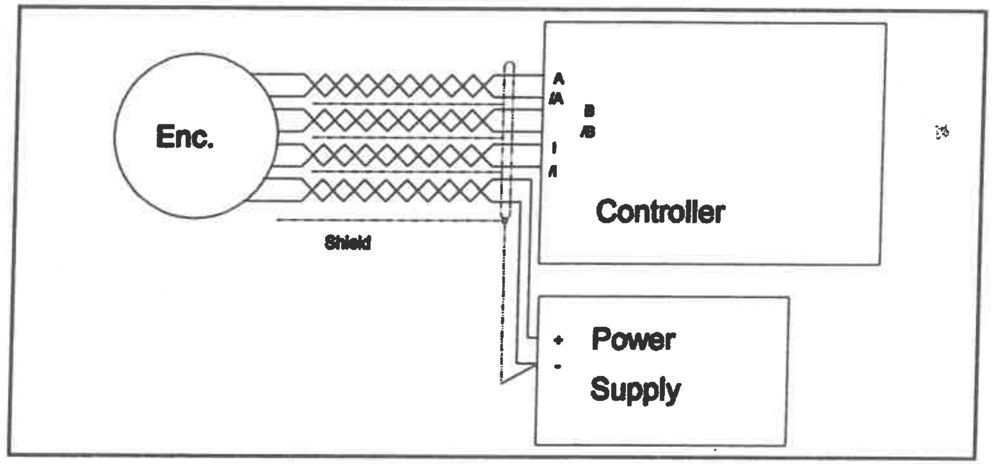

Figure 13.1 Connecting the shield on encoder differential pairs.

The key is to know what it is that we are shielding against. For example, in the case of a multi-conductor, twisted-pair shielded cable (each pair shielded) used for the transmission of TTL level encoder signals, I would connect one end of the shields to the power supply common (the power supply that is providing operating power to the encoder), and not connect the other end of the shield to anything (see Figure 13.1). This arrangement would prevent ground loops, and help eliminate the crossover signal injection into other

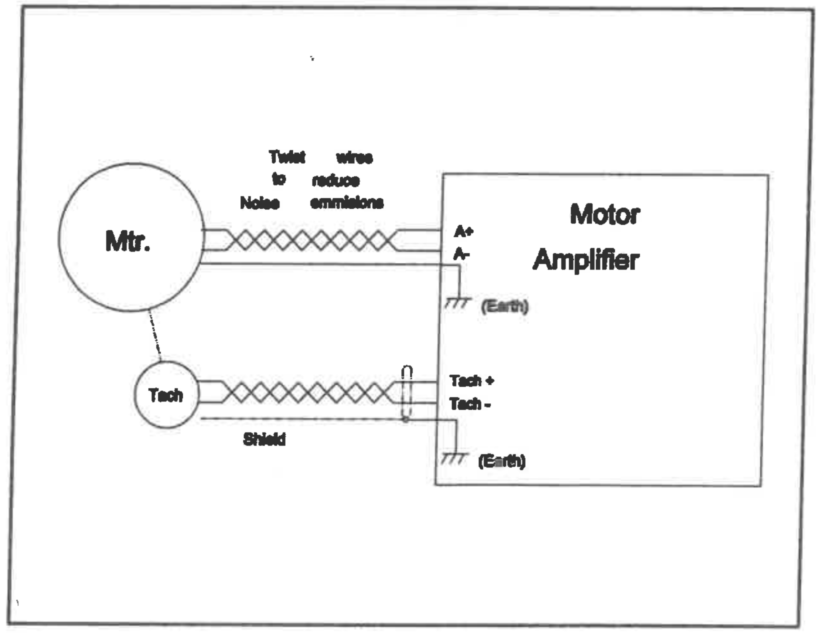

Figure 13.2 Connecting the encoder shield to protect against motor noise.

transmission wires in close proximity to the encoder wires (including the other encoder signal wires themselves). On the other hand, if I wanted to shield against motor noise, I would possibly tie the shields to the motor ground (see Figure 13.2). Using a high quality portable oscilloscope, I could quickly determine which ground is the best for the given noise to be suppressed.

Problem Overview

The overall problem may be characterized as one or more of the following:

- Highly sensitive electronic devices in a high noise environment such as a factory where a significant amount of welding is being done.
- Noise that may be self-induced such as in high power switching equipment (stepper, brushless, and PWM devices, as well as contactor control of AC or DC motors or HV switchgear).
- Interaction between randomly occurring noise impulses (turning a valve coil On or Off) and the specific moments when signal circuits are enabled (generally the most susceptible point). These usually show up as intermittent operating faults, the most difficult to locate.
- Radiated noise (electromagnetic interference), which can be picked up by sensitive electronic devices in proximity to the offending equipment.
- Difficulty in distinguishing between the various possible causes of signal corruption. Electrical noise, marginal components, and marginal software can all create similar malfunctions.
- Missing or improper system grounds. Connecting too many grounds or grounds at the wrong power points can be just as devastating as having no grounds at all.

Determining Noise Sources

Finding the cause of noise is not as simple as it may first appear. Equipment, timing, system layout, improper grounds, and software combinations can all contribute to the overall noise problem that is actually disturbing the process. Because more than one noise source may exist, the noise may appear to *jump around* as debugging progresses. This, in turn, may distract you as you debug the original problem—possibly throwing you off the track.

Most electronic equipment is mounted in some form of metal industrial enclosure. The problem may disappear when you open the enclosure doors, allowing radiated noise to escape rather than *bounce* around inside. Remember, grounding the cabinet and closing the cabinet doors do not mean **<u>all</u>** radiated signals within the enclosure are absorbed. It only means that signal noise radiated from the equipment inside or outside the cabinet is blocked from escaping or entering the cabinet, respectively. Equipment may still be susceptible to noise problems inside or outside the box by radiated signals from other equipment in direct proximity, or by signals that are allowed to travel along the interconnecting electrical wiring to devices inside or outside the cabinet.

Noise Detection Tools

The best tool for detecting ground problems is a simple voltmeter; the best tool for detecting noise problems is an oscilloscope. Together, these instruments generally allow you to pinpoint a problem within minutes. However, a common mistake when troubleshooting equipment is to use an earth-grounded oscilloscope. The scope ground, when connected to the equipment ground circuit, can actually cause more problems than you started with. At that point, you may find yourself chasing ghosts. The best oscilloscope for the job is usually a battery-powered portable unit, which maintains complete isolation from the circuit under test, and yet complies with all required safety precautions.

The overall best tool for debugging both noise and system ground problems is a thorough knowledge of the system, its operating sequence, and the electrical interface. I usually have all of the components, subsystem wiring diagrams, and manuals at hand. This, together with the system electrical prints, system flow charts (timing diagrams), and any other pertinent PC, or PLC logic information that I can obtain, will greatly help in understanding what the symptoms are indicating.

Basic Principles of Noise Transmission and Suppression

When a voltage impulse is applied to one end on a conductor, it does not reach the other end instantaneously. Depending on the physical characteristics of the conductor, and the insulation dielectric between the conductor and the return path, electric and magnetic fields are created as the voltage wave moves toward the receiving end(s). The energy in this voltage impulse wave does not exist in the conductor. It exists completely outside in the electric field between the conductor and its return path, and in the magnetic field around each the conductor and its return path. Instead of the energy flowing through the wires, the wires merely guide the field. Moreover, there is no such thing as current flowing through a conductor into a ground (rod) without a return path **somewhere**. All electrical signals (even noise) flow in complete circuits. To be more specific, if noise current is being detected in a grounding conductor attached to a ground rod, whatever is flowing into the ground circuit is being felt **<u>somewhere else</u>**!

The propagation velocity of a travelling voltage or current wave will be controlled by the distributed inductance, resistance, and stray capacitance of the conductor. Typical velocities are 0.5 to 0.6 times the speed of light (about six to 10 inches per nanosecond or 500 to 850 feet per microsecond).

This may not seem pertinent until you remember that computer control circuits operate at 10 megabits per second or greater. Update times in motor control circuits in use today are under 60 microseconds. If the signal frequency in use were 10 MHz. (assume an AC signal), the velocity of wave propagation would carry it typically 85 feet during one complete cycle of the signal. To be effective as voltage difference equalizers, ground conductors carrying 10Mhz noise signals should be no longer than 1/5 of a wavelength, or about 8.5 feet. If exceeded, the effectiveness of the ground conductor to equalize voltages disappears. However, the conductor will still provide the safety functions of limiting touch voltage, and allowing proper ground fault protection. To ensure good grounds at the point of concern, it might be appropriate to sink a ground rod at the critical location, rather than attempting to run a ground wire to the main power cabinet.

Traveling waves are difficult to absorb. Unless impedances are carefully matched to that of the transmission characteristics of the conductors at their terminations, the energy will be reflected or diverted—possibly creating more problems. Generally, there will be some absorption, some reflected, and some diverted energy.

Dealing with Common and Normal Mode Noise

Normal-mode voltage is that which exists between pairs of power or signal conductors. *Common-mode* voltage is that which exists between each power or signal conductor and power or signal ground.

In a system where there may be signal differences between parts of an interconnected grounding conductor network, there may be some differences of opinion about what *common-mode* voltage might be. In many instances, it is possible to select a ground reference point that has a minimum *common-mode* voltage with respect to the circuit of interest, especially if the ground reference point and the circuit of interest can be connected by a very short conductor. To do this, isolation devices are sometimes necessary to avoid **creating** paths for noise currents to flow and electromagnetic fields around those paths that can be coupled into sensitive circuits.

Common-mode noise may be caused by one of the following:

- **Electrostatic Induction –** With equal capacitance between each of the signal wires and the surrounding conducting planes, the noise voltages and currents developed will be the same on both signal wires.
- **Electromagnetic Induction –** With magnetic fields linking both wires equally, the noise signals developed in each wire will be the same. In practice, there is rarely a pure, perfectly balanced *common-mode* noise or signal. There is more often a component of *common-mode*, and a component of *normal-mode* noise or signal. Unless the circuits are extraordinarily well balanced, one will convert some of its energy to the other mode.

A frequent source of combined *common-mode* and *normal-mode* noise is the result of a momentary impulse voltage difference between parts of a system that have different ground references. If the two systems are interconnected by a signal path in which one of the conductors is grounded at each end, the ground offset voltage impulse will create a current in the ground conductor. As this current propagates, its distributed inductance and capacitance induces a similar voltage in the closely coupled return wire [supporting the reason for shielding (wrapping) the signal and return wires within a shielding braid, and only connecting one end of the shield to signal common or earth as required].

Methods to Overcome the Problems

Three basic ways you can attack noise problems:

- Eliminate the noise at its source.
- Reduce the noise susceptibility of the disturbed circuit.
- Reduce the intercoupling between the noise source and the disturbed circuit.

Some application guidelines for grounding and noise control:

- **Comply with safety code requirements!** Safety first.

Remember: Safety First !

- Apply noise suppression **directly** to devices that are *known* to generate noise spikes (impulse voltages) such as relays and valve coils, . . .
- Use dedicated power feeders; and if possible, dedicated transformers for critical loads.
- Place the central grounding point as close as possible to the critical control circuit(s).
- It is essential to ensure that the system enclosure is at *true ground potential.* If not, the enclosure walls will not provide a noise barrier for the electronics within. Connect all enclosure panels (i.e., doors, . . .) together with 0.5 to 1 inch braided ground strap cable. Enclosure hinges and construction bolts generally do not provide a qualified connection. Also, insulate the ground braid from the cabinet, or other metal, except where the braid is to be connected to the cabinet. Failing to do so will defeat the purpose of ground braid, and it may actually create a ground loop.
- If the critical load area is large (over 30 feet) or a significant distance from true earth ground, it may be necessary to sink one or more ground rods at strategic locations. Refer to local safety codes to find out if the installed ground rods can suffice for equipment power grounds (ground fault detection). If not, it may be necessary to have a power ground network as well.
- If multiple power sources are used, isolation may be maintained, but the earth of each source must be at the same potential for safety and noise reduction.
- UPS systems allow the best immunity from power source noise while protecting controls from sporadic power surges, and/or factory power factor problems.

- Make it a practice to **pair and twist** conductors whenever possible. This will minimize the area between conductors and the magnetic field that they will either create, or intercept (noise pick up). By twisting the pairs, transmitted noise will be reduced, while received noise will be almost eliminated. You should get into the practice of twisting wire pairs regardless of transmission mode—single-ended or differential. Critical signal cables must be shielded with the shield connected to the signal common **only** at the source end.

- In the case of encoders, where the power is supplied from one end of a cable, and the signals are produced at the other end, connect the shield to the end that supplies the power.

- In the case of multiple-shielded twisted pairs, make sure that the signal and return wires of all pairs are sourced from a common piece of equipment. Otherwise, if shields are at different potentials, noise generating ground faults can occur.

If you are unsure, the best approach for critical signals is to use a separate shielded twisted-pair cable for each.

Lightning arresters or other power conducting approaches should be placed at the entrance point of the prime power source. If the arrester is placed at the equipment, by the time the arrester works, the system may already be damaged.

Remember that the energy of a voltage surge impulse travels outside the conductor pair in which the voltage is applied. One wire of the pair may ground to the nearest *earth ground* rather than the conduit or equipment ground. The electromagnetic field created by this loop will induce voltages and currents in other nearby conductors depending on proximity, geometry, and orientation. It may be possible to physically arrange conductors to minimize unwanted intercoupling.

Ground conduction paths for the purpose of draining static electricity do not need to be low resistance to be effective.

Discussion

To summarize:

- Select equipment with reasonably high tolerance to electrical noise.
- Eliminate or reduce those accessible noise sources that can be identified.
- Comply with all grounding requirements for safety.
- Make the electrical environment as *noise-free* as needed to meet specification and allow as much overhead as you can afford.
- Place the system's central grounding point as close to the system as possible.
- If parts of a system must have a equipotential ground, they must be placed close together and interconnected with a conductor or network of conductors having a low impedance over a broad frequency range.
- If interconnected systems cannot be placed close together, it must be assumed that there will be voltage differences between their respective grounds. Use techniques to accommodate these differences (such as differential interfacing).
- Provide paths for ground equalizing currents to flow where they will not couple into signal circuits.
- Where ground reference voltages of separate systems exist and cannot be equalized completely by safety equipment, ground conductors, or conducting paths supplied by conduit, make use of appropriate isolation techniques for power, communication, and/or control signals as appropriate. Some of these include: isolation transformers, optical isolators, modems, and differential interfacing.
- Pair all power and signal conductors with their return paths. For AC power circuits, include a ground conductor if the return path is not grounded. For low voltage DC, place the two conductors (signal and return) within a shield, and connect one side only of the shield wire to the signal-common wire at the **source** side of the signal.
- Powering parts of a critical load from different power sources (modularity) is not only acceptable, but desirable, provided that the ground reference points of the various sources are at the same potential. This can be done using isolation transformers at the load and with closely interconnected secondary grounding points.
- Coordinate all grounds of all circuits extending into the critical load area including life-safety alarms, controls, air conditioning, and others.
- Arrange power and signal circuits for minimum coupling. Use separate conduit runs for each if you have to.
- Review and initiate static abatement measures as required.