# OIT Ground Wiring and Electrical Noise Reduction

## System Grounds

There are two basic types of grounds in any electrical or electronic system - earth ground and signal ground. Understanding how to implement proper grounding is vital in creating control systems that operate correctly, since improper grounding is one of the primary causes of control system failures.

The first thing most people learn about electricity is that current won't flow unless it can travel in a closed loop. This simple fact is often overlooked when a system is developed using the ground symbol. By a stroke of the pen one avoids having to draw the return paths of most of the current loops in the system. The "ground" turns into an apparently infinite current sink, so that any current that flows into it is gone and forgotten. Forgotten it may be, but it's not gone. It must return to its source to create the closed loop required by any current flow.

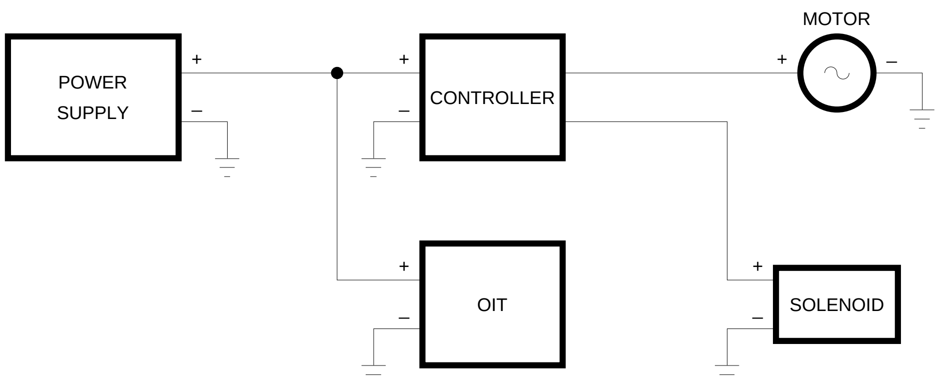


Figure #1 Circuit as Drawn

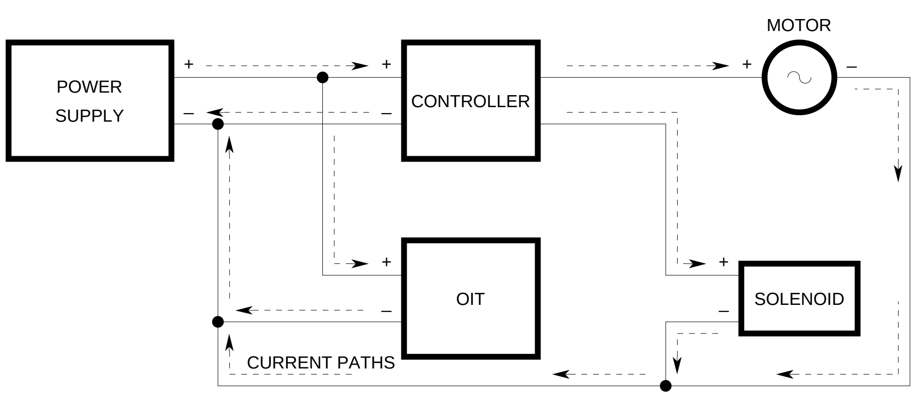


Figure #2 Current Loops in Circuit

The use of the ground symbol also causes many developers to "abuse" the chassis ground by using it as the primary system ground. This can cause vast amounts of electrical noise to be injected into the control electronics, resulting in systems that fail constantly after they are installed in the field.

## 1. Chassis and Earth Grounds

The chassis or "earth" ground is used as a protection against electrical shock. The earth is not a "zero-resistance" surface, so earth ground potential can vary. However, circuits are almost always connected to earth ground for prevention of shock hazards.

In a standard 3-wire single-phase AC power system, the white wire is earth-grounded at the service entrance. If a load circuit has a metal enclosure or chassis, and if the black wire develops a short to the enclosure, there will be a shock hazard to operating personnel if the enclosure is not also earth-grounded. If the enclosure is earth-grounded, then a short results in a blown fuse instead of creating a "hot" enclosure.

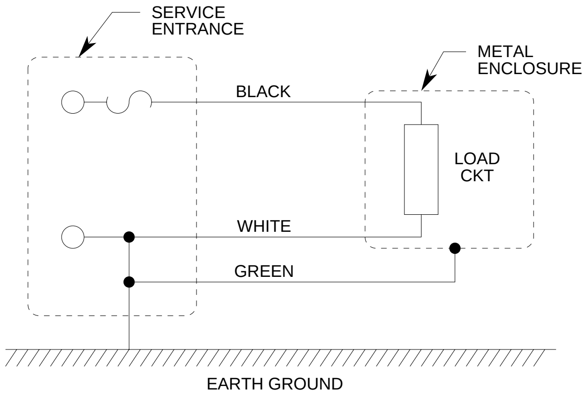


Figure #3 Single-Phase Power Distribution

The earth-ground wire should not carry any current (except in the case of a fault), so it should be at earth-ground potential along its entire length. The "neutral" white wire, on the other hand, may be several volts off of earth-ground, depending upon the gauge and length of the wire as well as the level of current flowing through it.

## 2. Signal and Power Supply Grounds

The signal ground is a single point in a circuit that is designated to be the reference node of the circuit. Wires that connect to this single point are also referred to as "signal grounds". The manner in which these wires connect to the actual reference point determines whether a "series" or "parallel" ground method is being used.

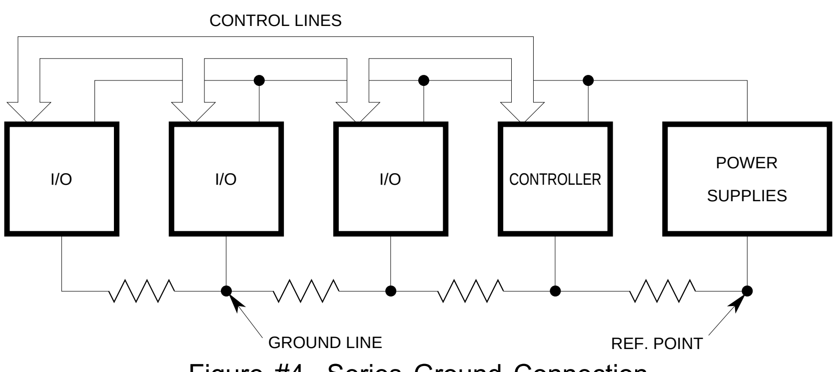


Figure #4 Series Ground Connection

The series ground connection is pretty common because it's simple and economical. However, this "cheap and dirty" connection is also the noisiest due to common ground impedance between the circuits (as indicated by the resistor symbol). When several circuits share a ground wire, currents from one circuit (flowing through the finite impedance of the common ground line) can cause variations in the ground potential of the other circuits. If the ground currents are large enough, the variations of the ground potential can cause serious disruptions in the operations of all circuits attached to the common signal ground.

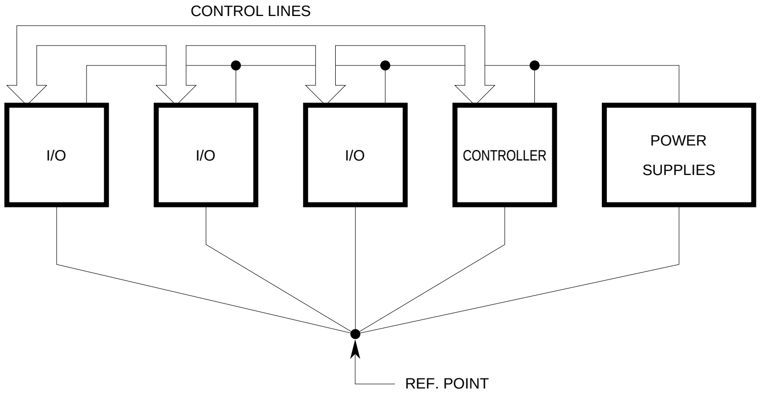


Figure #5 Parallel Ground Connection

The parallel ground connection eliminates common ground impedance problems, but does so at the expense of using a lot of wire. Also, the impedance of each individual ground wire can be very high, and the ground lines themselves can become sources of system noise. Most of the impedance and noise problems can be minimized by choosing the correct size and type of ground conductor. Use 14 AWG or thicker stranded grounding wire for each distribution loop. The use of large gauge wire helps reduce the ground resistance, while the use of stranded wire reduces the ground impedance. Never use solid wire for the ground distribution loops.

A combination of series and parallel ground-wiring methods can be used as a practical compromise between economic and various electrical considerations. The idea is to run series connections for circuits that have similar noise properties and tolerances, and connect them to a single reference point, as in the parallel ground method.

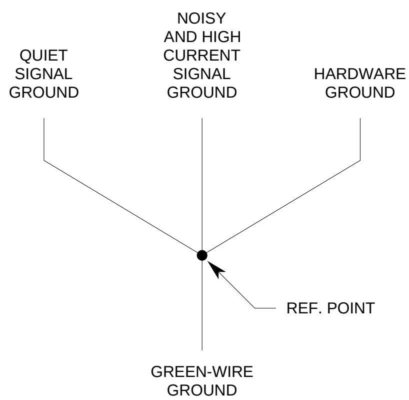


Figure #6 Parallel Connection of Series Grounds

The “Noisy Signal Ground” connects things like motors, solenoids, and relays. Hardware ground is the safety or earth ground connection to chassis, racks, and cabinets. It’s a mistake to use the hardware ground as a return path for any signal currents, because it’s fairly noisy and tends to have high resistance due to joints and seams. Also, the hardware ground is usually the place where ESD sparks are discharged.

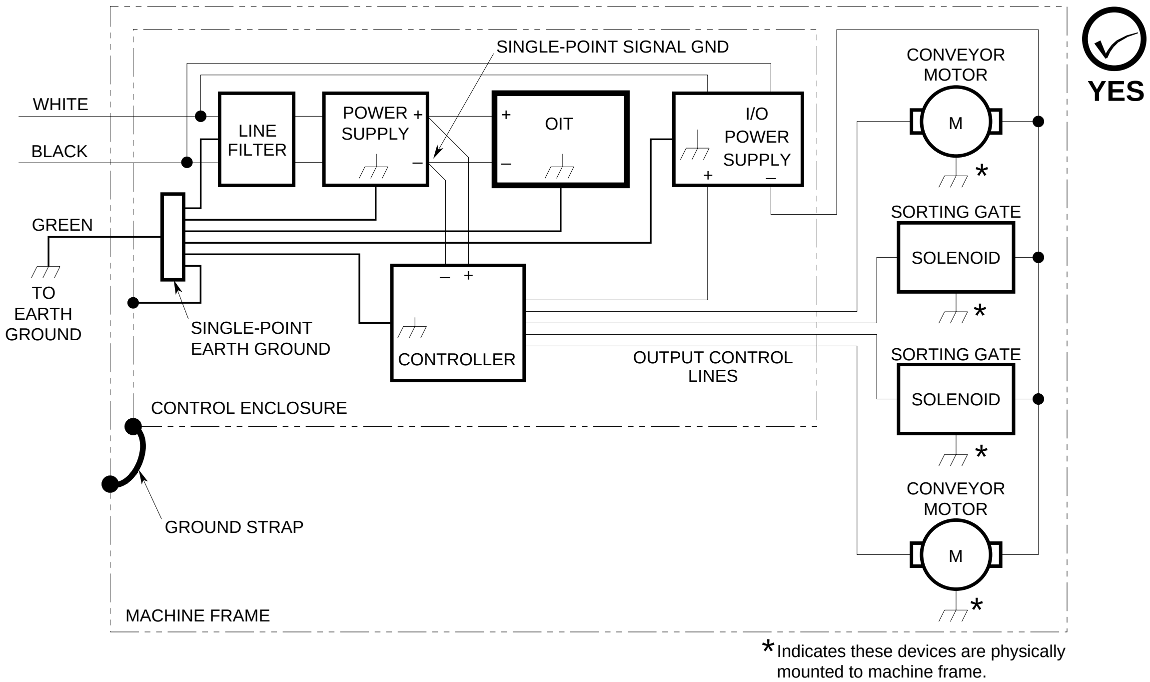


Figure #7 Typical Grounding System

Figure #7 illustrates a grounding system for a Conveyer Sorting Station, showing an application of the series/parallel ground-wiring method. It correctly connects all of the signal grounds together at the single reference point. The chassis or earth ground connection is not used for any of the signal ground returns. The chassis grounds of all components also connect together at a clean, single point earth ground.

Notice that the chassis ground connection from the control panel to the frame is made through a braided cable ground strap, not panel screws. Screws and bolts don't always make good electrical connections because of galvanic action, corrosion, and dirt. These kind of connections may work well at first, and then cause mysterious errors and problems as the system ages.

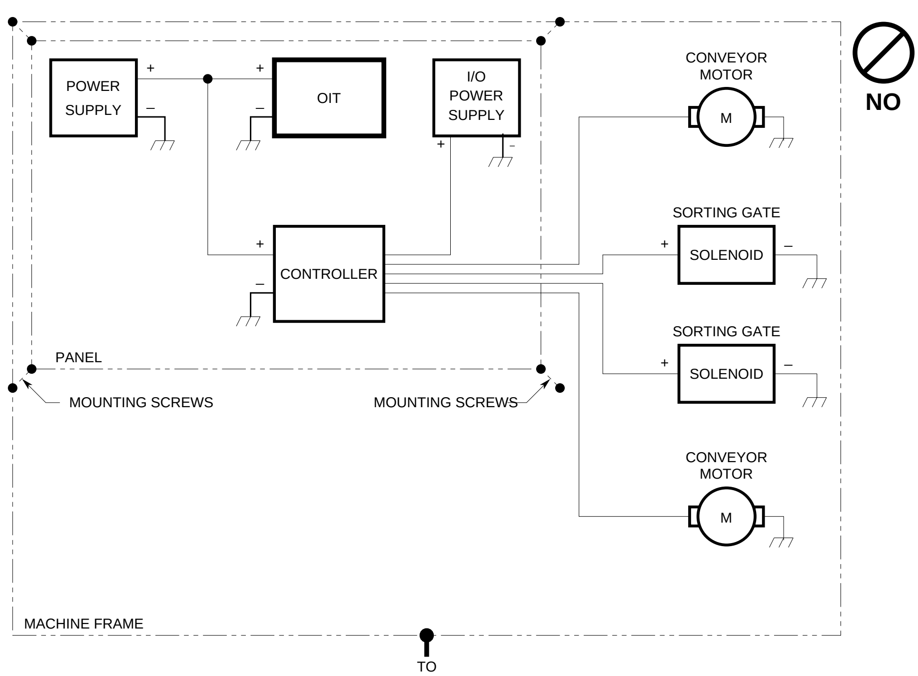


Figure #8 Improper Use of Chassis Ground

Figure #8 illustrates one of the worst (and most common) mistakes when specifying and installing a control system. Here, an attempt to reduce cost is made by eliminating all signal ground wires and using the chassis as a large "ground return". This type of grounding system is almost guaranteed to fail after installation.

### 3. Cable Grounds

There are two separate grounds in the cable that connects the OIT to the PLC. The shield is used as an earth ground connection from the OIT's enclosure and doubles as a Faraday shield against capacitively coupled noise. The signal / power supply ground is carried by one of the conductors inside the cable. These grounds should not be connected directly together, but should be connected to the proper ground points as detailed in the previous section.

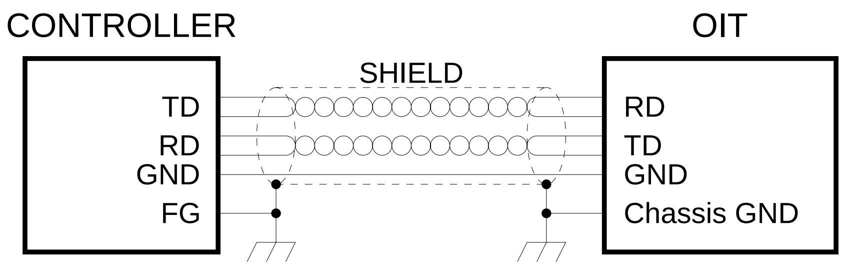


Figure #9 Cable Ground Connections

### 4. Avoiding Ground Loops

Any type of unwanted or unexpected current flowing through a ground line is referred to as a "ground loop". Noise in the ground lines is also referred to as a ground loop problem. The basic concept of the ground loop is shown in the following illustration.

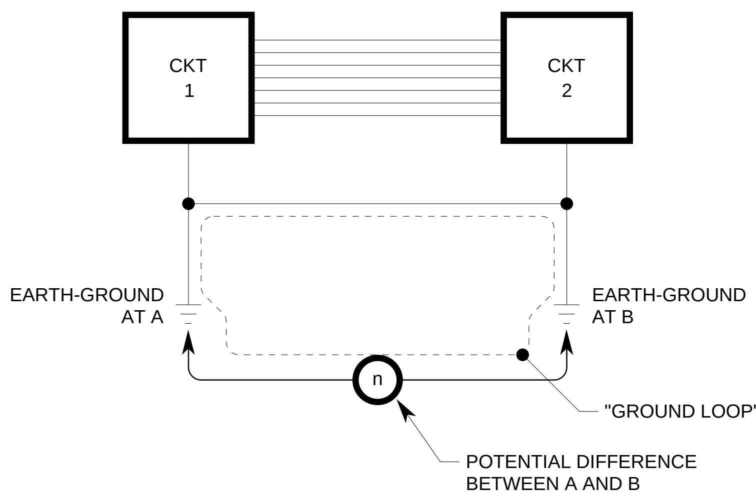


Figure #10 What a Ground Loop Is

The main problem is that true earth-ground is not really at the same potential in all locations. Earth ground potential and resistance can vary due to environmental conditions such as soil composition, water content, time of year, and corrosion of the earth ground conductor. If the two ends of a wire are earth-grounded at different locations, the voltage difference between the two "ground" points can drive significant currents (often several amps) through the wire. Consider the wire to be part of a loop which contains a voltage source that represents the difference in potential between the two ground points, and you have the classical "ground loop".

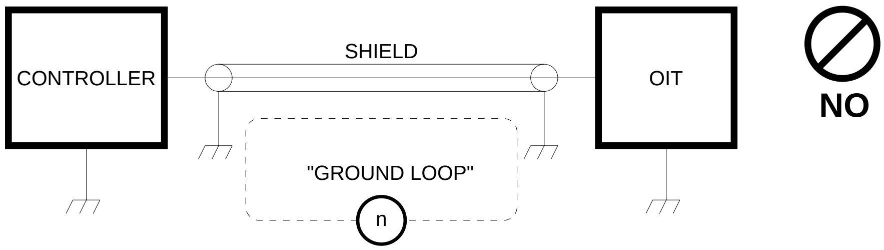


Figure #11 Ground Loop Caused by Cable Shield Connection

If an earth ground loop is caused by a cable's shield connection between two machines, then the solution is to disconnect the shield from one of the two ends of the cable. Since the shield (if connected correctly) isn't used as a signal ground path, it's use as a Faraday shield against capacitive noise is unaffected.

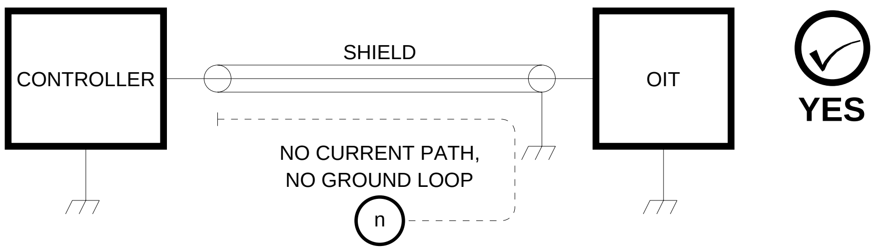


Figure #12 Breaking a Cable Shield Ground Loop

Signal grounds are also prone to "loop problems". This is usually caused by improper signal and chassis ground connections, and often occurs inside a single piece of machinery.

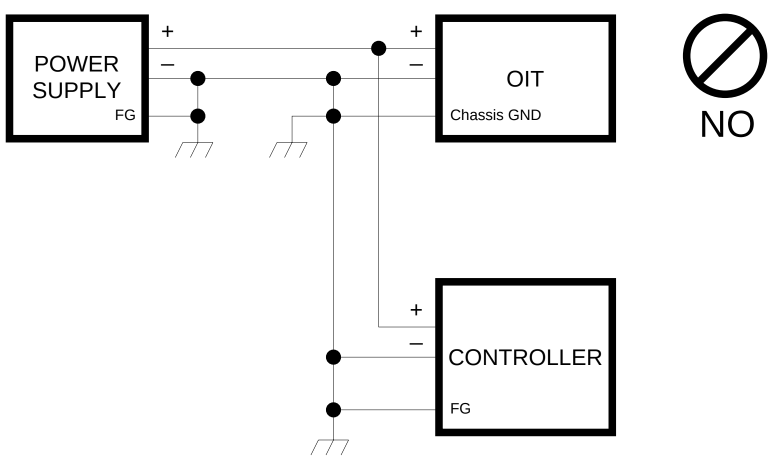


Figure #13 Improper Ground Connections

This incorrectly connects signal ground to the chassis ground at more than one point. Since the impedance of the signal ground is usually much lower than the impedance of the chassis, any ground noise and currents will flow through the signal ground wire, creating a ground loop problem. The solution is to connect the grounds properly in the first place, since it can be very expensive to rewire machinery after it has been installed by a customer in the field.

## 5. Identifying System Noise

Noise problems are not usually encountered during the development phase of a control system. This is because benches rarely simulate the system's intended environment. Noise problems don't normally show up until after the system is installed and operated by the end customer. Then, after a few minutes or hours of normal operation the system finds itself someplace "out in left field". Inputs are ignored and outputs become gibberish. Displays mysteriously clear by themselves, or keyboards "lock up" and stop responding to operator input. The system may respond to a reset, or it may have to be turned off physically and then back on again, at which point it starts to operate as if nothing had happened. There may be an obvious cause, such as an electrostatic "spark" from someone's fingertip to a keyboard, or the upset may occur every time a particular motor or solenoid is turned on or off. There may be no obvious cause, and nothing that the operator can do will make the upset repeat itself. But a few minutes, or a few hours, or a few days later it happens again.

One symptom of electrical noise is randomness, both in the occurrence of the problem and in what the system does in its failure. All operational upsets that occur a seemingly random intervals are not necessarily caused by noise in the system, and some noise sources can produce upsets downright periodically. Nevertheless, the more difficult it is to characterize an upset as to cause and effect, the more likely it is to be a noise problem.

## 6. Reducing System Noise

There are several practical steps that can be taken to reduce the amount of noise in a control system. Some of these must be designed in, others can be installed "after the fact" to help reduce the effects that unavoidable noise has on the control system.

*A) Design a proper ground and power distribution system.*
This is probably the most important (and overlooked) part of a control system. Noise on the power and ground lines is distributed to practically every point of the entire system. Unfortunately, improper "cost cutting measures" often attack the power supply, wiring, and mechanical installation of the power circuitry first.

***The importance of a properly grounded system cannot be overemphasized.***

*B) Make sure all ground lines are "Class 3" grounds.*
Use 14 AWG or thicker stranded grounding wire for each distribution loop. The use of large gauge wire helps reduce the ground resistance, while the use of stranded wire reduces the ground impedance. Never use solid wire for the ground distribution loops.

*C) Don't route power cables in the same bundle with I/O or control cables.*
If power cables must run parallel to the I/O wiring, separate the bundles with grounded metal plates, allowing at least 12" (305 mm) of space between the bundles.

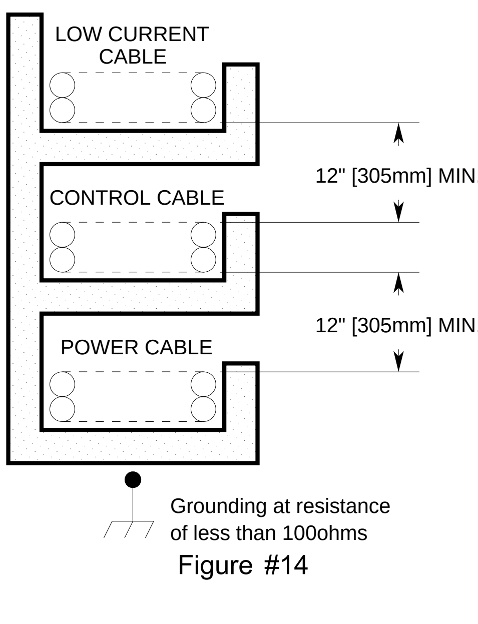


Figure #14

If power cables must be placed in the same duct (for example, where they are connected to the equipment), they must be shielded from each other using grounded metal plates.

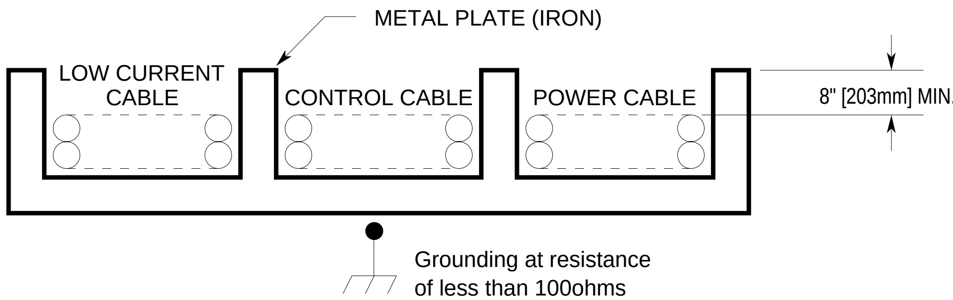

Figure #15

*D) Isolate the power cabling from the PLC and OIT.*
Use standard shielded conduit to route the power cabling, and avoid mounting either PLC or OIT closer than 8" (203mm) from the power cabling conduit.

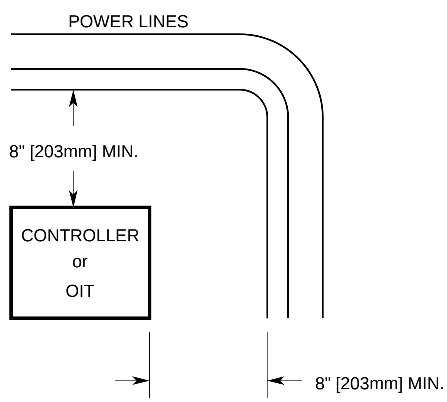

Figure #16

*E) Supply clean AC power to the control system power supplies.*
If the AC input power to the local power supplies produces large voltage fluctuations, use a constant-voltage transformer to isolate the AC input from the surge voltages.

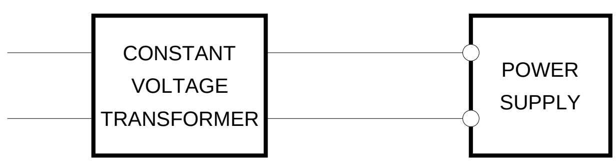

Figure #17

Use varistors on the AC input lines as a protection against large voltage surges and spikes.

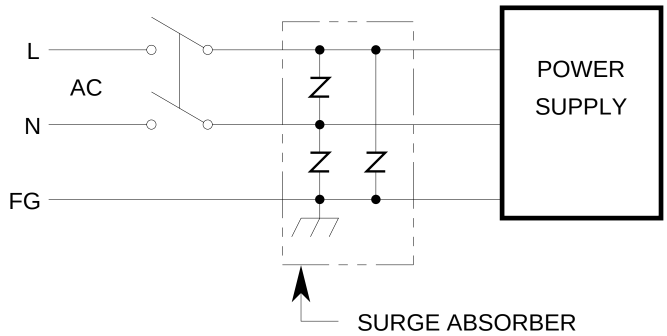


Figure #18

If the AC input power is excessively noisy, insert a line filter circuit between the AC input and the local power supply.

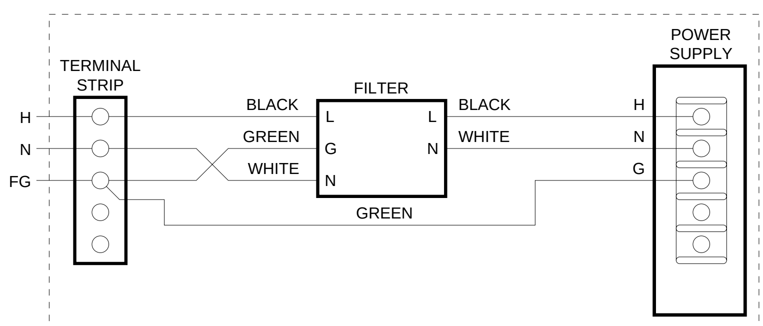


Figure #19

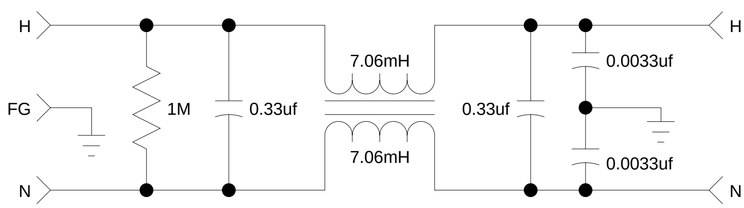


Figure #20

The following is a list of recommended AC line filters:

| | |
|---|---|
| Corcom | P/N 3ET1 |
| Curtis | P/N F1400AA03 |
| SAE | P/N STE1-3 |
| Potter | P/N 622A3 |

*F) Power the I/O separately from the PLC or OIT.*

Use separate power supplies for the I/O. If necessary, use individual supplies for the PLC and the OIT as well.

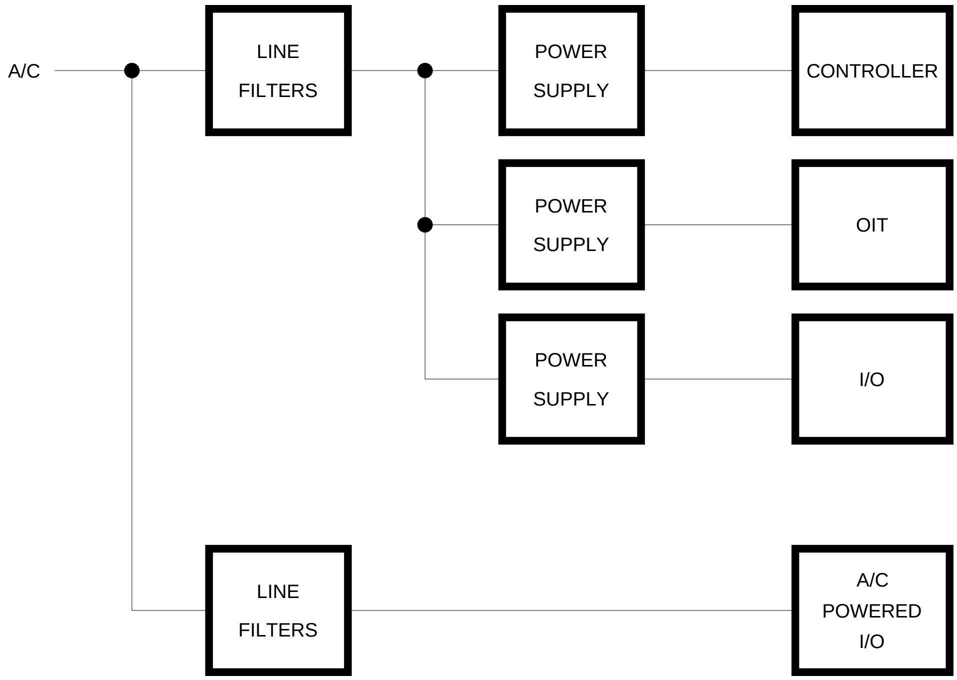


Figure #21