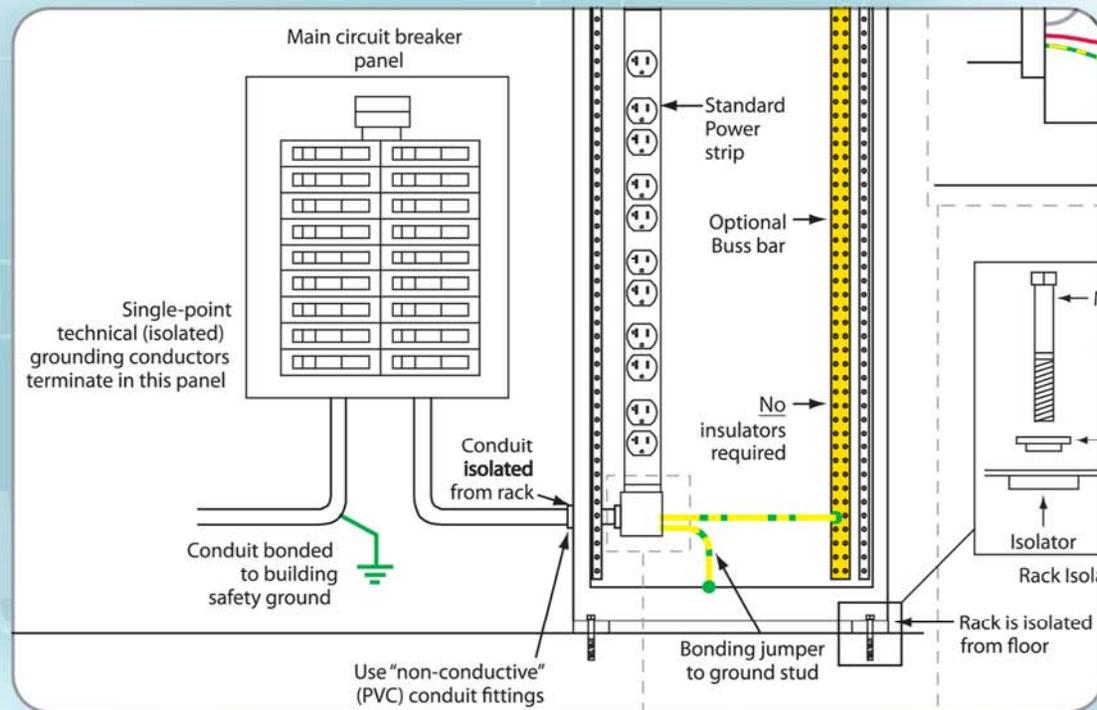


# Integrating Electronic Equipment and Power Into Rack Enclosures

## Power Distribution and Grounding of Audio, Video and Telecommunications Equipment



Rev. 2b 8/7/2007

## Preface

In providing this information, the intent is not to make audio/video equipment installers into electricians. Installers, however, do need a basic understanding of properly installed power distribution to avoid potential problems during installation.

In order to get a good understanding of how some potential power and grounding problems present themselves, basic knowledge of power distribution is required. It is the intent of this document to provide this information.

Every state, city and municipality in the United States is responsible for its own safety standard for electrical installations. While some choose not to adopt any standard, most adopt and enact the widely-accepted National Electrical Code (NEC) or a version of the NEC enhanced to reflect the needs of their respective jurisdictions. Each is at liberty to incorporate additional requirements or remove exceptions, as they see fit. The state of New Jersey, for example, replaced the term “authority having jurisdiction (AHJ)” with “electrical subcode official” before enacting the NEC standard. Always be sure to check the requirements of the local authority having jurisdiction. The information presented in this paper is based on the NEC as it is written. Some areas may have more rigid requirements; however, the NEC is generally the minimum requirement. The NEC is updated every three years. This document is based on the 2005 version.

The NEC is not intended to be used as a design specification or an instruction manual for untrained persons. In fact, some experienced installers have problems adapting the NEC to specific installations. Much of the problem is due to the many exceptions to the rules. The fact is there are more exceptions than there are rules. In addition many rules refer to, and are superseded by, several other sections of the NEC. This document should help to clarify the intentions of the NEC.

## Important Things To Remember When Installing Audio / Video Equipment:

- 1) Bypassing or lifting equipment safety grounds may reduce hums and buzzes; but this is dangerous, violates the NEC and should never be done!
- 2) Ground loops are an entirely normal phenomenon. Their severity depends on many factors. Generally, they cause significant noise problems when safety grounds of equipment and enclosures are not connected at a common point.
- 3) Untwisted signal conductors inside the equipment rack should not be installed in close proximity (within 2") parallel to power conductors or speaker wires. A hum may be induced from these wires into the signal conductors. This is especially likely in long parallel wire runs, where more separation may be required.
- 4) When it is necessary to install signal conductors and power conductors or speaker wires in close proximity to each other, coupling is minimized when the cables cross at 90-degree angles.
- 5) Some equipment is designed to pass noise onto the ground circuit. This noise may manifest itself as a hum or buzz in the signal path.
- 6) There are many causes of signal path noise. Two common problems are equipment that does not comply with either the AES48 standard ("pin one problem") or shield current induced noise (SCIN). Both are beyond the scope of this paper and are well documented elsewhere (please see references listed at the end of this paper).
- 7) Equipment racks should be bonded per the NEC or local authority having jurisdiction. Best practices dictate that equipment racks must be bonded together. It is best to purchase racks with pre-installed ground studs for convenience and to ensure good conductivity.

# Dealing With Electrical Inspectors and Electrical Contractors

"Inspectors are like fuses... They only blow if there's a problem. And like fuses, they are there for your protection; they're not just an inconvenience." - Jim Herrick, 2002

Most electricians and inspectors (who are usually very experienced electricians) don't know much about audio, video or communications installation. What they usually do know very well is power distribution, as far as wiring and associated wiring methods are concerned. For the most part, they are only concerned with electrical safety. Incorrectly installing a technical ground system may be safe, but may create multiple ground paths, which could contribute to system noise problems.

In most areas of the country an electrical contractor's license is required to do any type of electrical work (sometimes even low voltage). An electrical permit, issued by the municipality, is almost always required. If you are caught doing work without a permit you could pay more in fines than what you might earn on the job.

If you're not a licensed electrical contractor, it's a good idea to develop a working relationship with one.

## Inspectors Will Look For:

- 1) Permits and licenses (State and local law).
- 2) *Wiring installed in a neat and workmanlike manner.*  
-NEC: 110.12/640.6/720.11/725.8/760.8/800.24/820.24/830.24.
- 3) Wiring methods that are consistent with the area you're working in. Places of Assembly, such as churches, schools and auditoriums require different wiring methods than residential installations.
- 4) *UL Listed equipment.* -NEC: 110(Labeled)/110.2
- 5) Honest answers, and somebody there to give them, during the inspection (Don't leave a person with limited knowledge at the job site to wait for the inspector!)

## You'll Need To:

- 1) *Know where the circuit breakers are that feed the equipment, and be sure the breakers are marked.* -NEC: 110.22
- 2) *Know the electrical load of your equipment and be sure wiring is of adequate size.* -NEC: 220/210.18
- 3) *Ensure low voltage wiring is not installed in the same raceway or conduit, or in close proximity to the power wiring.* -NEC: 640(c)/725
- 4) *Know your local codes that may supersede the NEC, which is often the case in large cities.*

**If your equipment is installed properly, and looks like it, you most likely will not have any problems with the inspector.**

"Arguing with an inspector is like wrestling with a pig in the mud... After a while you realize the pig likes it." (Author Unknown)

# North American Product Safety Certification

Underwriters Laboratories, Inc. (UL) is an independent, impartial and nonprofit organization that has devoted itself to testing for public safety. To meet this objective, UL acts as a third party, evaluating thousands of different types of products, components, materials and systems.

Described here are three UL classification types: Listed, Classified and Recognized. UL specifically forbids the use of the following terms:

## “UL Approved” or “UL Pending”

Be skeptical of equipment that is marked in such a way.

UL is the most well known nationally recognized testing laboratory (NRTL). There are many others, however, including the Occupational Safety and Health Administration (OSHA). Further information on OSHA can be found on its website at <http://www.osha.gov>



**UL Listed:** This symbol represents a product that UL has tested representative samples of, and has determined that they meet UL requirements for that specific product type in the United States only.



This symbol represents a product that has passed UL listing tests in both the United States and Canada.

UL Inspectors also visit the factories where the UL listed products are manufactured on a regular basis to ensure products are manufactured according to UL safety standards.



This is the logo for Canada only.



**UL Classified:** This category of products is tested to meet specific uses or restrictions for their use, such as, “Explosion Proof” or “For Marine Use”.



**UL Recognized:** This category is for components ONLY. Generally UL listed products are manufactured using all “Recognized” components; however, this does not mean that the product is “UL Listed”. Although all recognized parts are used, the end product must still meet UL requirements to be UL listed.

# Typical 120-Volt Receptacles Used For Electronic Equipment

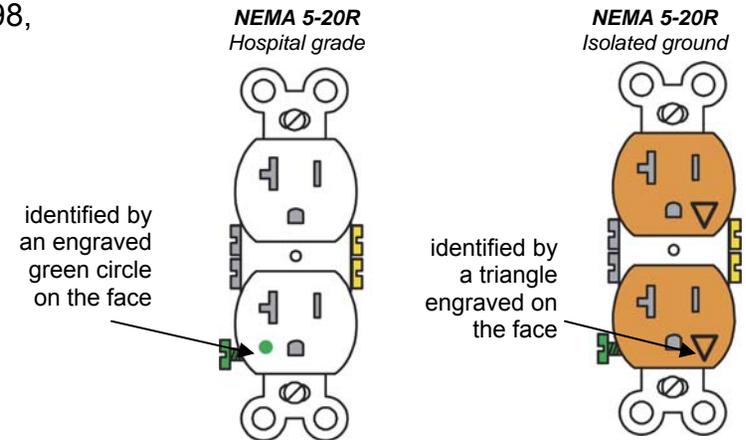
Receptacles have specific prong configurations indicating the voltage and amperage of the circuit for which they are designed. These receptacles and the corresponding circuit must match the plug that is attached to your equipment.

Isolated ground receptacles are identified by a triangle engraved on the face and are available in all standard colors; however orange is the most typical. The triangle is not to be confused with an engraved green circle, which indicates a hospital grade device. Both symbols may appear on the same outlet.

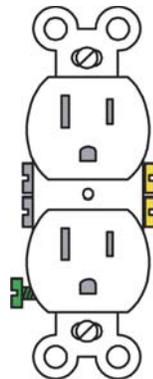
Hospital grade receptacles must pass additional UL testing, per UL Standard 498, including:

- Abrupt Plug Removal Test
- Ground Contact Overstress Test
- Impact Test
- Assembly Security Test

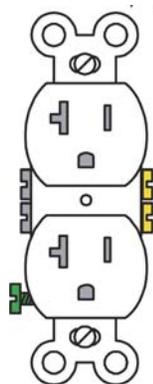
*Do not modify the plug on your equipment to match a receptacle that is not intended to work with your equipment. (NEC-406.7)*



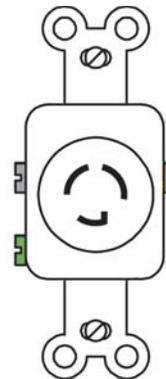
**NEMA 5-15R**  
15 amp circuit  
Accepts NEMA 5-15P plug



**NEMA 5-20R**  
20 amp circuit  
Accepts NEMA 5-15P, or  
NEMA 5-20P plug



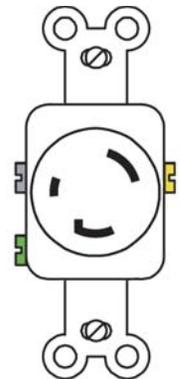
**NEMA L5-15R**  
15 amp circuit  
Accepts NEMA  
L5-15P plug



**NEMA L5-20R**  
20 amp circuit  
Accepts NEMA  
L5-20P plug



**NEMA L5-30R**  
30 amp circuit  
Accepts NEMA  
L5-30P plug



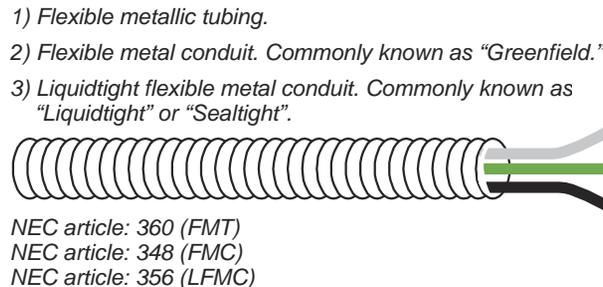
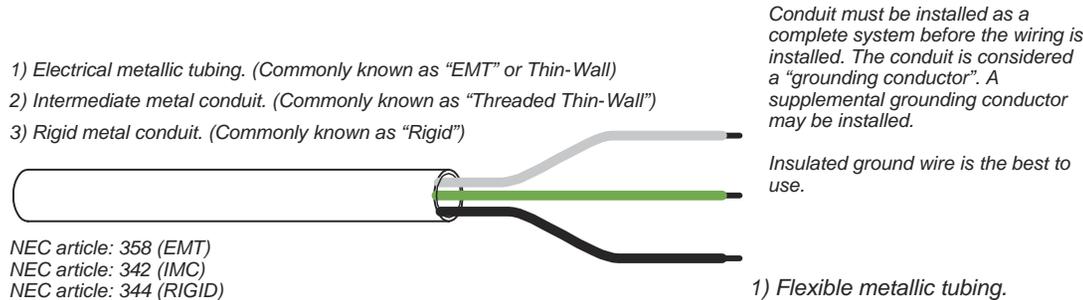
# Wiring Types

The NEC does not require a supplemental equipment grounding conductor in conduit. However, it is highly recommended. The integrity of the ground is dependent on all of the conduit fittings. If one fitting is loose or corroded, the safety ground system is compromised.

Pulling a supplemental equipment grounding conductor, along with the power conductors, assures a low impedance ground path for fault current. **The supplemental equipment grounding conductor must be installed in the conduit with the power conductors.**

Note: Flexible conduit over 6' in length does require a grounding conductor.

MC cable is manufactured in both steel and aluminum. **"Steel-Clad MC"** cable with insulated ground wire is the best choice for AV systems. It has twisted conductors that help reduce AC magnetic fields, however the **steel** jacket is what helps most.



This type of raceway has limits as to the use of the conduit as a grounding conductor. A supplemental grounding conductor is generally required on lengths over 6 ft.

Insulated ground wire is the best to use.

# Relative Milligauss Readings of AC Magnetic Fields from Different Wiring Methods & Plug-In Power Supplies (Wall-Warts)



Field strength, in milligauss, is a unit of measurement of AC magnetic fields. Not to be mistaken for static magnetic fields like the souvenir magnet on the fridge at home, AC magnetic fields are produced by AC electrical current flow and are a component of Electromagnetic Fields. These fields are notorious for getting into the signal path, creating “hum”. The following measurements show the AC magnetic fields of different wiring types at a specified distance from the signal wires.

Note: While any twist of current-carrying conductors reduces emitted electromagnetic fields, the more twists per length, the greater the reduction.

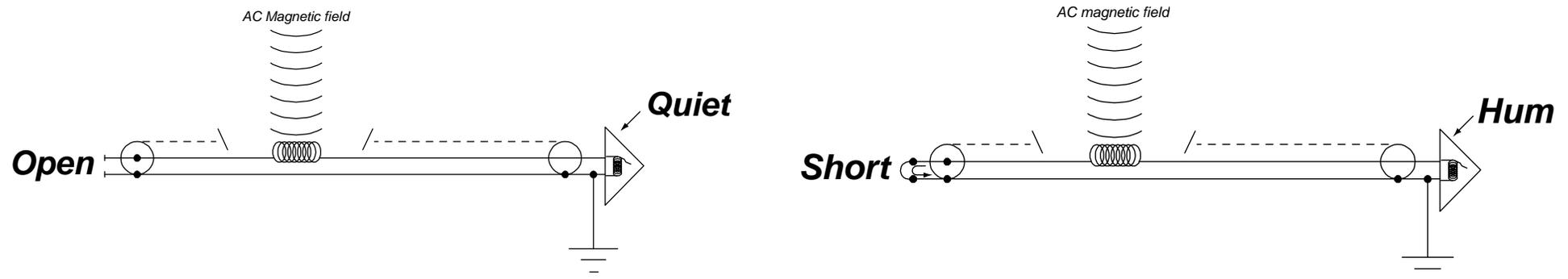
Wire Type	Casing	Resistive Load @ 120V	milligauss reading	
			1/2" Away	2" Away
	24 Volt Wall-wart, transformer type	none	260	101
	24 Volt Wall-wart, transformer type	.06A (7.2 watts)	270	132
	6 Volt Wall-wart, transformer type	none	147	56
	6 Volt Wall-wart, transformer type	.01A (1.2 watts)	145	70
Single #12	Conductor only, not in conduit	7.5A (900 watts) not in proximity to return conductor	180	135
12-2	Romex	7.5A (900 watts)	12.0	7.2
12-2	1" EMT	7.5A (900 watts)	6.9	4.6
12-2	1/2" EMT	7.5A (900 watts)	2.7	1.7
12-2	1/2" Rigid	7.5A (900 watts)	1.5	0.9
14-3	Rubber Cord, approx. 2" twist	7.5A (900 watts)	1.2	0.4
12-2	1/2" steel-clad spiral MC	7.5A (900 watts)	0.6	0.1
12-3	THHN, 1" twist, no conduit	7.5A (900 watts)	0.3	0.2
12-3	THHN, 1/2" twist, no conduit	7.5A (900 watts)	0.1	0.0

## AC Magnetic Fields & Their Effect on Signal Wiring

Diagnosing Hum & Buzz: When diagnosing signal problems caused by electromagnetic fields, it is helpful to short the source end of the cable. Cable shields protect against electric fields, not electromagnetic fields. Permanent magnets cannot affect the signal path. If a signal cable with a shorted source end hums and the hum goes away when the short is lifted, the interfering field is likely an AC magnetic one. AC magnetic fields generally sound like “hum,” electrical fields and high order triplen harmonics generally sound like “buzz.”

There are two effective ways to reduce the effect of AC magnetic fields on the signal path:

1. Physical separation of at least 2” between the signal and power conductors inside a rack
2. Using tightly-twisted signal wire and AC power cables



## Electric Fields & Their Effect on Signal Wiring

Diagnosing Hum & Buzz: When diagnosing signal problems caused by electric fields, it is helpful to open the source end of the cable. Cable shields protect against electric fields, not electromagnetic fields. If a signal cable with an open source end buzzes and the buzz goes away when the cable is shorted, the interfering field is likely an electric one. There are many ways electric fields cause current flow in the signal path; one example is shown.

There are many effective ways to reduce the effect of electric fields on the signal path:

1. Use cables with heavy braided-copper shields
2. Follow good signal path design and installation practices.

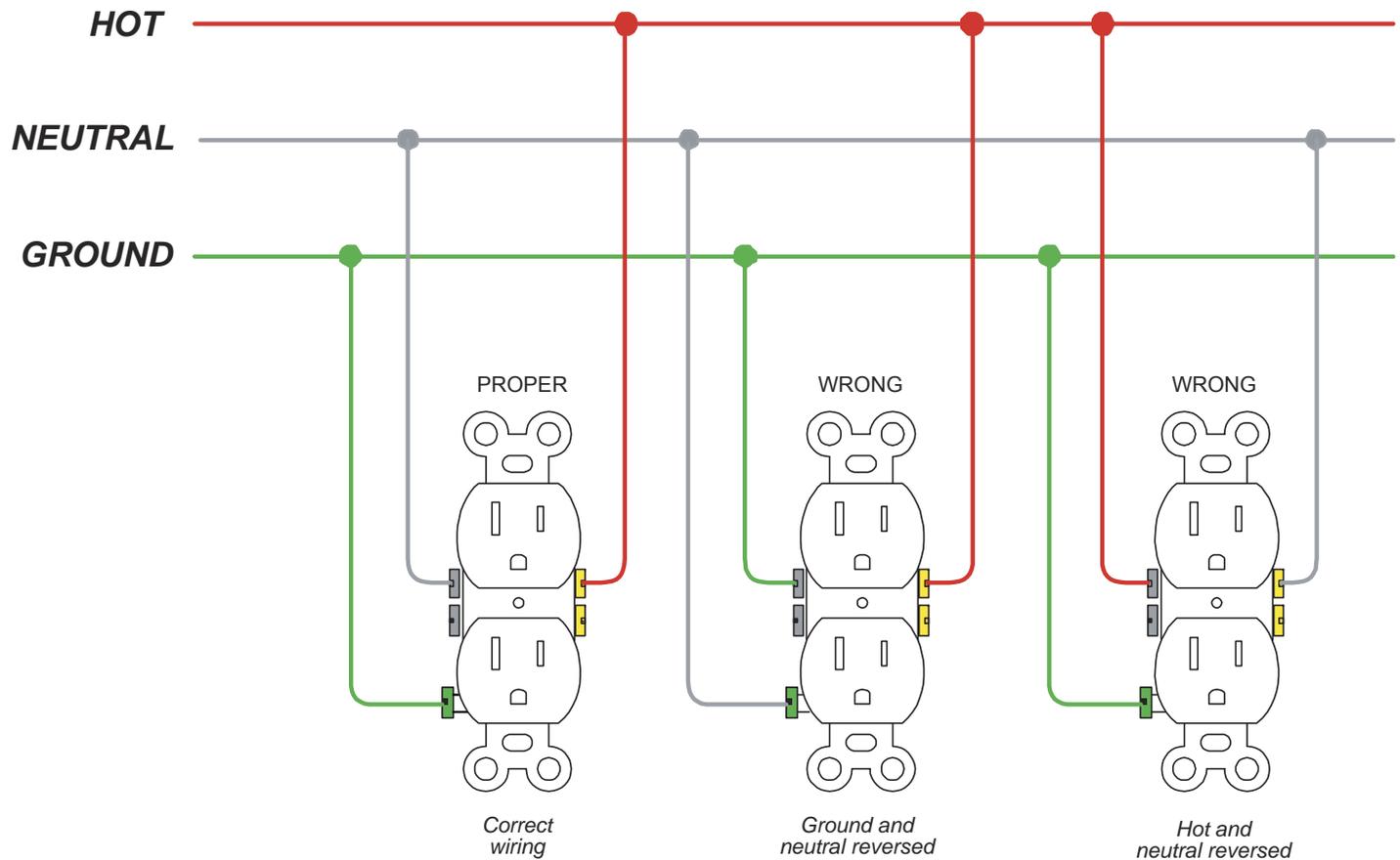


For more information on good signal path design, refer to these and other published documents\*:

- "Hum & Buzz in Unbalanced Interconnect Systems" – Bill Whitlock
- "Noise Susceptibility in Analog and Digital Signal Processing Systems" – Neil Muncy
- "Common-Mode to Differential-Mode Conversion in Twisted-Pair Cables (Shield-Current-Induced Noise)" – Jim Brown & Bill Whitlock
- "Testing for Radio-Frequency Common Impedance Coupling (the Pin 1 Problem) in Microphones and Other Audio Equipment" – Jim Brown

\*publishing information for listed articles can be found in references section

## Common Wiring Errors



These wiring errors may not be detected by simply plugging in your equipment; it will seem to work ok, but it may cause electrical noise and may be hazardous. Always test the outlets by using a meter.

If the neutral and hot conductors are reversed, it can be detected by using a voltmeter. Between neutral and ground the meter should never display more than a few volts. Between hot and ground the meter should display 120 volts (nominal).

If neutral and ground conductors are reversed, it can be detected by using a clamp-on amp meter installed on the ground conductor (with a load on the circuit). No current should flow through the ground conductor (other than equipment leakage current) under normal circumstances.

Inexpensive “three prong” testers **cannot** detect ground and neutral reversal. **This reversal can be a significant cause of system noise.**

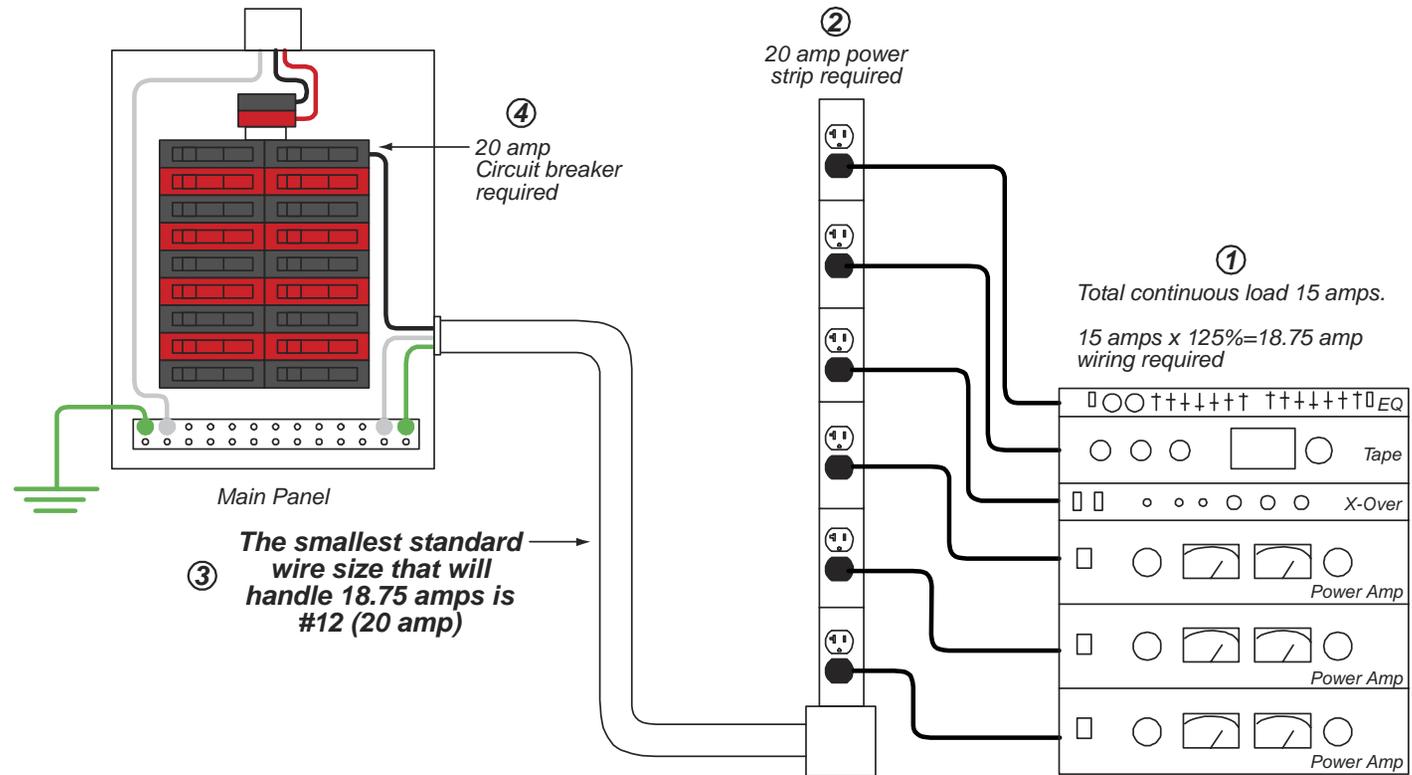
# Calculated Load

If an electrical load is normally operated for three hours or more it is termed by the NEC as “continuous” (Article 100, definitions). The wiring and the over current protection (circuit breaker) must be sized at 125% of the load. If the load is normally operated for less than three hours, the wiring may be sized at 100% of the load. Although the NEC allows 100% circuit sizing, it is not advised due to the amplifier headroom that may be required to faithfully reproduce peaks.

General Rule: The load determines the wire size; the wire size determines the circuit breaker size.

There are many other factors that may increase the wire size required. The most common factors include:

- a) Length of run (voltage drop)
- b) Ambient temperature
- c) The number of conductors in a conduit (heat build-up)



## Amplifier Load

Since the current demand of audio amplifiers is dependent on many factors, do not rely solely on the nameplate or spec sheet rating for load calculations.

Following are typical examples of how applying different loads and varying program material can change the overall current draw of the **same amplifier**.

<u>Program Type</u>	<u>Speaker Ohms</u>	<u>AC Current Draw</u>
Individual Speech	8 Ohms (Stereo)	4.1 Amps
Individual Speech	2 Ohms (Stereo)	5.8 Amps
Compressed Rock Music	8 Ohms (Stereo)	13.4 Amps
Compressed Rock Music	2 Ohms (Stereo)	20.1 Amps

As you can see from the above example, the current draw varies considerably depending on the intended use of the amplifier and the way it's connected.

These factors, depicted in the above examples, will have an affect on selecting the proper ampacity of the circuit(s) required to power your amplifiers.

When sizing an amplifier power supply circuit, the calculated load should be multiplied by 125% in order to determine the conductor size and overcurrent protection (circuit breaker) required. This additional capacity will allow for adequate "headroom", and compensate for voltage drop when your amplifier is required to reproduce peaks in program material.

Calculation Example: If the calculated load is 17 amps, the minimum size conductor would normally be #12 copper (20 amps), however, if the 125% factor is applied ( $17 \text{ amps} \times 125\% = 21.25 \text{ amps}$ ), the next standard wire size is #10 (30 amps).

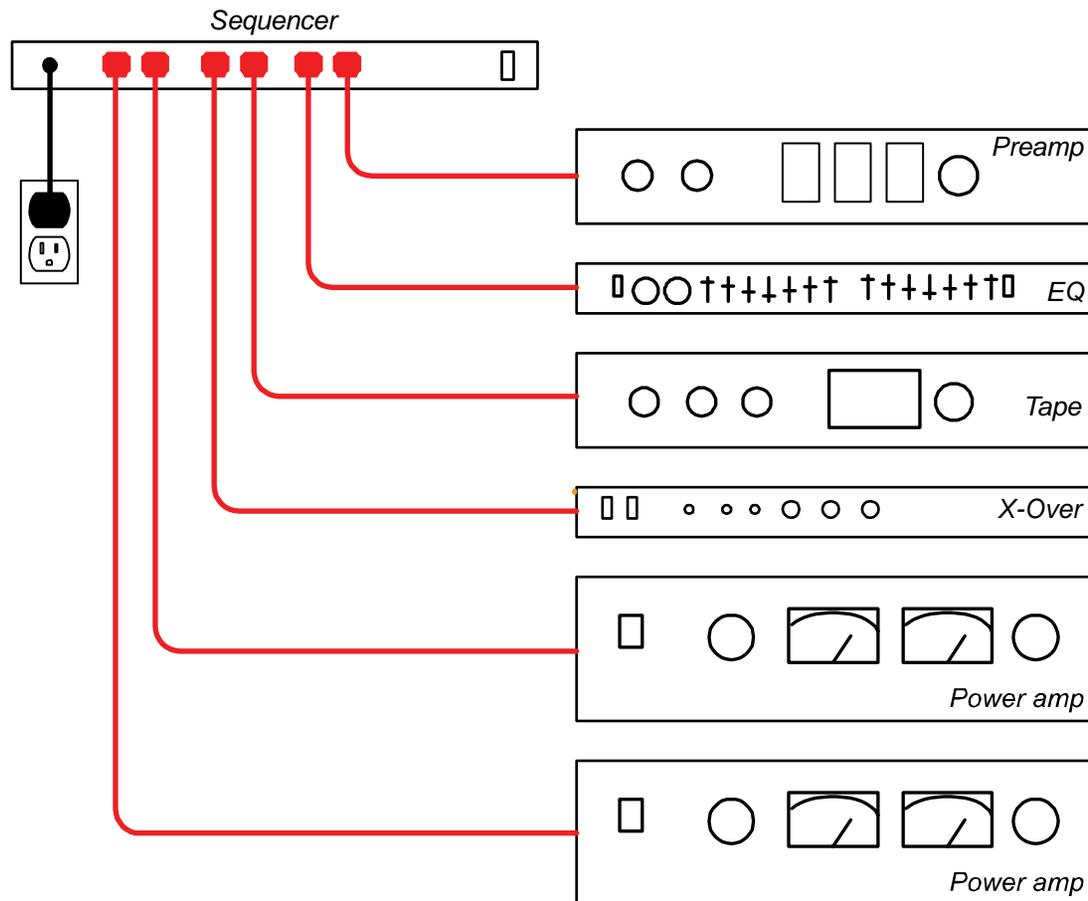
The gross over sizing of branch circuits may be somewhat restricted by the National Electrical Code in some cases. Consult the amplifier manufacturer for maximum circuit size specifications. Modifying or changing input connectors (plugs) could void the UL listing and the product warranty if it is done in such a manner that is inconsistent with the installation instructions.

# Single Circuit Sequencer System

Two problems can occur when a sound system requires power switching on and off on a regular basis: loud “pops” result from source or processing equipment that is turned on after power amplifiers, putting speakers at risk, or the circuit overloads from the in-rush current to power amplifiers. These problems can both be solved with a sequencing system.

This type of system is used when the total electrical load of all the controlled equipment does not exceed 80% of the capacity of the stand-alone sequencer.

Power amp section must switch on last and switch off first.

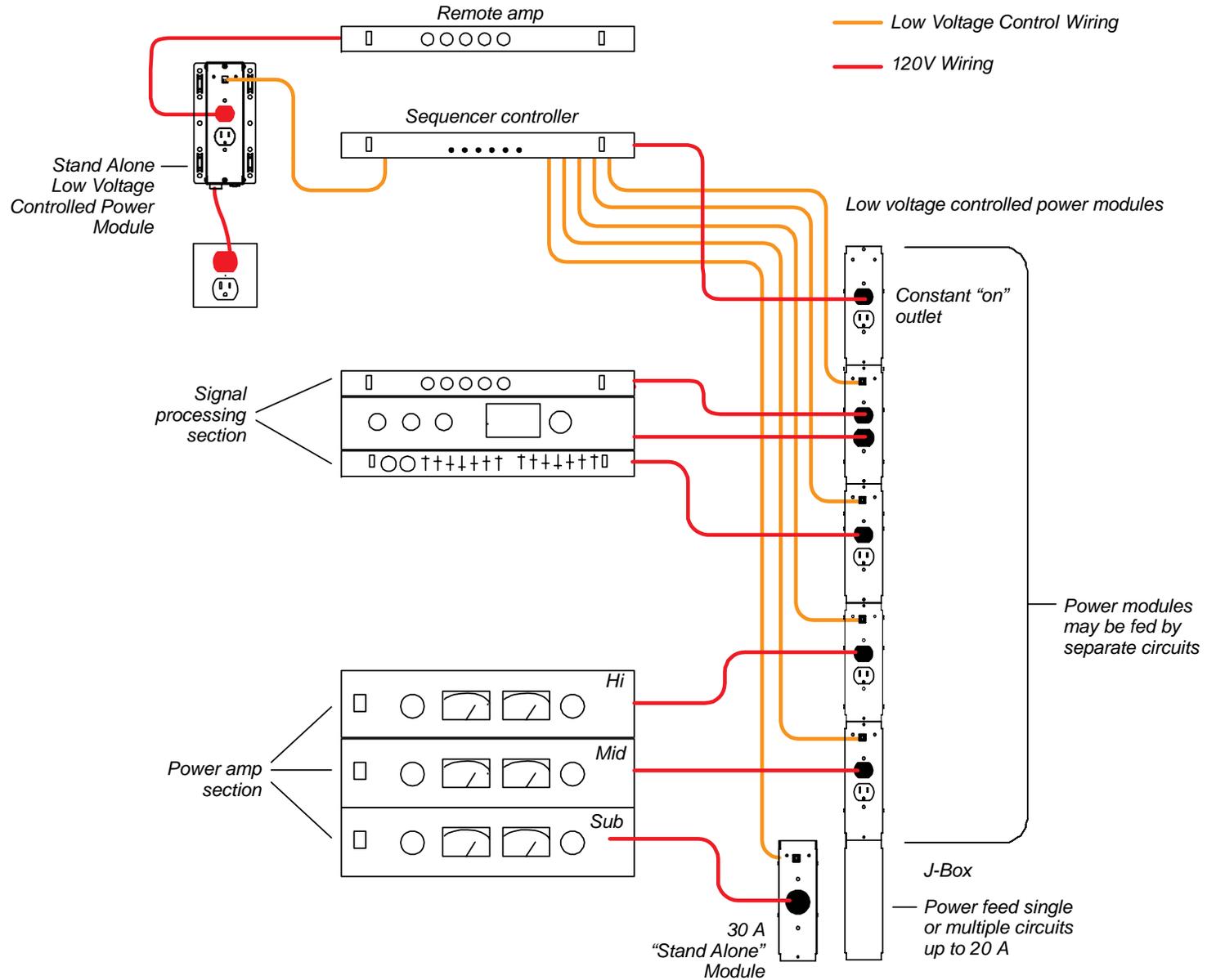


# Sequencer Systems (Multiple Modules)

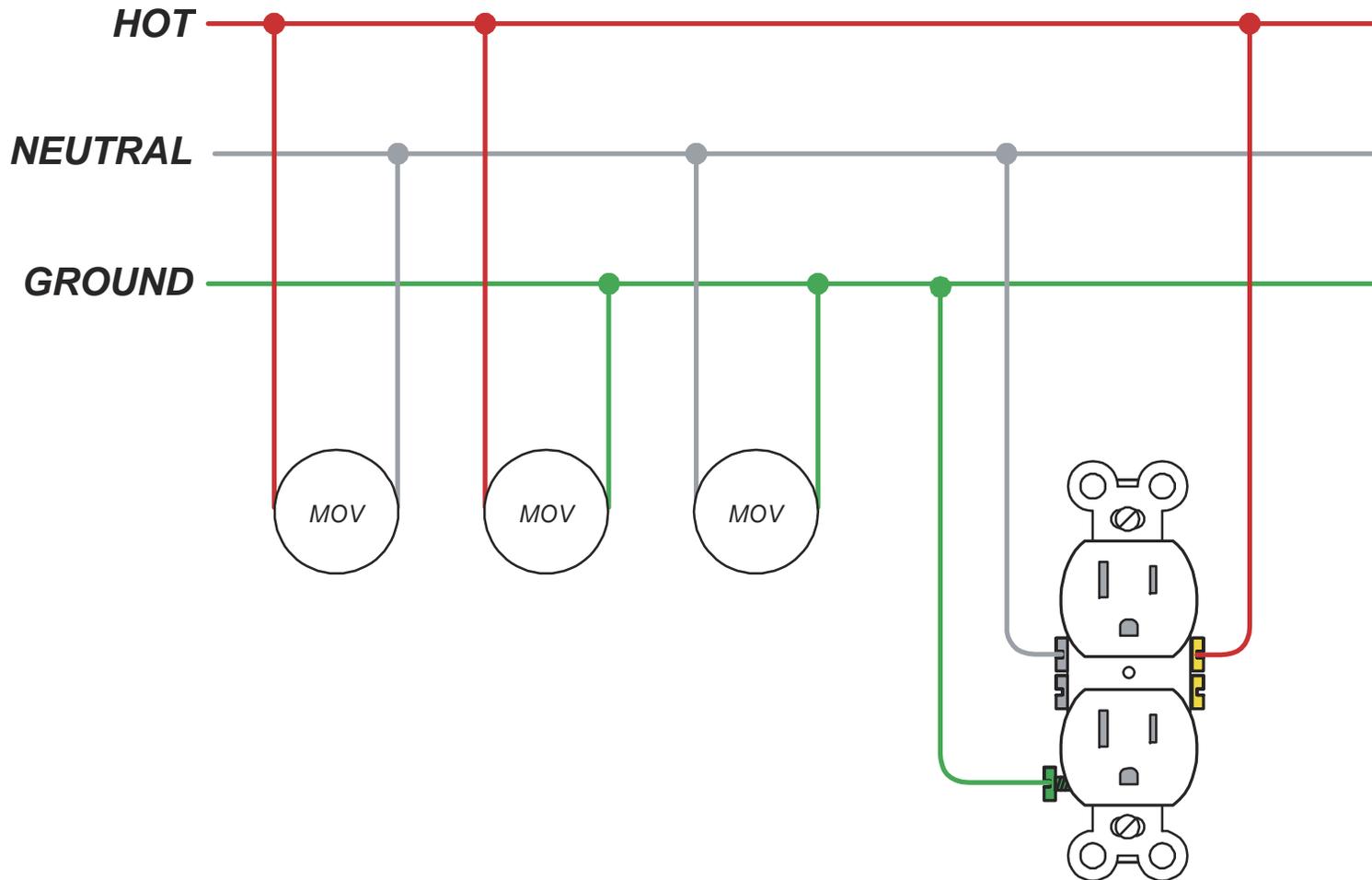
This type of system is used when the total electrical load of all the controlled equipment exceeds the capacity of a stand-alone sequencer, or if multiple locations are required.

Power amp section must switch on last and switch off first.

## Sequencer Systems

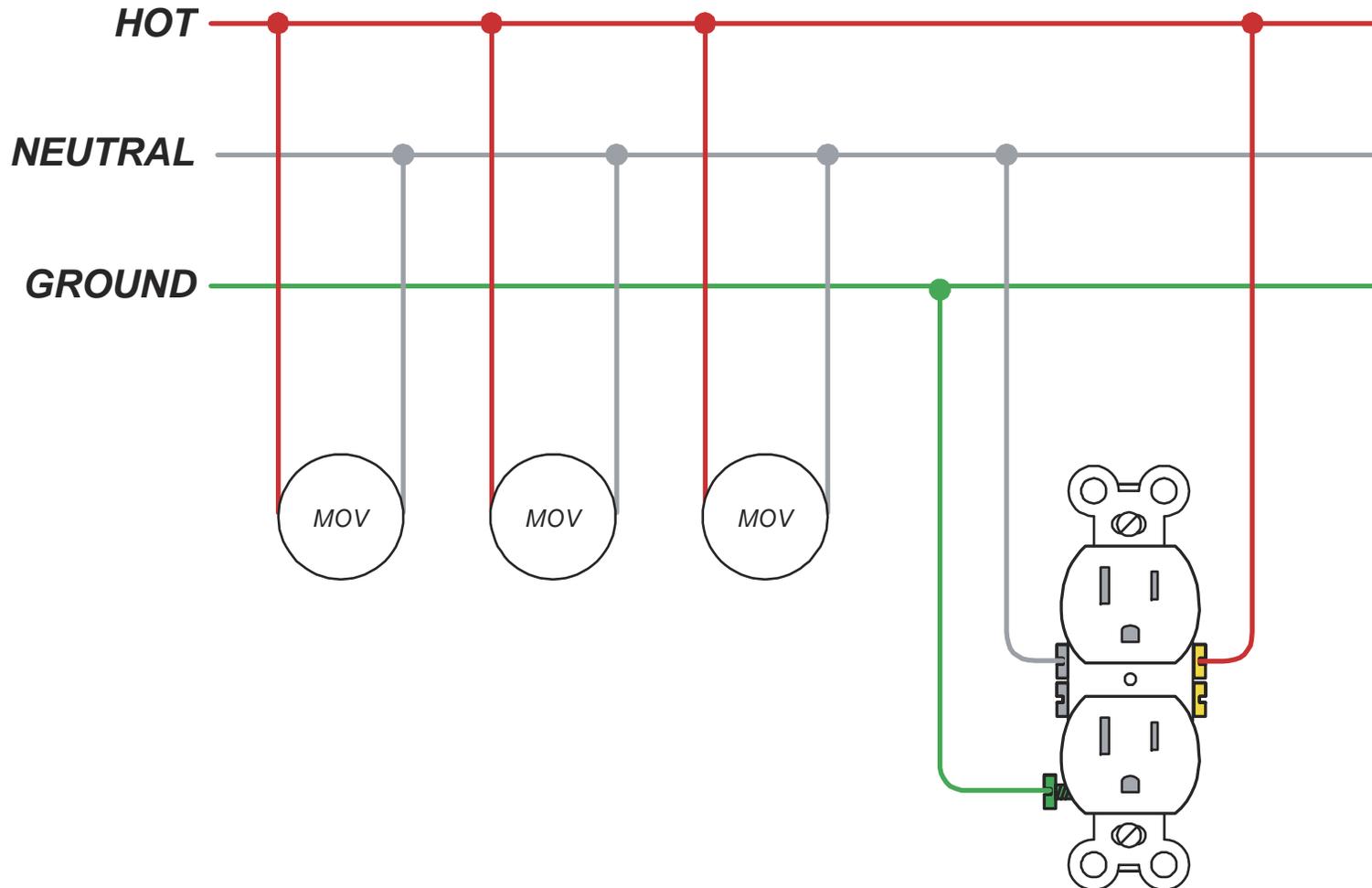


## Branch Circuit Surge Suppressor Design that **Can Pass Noise** to Ground



A disadvantage with this design is that the MOV's capacitance couples higher frequency line noise to the ground circuit. Another disadvantage is that the ability of an MOV to absorb further surges is permanently reduced when subjected to surges above its rated capacity. The use of this type of surge suppressor at outlets can actually increase the risk of equipment damage. This occurs because during a large surge or spike, very high voltage differences are created in the safety ground system. These differences can appear across the signal wires interconnecting equipment and damage input and output circuitry.

## Branch Circuit Surge Suppressor Design that Does Not Pass Noise to Ground



Since the MOVs are not connected to ground, this design eliminates the possibility of noise returning to ground.

Metal oxide varistors (MOV) conduct electricity above a predetermined voltage. When this predetermined voltage is reached, the MOV conducts and shunts the surge. Since single MOVs are limited in their ability to pass large surges, several MOVs may be wired in parallel to increase their capacity.

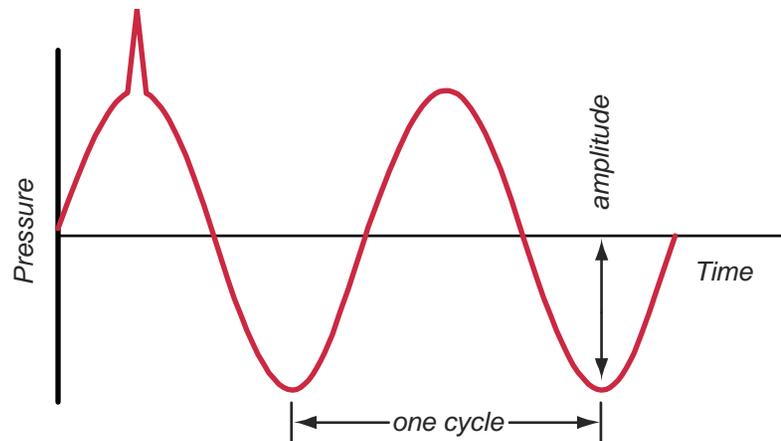
## The Specifics of Transformer Action on Transients

Voltage transients (sometimes called spikes) are rapid changes in voltage typically caused by nearby lightning strikes, power grid switching, motor control circuits, etc. Transients can be of two types, differential mode (also known as transverse mode or normal mode) or common mode.

Differential mode transients occur between load current conductors. Load current conductors on 120 volt circuits are known as line and neutral. Transformers, whether shielded or not, pass differential mode transients.

Common mode transients are generally defined as undesirable voltages appearing on the neutral conductor with respect to the grounding conductor. These transients may be coupled through the transformer's inherent inter-winding (primary to secondary) capacitances.

Including a Faraday (also known as electrostatic) shield inside the transformer diverts common mode transient current to ground, effectively preventing it from appearing on the secondary.



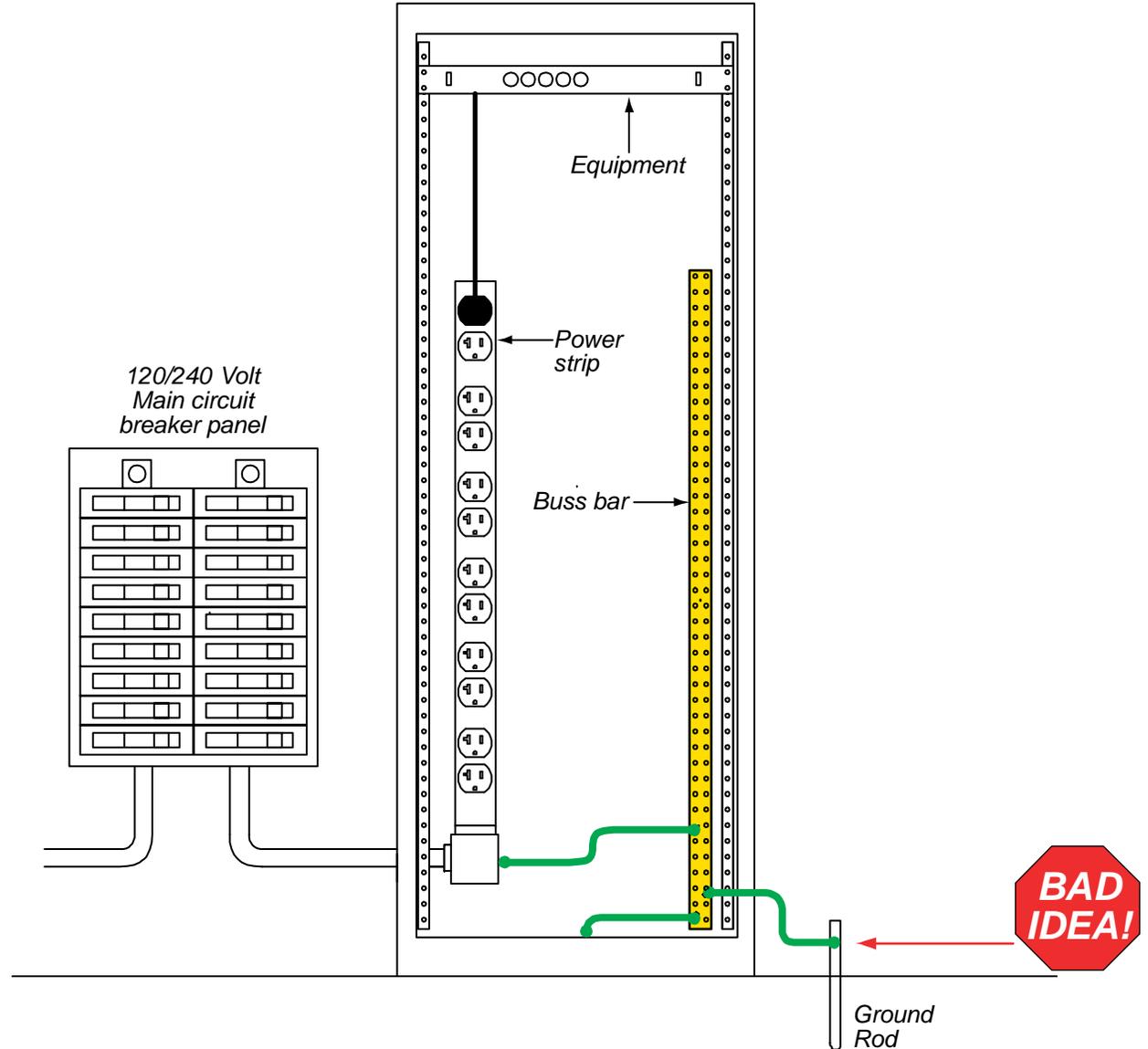
Supplemental grounding is not required or recommended because it may cause severe ground loops and may also be a safety hazard if not bonded properly.

Do not install multiple ground rods or additional ground rods, except as required per code.

Supplemental grounding via a ground rod or building steel is allowed by the NEC, though it must be bonded to the main safety ground (Article 250 III).

Never bond an isolated ground to the ground rod or building steel. Isolated grounding conductors must only be terminated in the main circuit breaker panel.

## Bonding Gone Bad



## Isolated Ground Receptacles

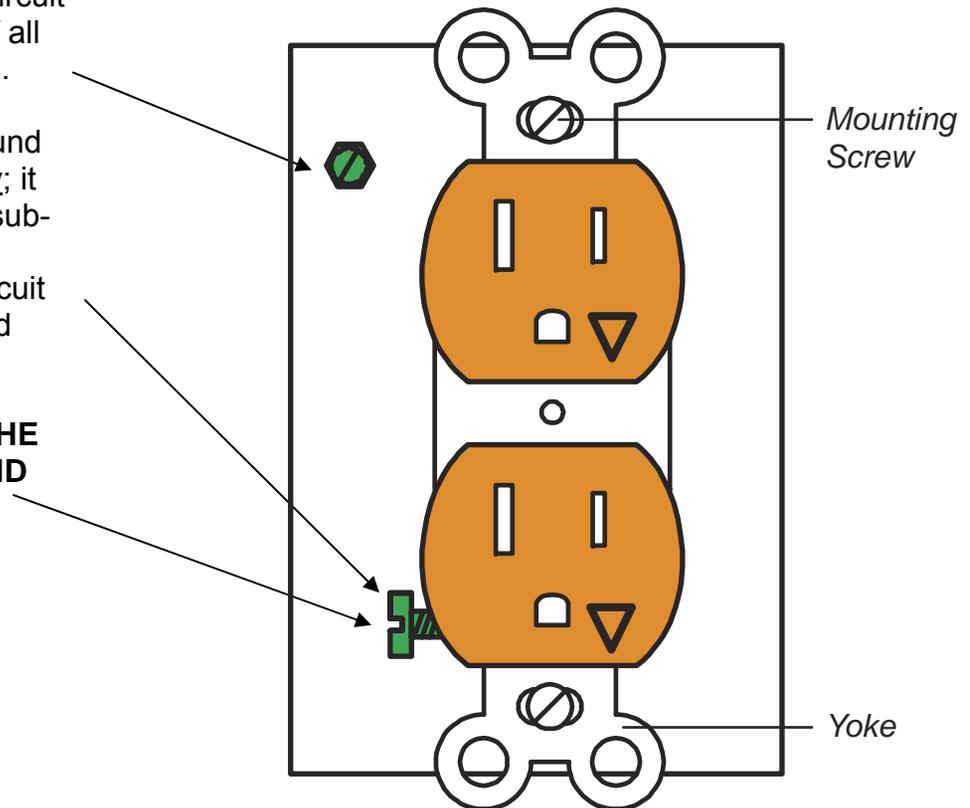
Mounting screws and yokes of isolated ground receptacles are not electrically bonded to the outlet ground screw. The outlet ground screw is only connected to the ground prong on the outlet face. This separates the isolated (technical) ground from the building ground.

The electrical box must be bonded to the building ground. If a supplemental equipment grounding conductor is installed for box grounding, it must be installed in the conduit with the circuit conductors. It may be bare or insulated. The grounding of all metallic components is also referred to as a Safety Ground.

The isolated ground conductor connected to the outlet ground screw must terminate in the main circuit breaker panel only; it may be spliced when passing through junction boxes and sub-panels, but must not terminate in them. Isolated ground conductors must be insulated, and must be run with the circuit conductors up to the point of their termination. The isolated ground is also referred to as the Technical Ground.

**DO NOT BOND THE OUTLET GROUND SCREW TO THE ELECTRICAL BOX WHEN USING ISOLATED GROUND RECEPTACLES**

*The mounting yoke is not bonded to the ground screw or ground prong hole on isolated ground receptacles as with standard outlets.*



# Isolated (Technical) Ground vs. Safety & Building Ground

## **Grounding in general:**

The National Electrical Code (NEC) defines ground as: “A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or to some body that serves in place of the earth.” Some may find this definition confusing and misleading. Here’s why:

In most electrical systems the term “grounding,” as it is commonly interpreted, has little to do with the connection to the actual “earth,” although it is required that the grounding system be in contact with earth, at the source of supply. One practical reason for the connection to earth is to divert current that is caused by a lightning strike. Diverting current that is caused by a lightning strike is important but in practical applications the term “grounding” refers to a return path of “fault current” back to its source. Fault current is commonly referred to as a “short circuit.” Fault current will return to its source, not to the ground (earth). The source may be a transformer, generator, UPS, etc.

An important reason equipment is grounded is to provide a low impedance path for fault current so that over-current protection devices (circuit breakers & fuses) can stop the flow of current in the event of a ground fault. Other types of faults include overloads, phase to phase, and phase to neutral. These types of faults will not be addressed here, since they have nothing to do with the grounding system.

## **Safety Ground & Building Ground:**

Safety ground is also referred to as “building ground”. Normal grounding schemes bond all metallic structures and include water pipes, building steel, concrete re-enforcing rods, machinery, A/C systems and any other parts of a building that are “likely to become energized” or that are in direct connection to earth.

A direct electrical service ground is one of the best points for grounding communications systems. In new construction, an electrical contractor must provide accessible means. NEC 250.94 requires any intersystem bonding connection accessible at the electrical service equipment.

Grounded building structures and piping systems have varying resistances and impedances. Voltages induced from power conductors or equipment leakage currents cause small amounts of current to flow on the ground circuit. Metallic building structures can act as receiving antennas for high frequency interference. All conductors in a facility modify the electric and magnetic fields in the area. They all carry current to some degree. Some people refer to metallic building structures as “dirty” or “noisy” but with a properly designed system (including proper grounding), these structures will have no effect on the signal.

Under many circumstances grounded building structures do not have an adverse effect on electronic equipment, and the ground circuit will perform as intended to conduct fault current back to the source. However, equipment that does not comply with the AES48 standard (“pin-1” problem) and signal interconnect cabling not installed to best practices may be susceptible to noise and be adversely affected by small currents on the ground circuit. Equipment must still be grounded for safety, so what can be done? Two effective equipment grounding schemes are an Isolated Ground System and a Mesh Ground System.

## Isolated (Technical) Ground vs. Safety & Building Ground (cont'd)

### **Bonding:**

The term “bonding” is often confused with “grounding”. Although these terms are sometimes used interchangeably, they are quite different. The NEC defines “bonding” as: “The permanent joining of metal parts to form an electrically conductive path that ensures electrical continuity and the capacity to conduct safely any current likely to be imposed.”

### **Isolated Ground:**

An isolated ground is also referred to as a “technical ground” or “isolated single-point ground”.

Equipment that is connected to an “isolated ground” system is still grounded, but the bonding point of the ground connection is ONLY at the main circuit breaker panel or at the first panel after a transformer. This grounding conductor must be insulated. It may be spliced when passing through sub-panels or junction boxes, but must not be terminated in them.

Since the isolated grounding conductor does not make contact with the building structure (except at the source end), undesirable current flow on this ground circuit is greatly reduced.

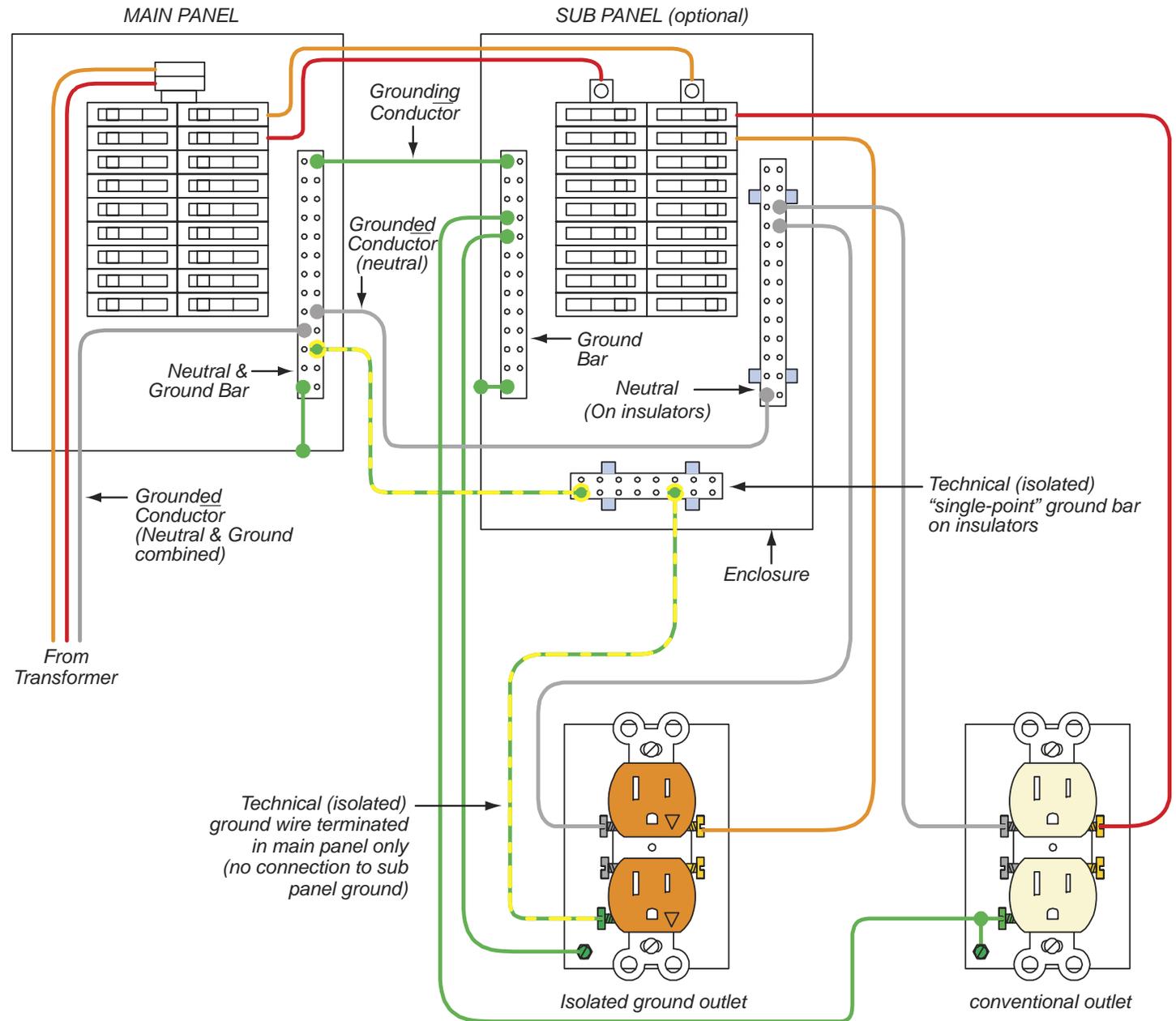
One problem with an isolated ground circuit is that its integrity is easily compromised. Any inadvertent connection between the isolated ground system and the building ground can actually increase undesirable current flow in the isolated ground system, giving an opportunity for noise to enter the signal path.

Other problems with isolated ground systems arise when the installation is in close proximity to wide-band RF sources (i.e. radio or TV transmitters). In these instances the system can act as an antenna to receive these RF sources. Further, isolated ground systems can be vulnerable to large induced voltages from nearby lightning strikes.

When isolated ground systems pose these problems, a mesh grounding system may be the best design. Please see the “mesh grounding” section of this white paper

# Wiring Isolated Ground Outlets and Conventional Outlets when Using a Sub Panel

The grounding conductor (ground) and the grounded conductor (neutral) are electrically common, but are bonded together only at the main service panel, at a separately derived transformer or immediately after a separately derived transformer. No further mechanical connection of the neutral and ground is allowed on the load side of the main panel.



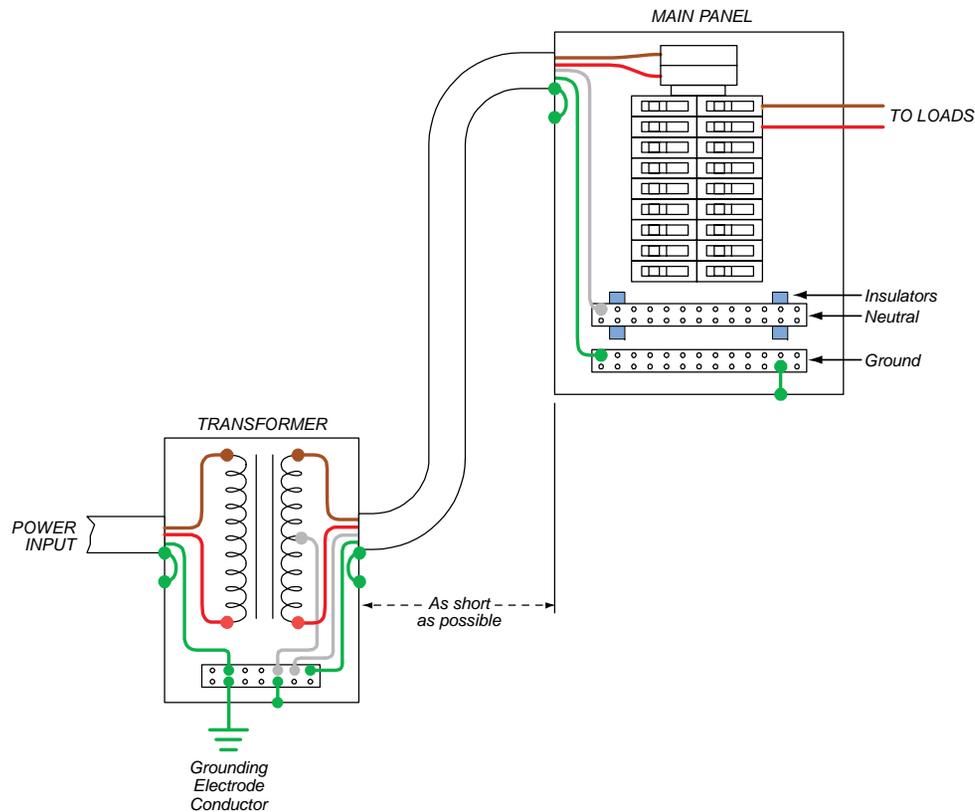
*Technical (isolated) ground wire terminated in main panel only (no connection to sub panel ground)*

# Different Wiring Methods for Separately Derived Systems (Isolation Transformers)

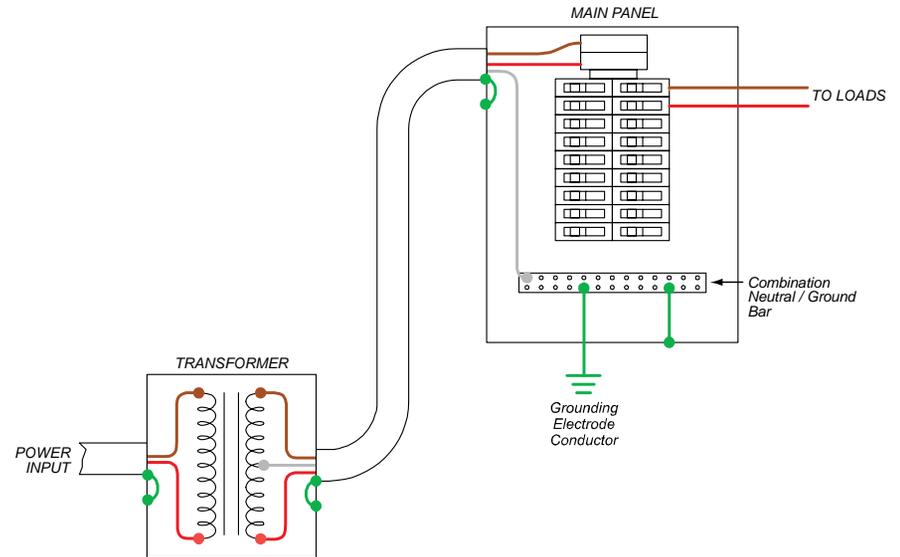
Common-mode noise is generated in facilities by many devices, including elevator motors, lighting dimmers, etc. This noise is present on the AC wiring system. To greatly reduce common-mode noise, an isolation transformer should be used. This provides a new neutral/ground point, and at that point there will be no common-mode noise. As the length of the wire from the isolation transformer to the equipment increases, the chance for induced common-mode noise also increases.

When a voltage is provided by a transformer or derived from a generator or UPS, it is termed “separately derived” (NEC Article 250.30). Technical (isolated) grounds must terminate in the first circuit breaker panel after the transformer or in the transformer itself.

## NEC Approved & Recommended for AV Systems

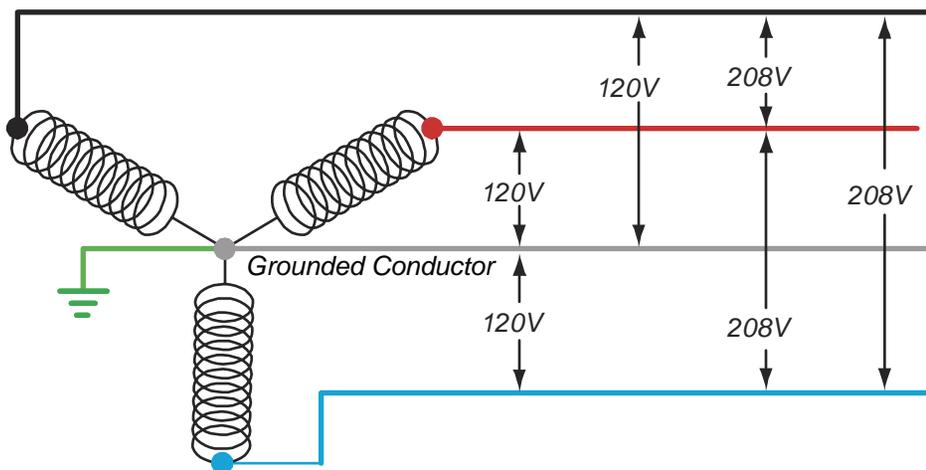


## Also NEC Approved

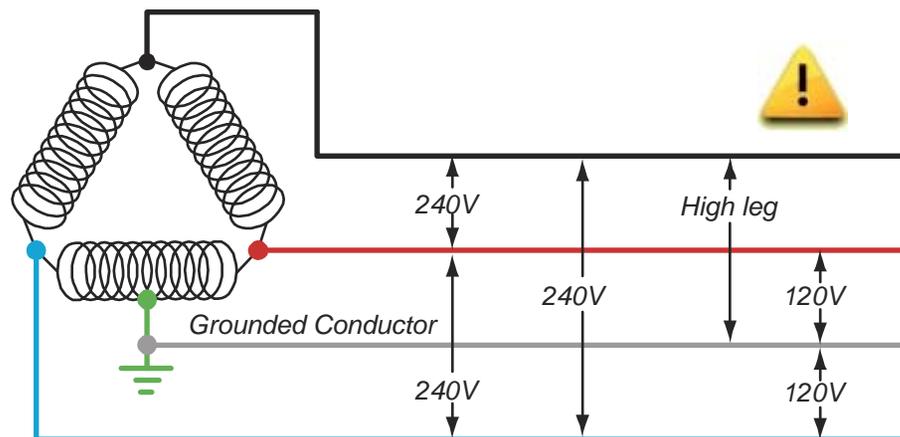


## Typical Three Phase Services

### 120 / 208 Volt "WYE"



### 120 / 240 Volt "DELTA" (High Leg)

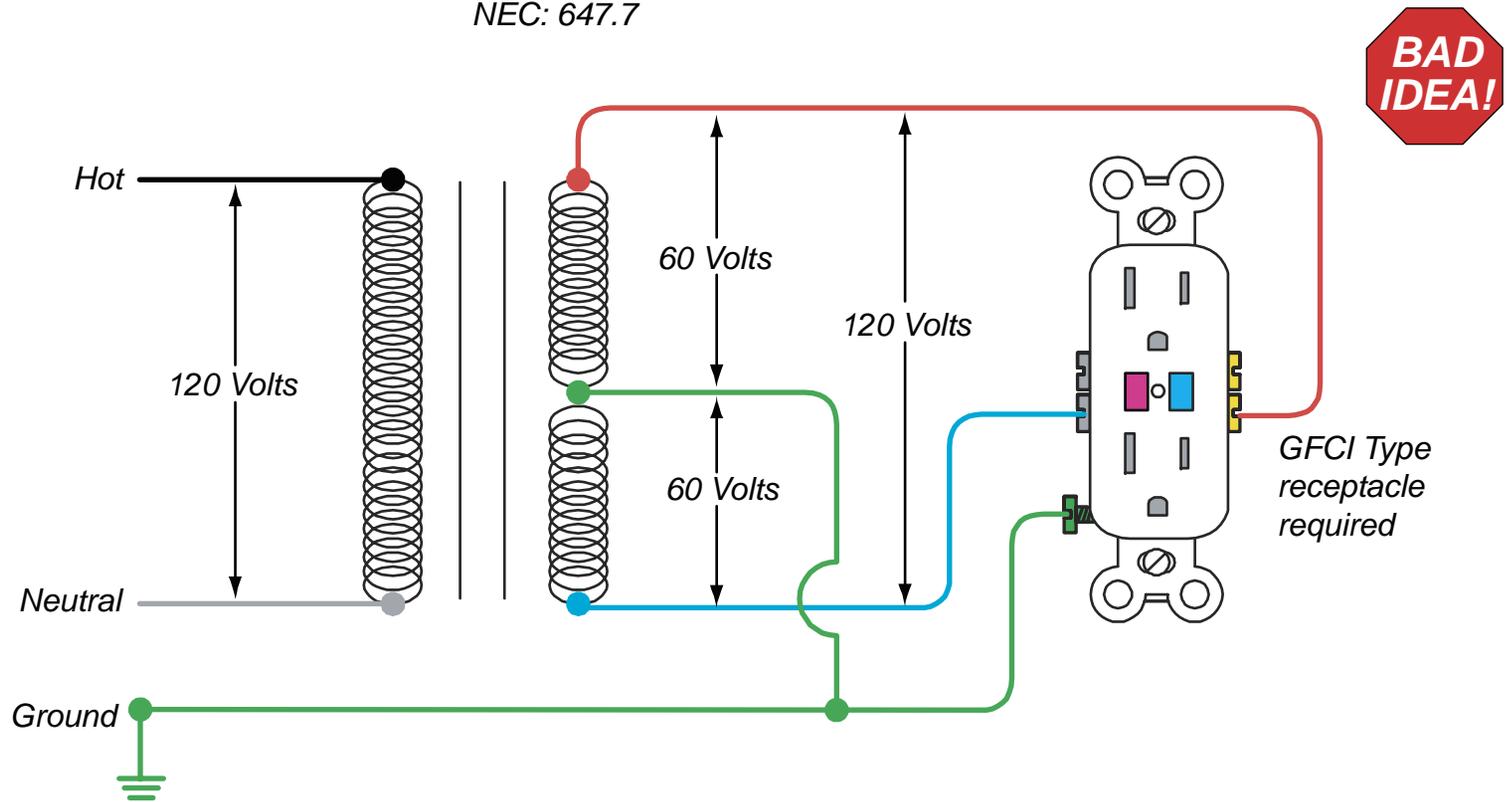


Always check the line voltage on the circuit supplying your equipment before plugging it in.

Although it is not recommended to have a neutral in the same circuit breaker panel that also contains a "DELTA" system "High Leg", there are several systems in the field wired this way. If an electrician mis-wires a circuit using a neutral and high leg, a voltage in excess of 200 volts will appear at what should be a 120-volt outlet! Additionally, if this transformer is shared by other facilities, the neutral/ground currents will also be shared.

# Symmetrical (Balanced) Power Transformer

NEC: 647.7

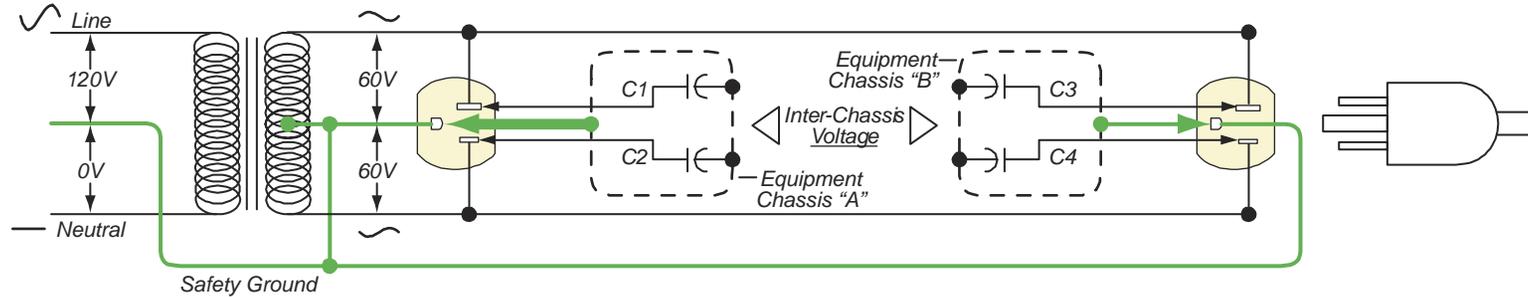


In this 60/120-volt symmetrical balanced power system the load current return path is not a grounded conductor, as it is for the standard 120-volt system. Neutral and safety ground are no longer tied together as in a standard electrical system.

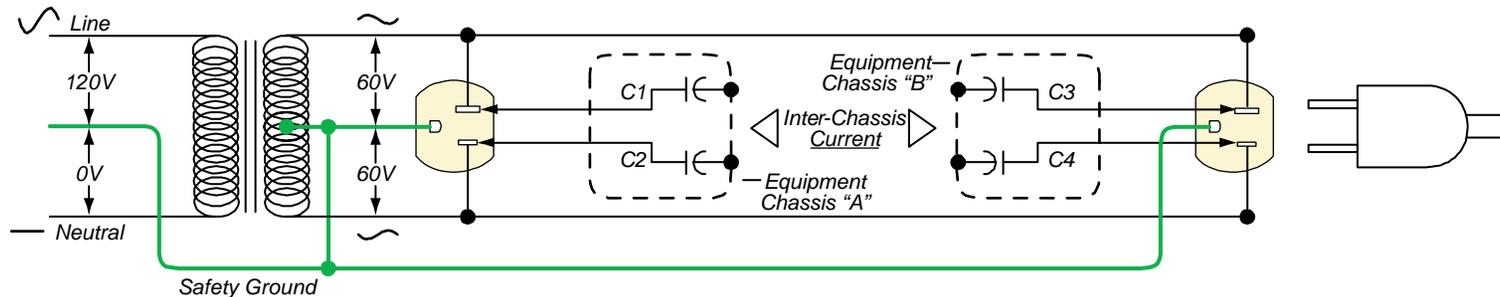
Symmetrical (balanced) power transformers **do nothing** to eliminate differential noise found on the power line.

Another disadvantage of balanced power systems is the requirement for ground fault circuit interrupter receptacles (GFCI). These receptacles can trip due to normal ground leakage currents, and currents that flow through signal interconnect cables in a system.

## Equipment with 3-prong Power Cord fed by Symmetrical (Balanced) Power Transformer



## Equipment with 2-prong Power Cord fed by Symmetrical (Balanced) Power Transformer



The less balanced the internal equipment parasitic capacitances are (pairs C1/C2 and C3/C4), the less effective a symmetrical (balanced) power transformer will be at reducing leakage currents, which are a significant cause of noise in unbalanced signal interfaces.

Since the noise reduction achievable with this scheme is typically only 6 to 10 dB, symmetrical (balanced) power transformers are not a cost-effective method of reducing system noise.

**It is more cost-effective to ground isolate unbalanced signal interconnections or eliminate them and use balanced signal interconnections which are inherently immune to the effects of leakage currents.**

# K-Rated Power Transformers

K-rated transformers are used to deal with harmonic loads. Harmonics generate additional heat in the transformer and can cause non-K-rated transformers to overheat, reducing the life of the transformer, and possibly causing a fire. The value used to describe how much harmonic current a transformer can handle without exceeding its maximum temperature rise is referred to as a K-Factor Rating. K-factor values range from 1 to 50.

K-4: A transformer with this rating has been designed to supply rated KVA, without overheating, to a load made-up of 100% of the normal 60 Hertz, sine-wave, fundamental current plus: 16% of the fundamental as 3<sup>rd</sup> harmonic current; 10% of the fundamental as 5<sup>th</sup>; 7% of the fundamental as 7<sup>th</sup>; 5.5% of the fundamental as 9<sup>th</sup>; and smaller percentages through the 25<sup>th</sup> harmonic. The “4” indicates its ability to accommodate four times the eddy current losses of a K-1 transformer.

K-13: A K-13 transformer can accommodate twice the amount of the harmonic loading of a K-4 rated transformer, and is recommended for normal AV systems.

Power conductors that feed audio and video equipment often contain harmonics. These harmonics consist of frequencies much higher than 60Hz.

Harmonics primarily originate in equipment such as:

- a) Computers and other equipment with switch mode power supplies that do not employ “power factor correction”
- b) Electronic Ballasts
- c) Motors and Controllers that use variable frequency drives
- d) Most lighting dimmers
- e) Power amplifiers and other equipment with DC power supplies containing large capacitors

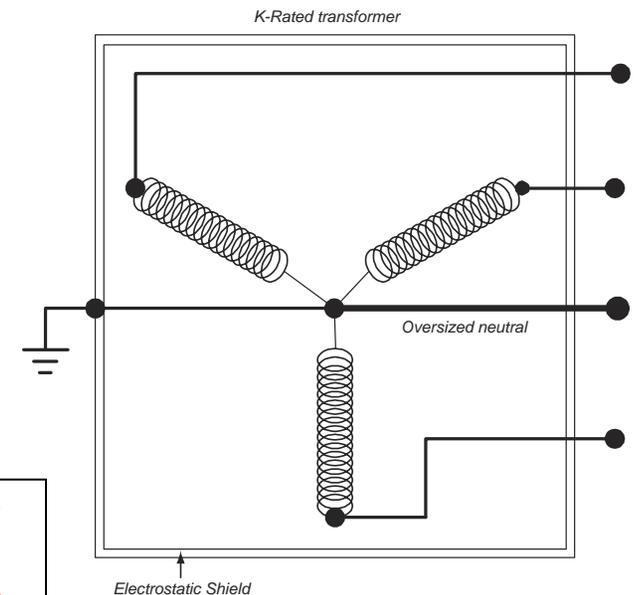
Some problems created by harmonic currents are:

- a) Over-heated neutrals
- b) Over-heated transformers
- c) Malfunctioning generators
- d) Burned-out motors
- e) Tripped circuit breakers

**K-Rated transformers do not eliminate harmonics. They are designed to tolerate the heating effects of harmonics created by much of today’s electronic equipment.**

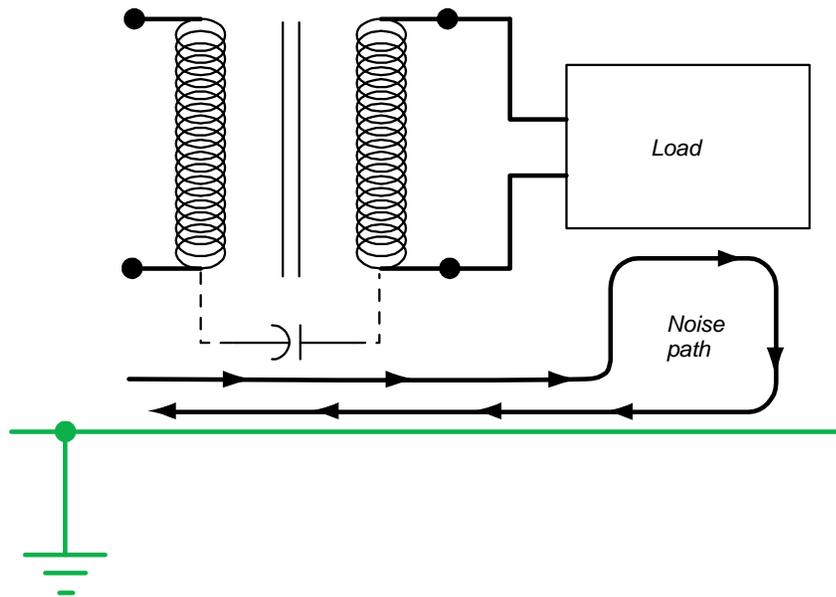
Some features of K-Rated transformers are:

- a) Oversized neutral, since much of the harmonic current appears on the neutral
- b) Special high efficiency coil windings
- c) Attenuates triplen harmonic currents from the line
- d) Low impedance and temperature rise

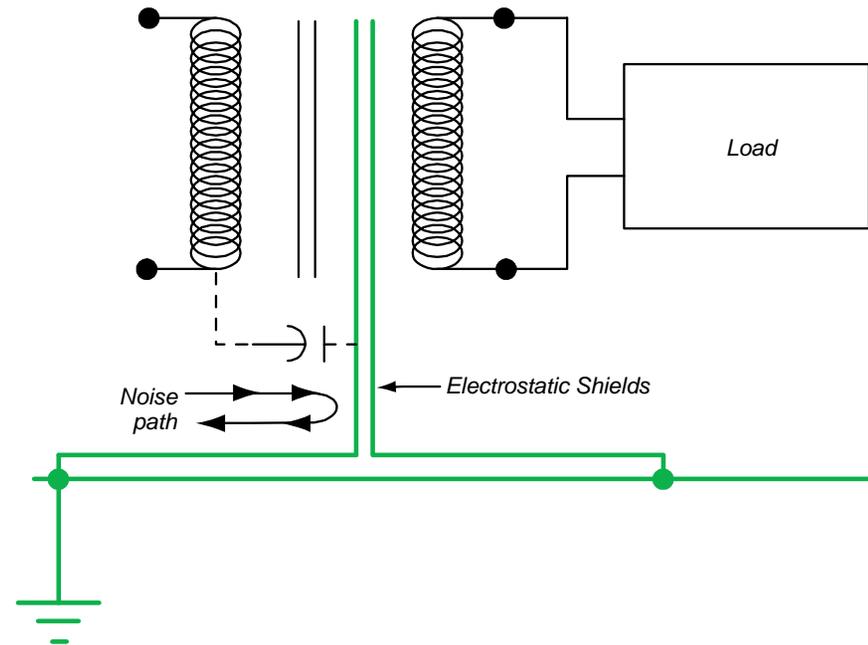


# Electrostatic Shielding in Power Transformers

Standard Power Transformer



Power Transformer with Electrostatic Shields



Electrostatic shields reduce common-noise coupling between the primary windings and the secondary windings, improving the isolation.

## Phasing of Supply Conductors

When designing power distribution systems under normal circumstances, electrical engineers will balance the loads among all the phase conductors in order to reduce the load on individual phase portions of transformers and circuit breaker panels. This is not always the best design for AV systems.

- **Three Phase** electrical service is most commonly found in larger commercial and industrial buildings where there are motors, air conditioners and lighting controllers. Due to leakage current and “conducted emissions” produced by most equipment, loads on each phase usually couple a small amount of noise onto the ground circuit. Because these phases are separated by 120 degrees, some of the harmonic current in the neutral conductor is tripled. These currents are referred to as “triplen” harmonics.
- **Split single phase** electrical service is most commonly found in residences and smaller commercial buildings, and can be used to feed AV equipment. One advantage it has over three phase is that “triplen” harmonics are not present. In addition, use of split single phase can result in at least a 6 dB reduction in noise floor as compared to three phase if the capacitances of the connected equipment are relatively well balanced.

### Note:

Video equipment is usually connected using unbalanced shielded cables, and is therefore very sensitive to ground loops. In an installation where the remote cameras are mounted to grounded building structures, the cameras will likely be at a different ground potential than the ground at the monitoring station. This difference in ground potential may induce a ground loop in the camera cable shield. Grounding problems will not be corrected by connecting all equipment to a single phase. To “break” the ground loop, ensure signal transformers are installed, or ensure the camera is isolated from building steel.

# Simplified Grounding Guidelines for Audio, Video and Electronic Systems

- **“Hum & Buzz-Free”** and “clean” video can ONLY be obtained by having a “noise-free” signal path. Signal path noise vulnerability depends on whether the interface is balanced or unbalanced. Design and installation of the signal path must include noise interference rejection schemes and effective grounding. Useful information about signal path design can be found by doing an internet search of “electromagnetic induced noise,” “AES48,” “pin 1 problem” and “shield SCIN.” There are also excellent design guidelines listed in the references section of this white paper.
- **Proper grounding** reduces only ONE source of noise. Best practices of good signal path design include good cable management (keeping signal cables more than 2” away from AC wires when run parallel) and twisting signal conductors. It is permissible to strap signal cables to power cables if the conductors of both cables are twisted tightly and evenly. Both the primary electrical system grounds and the signal interconnection system grounds need to be properly designed and installed to achieve a “noise free” system.
- **Electrical grounding** is necessary to limit danger to the user from hazardous voltages due to lightning, some surges, and ground faults caused by equipment failure or conductor insulation failure. Proper electrical grounding assures safety by providing a low impedance path for “tripping” protective devices such as circuit breakers and fuses when a ground fault (short circuit to ground) occurs. This saves lives. Defeating a safety ground to reduce noise is illegal, dangerous and should never be done!
- **There are several meanings of the word “ground”** which contributes to confusion and misunderstanding. Most commonly, ground refers to a return path for fault current. In electrical utility power, a ground is an actual connection to soil for the purpose of lightning diversion and dissipation and for the purpose of keeping the exposed surfaces at the same potential as the soil. Building safety grounds provide a return path specifically for fault current. The safety ground for audio, video, and other electronic systems must work in conjunction with the building (facility) safety ground. Safety ground connections that are loose or corroded may cause hazardous conditions and system noise.
- **For optimal performance of AV systems using a technical (isolated) ground scheme, all safety grounds must terminate at only one point.**

# Signal Wiring

Long runs of unshielded and untwisted conductors are susceptible to external noise emissions because they behave as antennas. A signal in a conductor can be coupled as noise to adjacent conductors running in close proximity. Telecommunications network cabling can also conduct EMI noise generated from internal sources and radiate or couple the EMI noise to other conductors.

Careful attention to audio or video system grounding can certainly reduce the severity of system noise problems. But, regardless of how intelligently we implement system grounding and power distribution, two system “facts of life” remain:

1. Tiny *voltages* will always exist between pieces of grounded equipment, and
2. Tiny *currents* will always flow in signal cables connecting ungrounded equipment.

As a result, ***small power line “noise” currents will always flow in the signal cables that interconnect equipment.*** In an ideal world, if all equipment had well designed balanced interfaces, these currents would not be a concern at all. However, real-world equipment isn’t perfect and can’t totally prevent coupling of noise into signal circuits as these currents flow in signal cables. Generally, the noise is heard as hum or buzz in audio and seen as hum bars in video. Shield current can be attenuated by routing wires near a ground plane.

**UNBALANCED** interfaces are widely used in consumer electronics and generally use RCA connectors. **Unbalanced interfaces are very sensitive to noise currents!** Because the grounded conductor (generally the cable shield) is a path for both the audio signal and power-line noise current, any noise voltage drop over its length, due to its resistance, is *directly added to the signal*. This mechanism, called common-impedance coupling, is responsible for virtually all noise problems in unbalanced interfaces. Therefore, reducing the resistance of the shield conductor can reduce noise. Some tips to lower noise:

- Obviously, avoid unbalanced interfaces whenever possible!
- Keep cables short – those over a few feet long are potential problems
- Use cables with heavy braided-copper shields instead of foil and drain wire
- Use a high-quality signal isolation transformer at the receive end of the cable
- Do not disconnect the shield at either end of any unbalanced cable

**BALANCED** interfaces are widely used in professional audio equipment and generally use XL connectors. **Balanced interfaces have substantial immunity to noise currents!** Since the impedances of the two audio signal conductors is the same, noise from any source is coupled to them equally and can be rejected by the receiving input. Power line noise current will harmlessly flow in the cable shield, if present. However, some equipment is of poor design and can create noise coupling problems in real-world systems. Some tips:

- ▶ Identify equipment having a “pin 1 problem” using the simple “hummer” test
- ▶ If necessary to circumvent a “pin 1 problem,” disconnect the shield only at the receive end of the cable
- ▶ If noise rejection is inadequate, use a high-quality signal isolation transformer at the receive end of the cable

An in-depth technical discussion of these topics by Bill Whitlock, including step-by-step troubleshooting procedures, is available at:  
[www.jensentransformers.com/an/generic%20seminar.pdf](http://www.jensentransformers.com/an/generic%20seminar.pdf).

Remember that signal cable shields are NOT intended to function as a safety ground! Safety grounding must be accomplished by the grounding conductor in the power cord.

**NEVER LIFT, OR OTHERWISE BYPASS THE POWER CORD GROUND...  
IT COULD BE FATAL!!**

# Myths

## Myth #1) An “Isolated Ground” system is not connected to ground.

MYTH BUSTED! “Isolated ground” system connects to “ground” (neutral) at the main circuit panel, isolated from any other ground connections. If equipment is mounted in a rack to conductive rack rails, the rack must also be isolated from any grounds, including concrete or conduit, to function as designed.

## Myth #2) A supplemental ground rod is a place where “noise” wants to go.

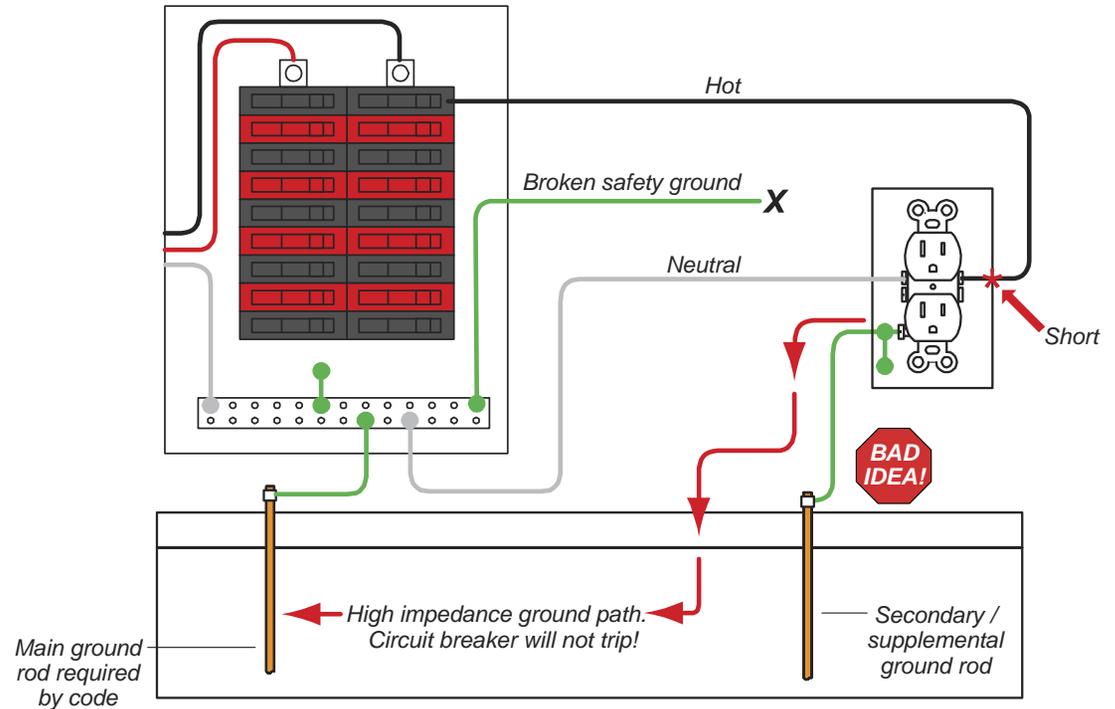
MYTH BUSTED! The primary purpose for a supplemental ground rod driven into earth is for diverting lightning. The NEC mandates that any supplemental ground rod be bonded to the neutral/ground bond of a separately derived system, the main service neutral/ground bond or the grounding electrode system. Any attempt to use a supplemental ground rod as a magical sink for “noise” can result in circulating currents flowing in the ground wires, adding to problems. There is no wire from a jet airplane to earth, yet it has an effective grounding system.

## Myth #3) The earth’s soil is an effective safety grounding point.

MYTH BUSTED! Earth ground is not a substitute for safety ground. Independent, un-bonded ground rods driven into the earth do not provide a low enough impedance to trip circuit breakers, is a violation of the National Electrical Code, **and will be life threatening when used as a safety ground.** (see diagram to right)

## Myth #4) More grounds always makes for quieter systems.

MYTH BUSTED! Ground only where required for safety. Any additional grounds may provide or create additional paths for ground loops and increase system noise. The only exception to this is when a “mesh grounding” scheme is used (refer to the mesh grounding section of this white paper).



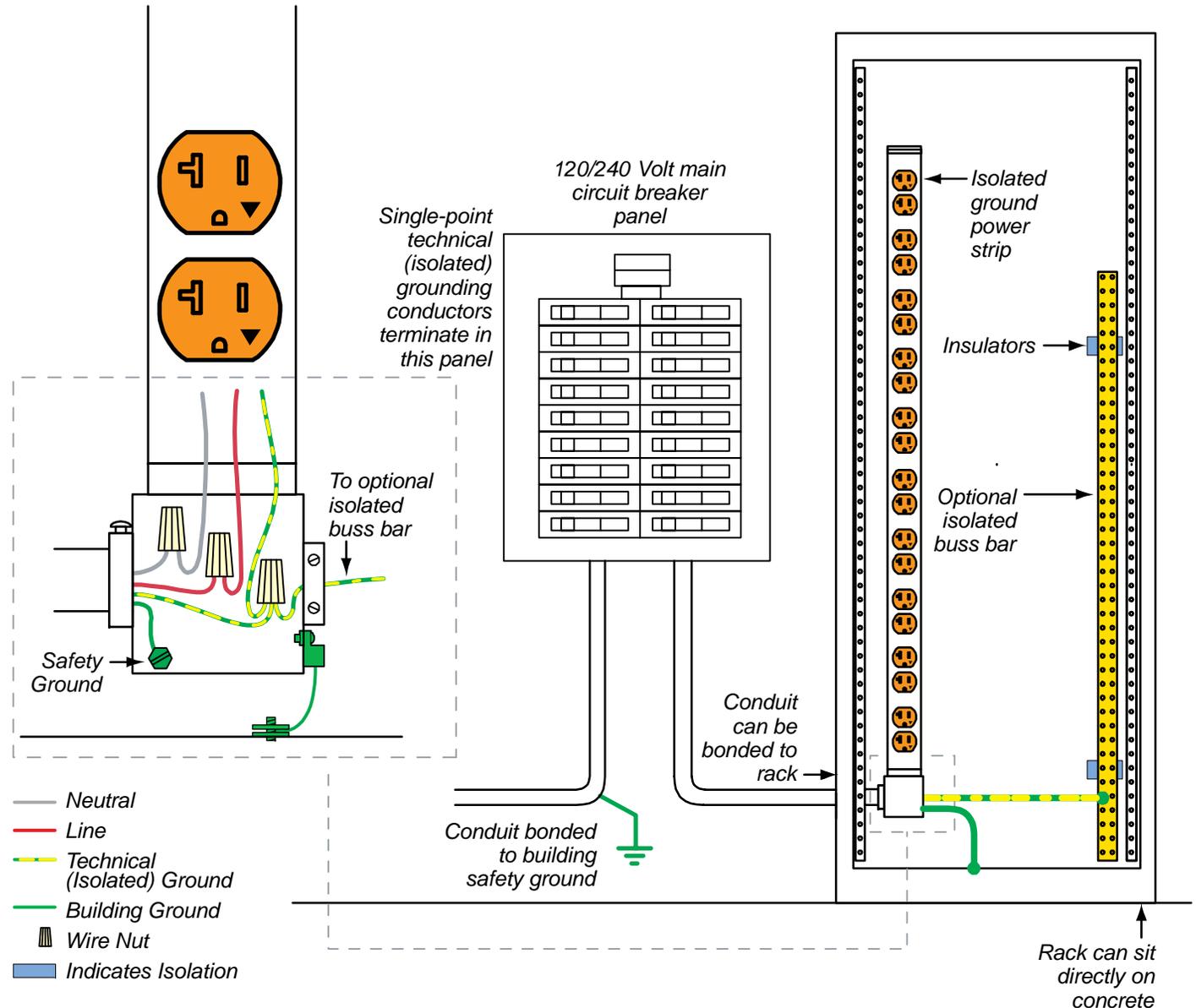
# Isolated ground power strip in a non-isolated rack

**This is not recommended**

Installing an isolated ground power strip does not necessarily result in a technical (isolated) ground system.

An “isolated ground” system installed in this manner does not guarantee a noise-free system, and is defeated by the smallest breach of isolation via a stray ground

Rackmounted equipment and connector panels, including cable shields, must be isolated from the rack.

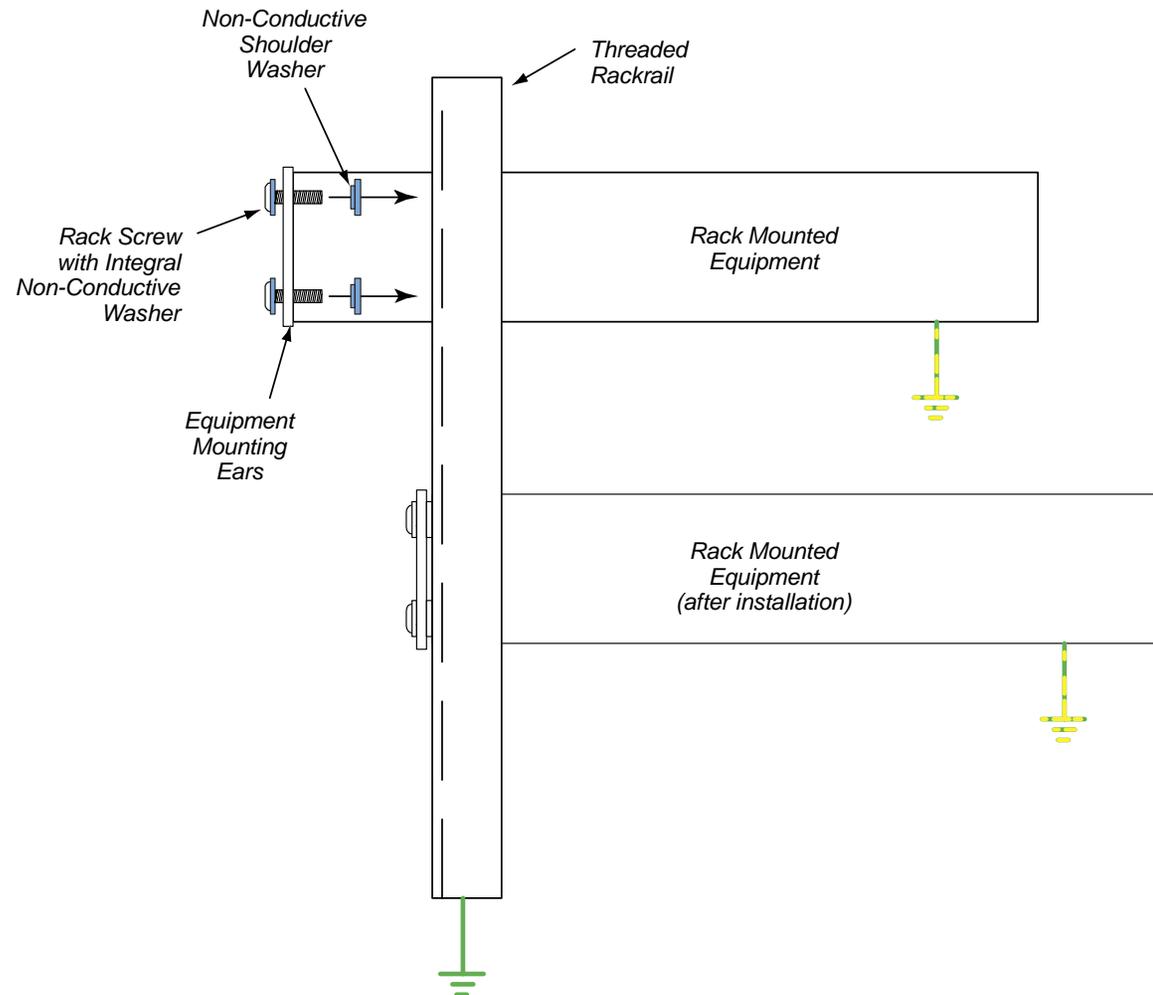


A potential problem may exist due to the fact that all equipment with a 3-prong (grounded) plug has the power cord ground conductor bonded to the chassis.

When rackmounted equipment is screwed to the rackrail an inadvertent ground connection may be present, causing a ground loop between the isolated ground and the safety ground.

When power to equipment is provided via an isolated ground power strip, the building safety ground (that is attached to the rack) must be segregated from the isolated technical ground. This is accomplished by installing non-conductive shoulder washers, as shown below:

### ***Rack Ear Insulators***



Isolate the entire equipment rack by connecting the conduit that feeds the rack via a non-metallic connection. A technical (isolated) ground conductor must be installed in this conduit and must also be bonded to the rack's ground stud.

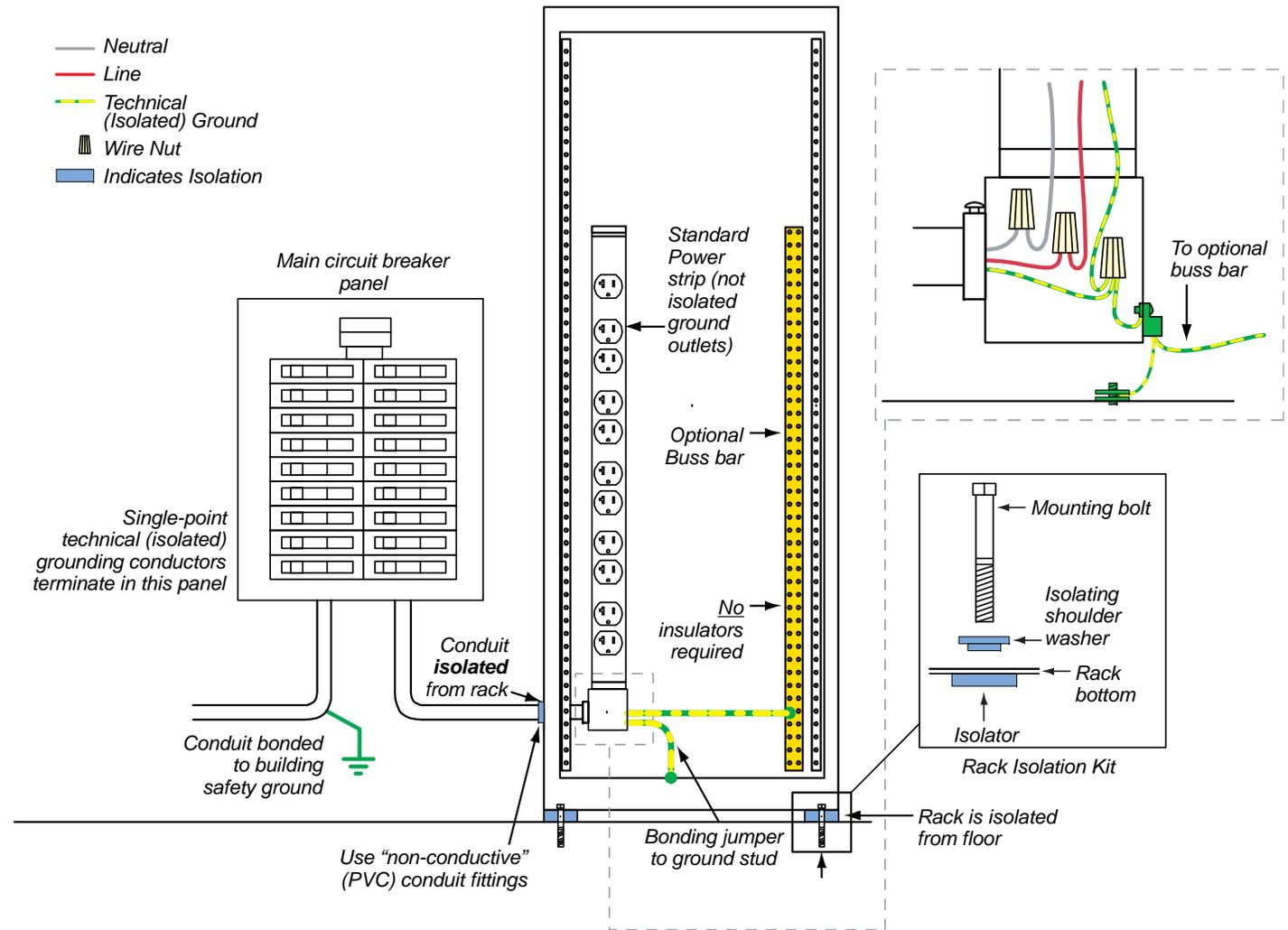
When the rack is sitting on or bolted to a semi-conductive surface, such as concrete, care should be taken to isolate the rack from the floor and mounting bolts. In some installations, it only takes a few milliamps of current to produce a noise problem. Isolating shoulder washers for installation of floor mounting bolts should be used.

Rackmounted equipment does not have to be isolated from the rack. However, "non-technical" metallic connections (stray grounds) must be isolated from the rack.

An "isolated ground" power strip may be substituted for the standard one, but there is additional cost and no additional benefit.

## Isolated rack with standard (not isolated ground) power strip

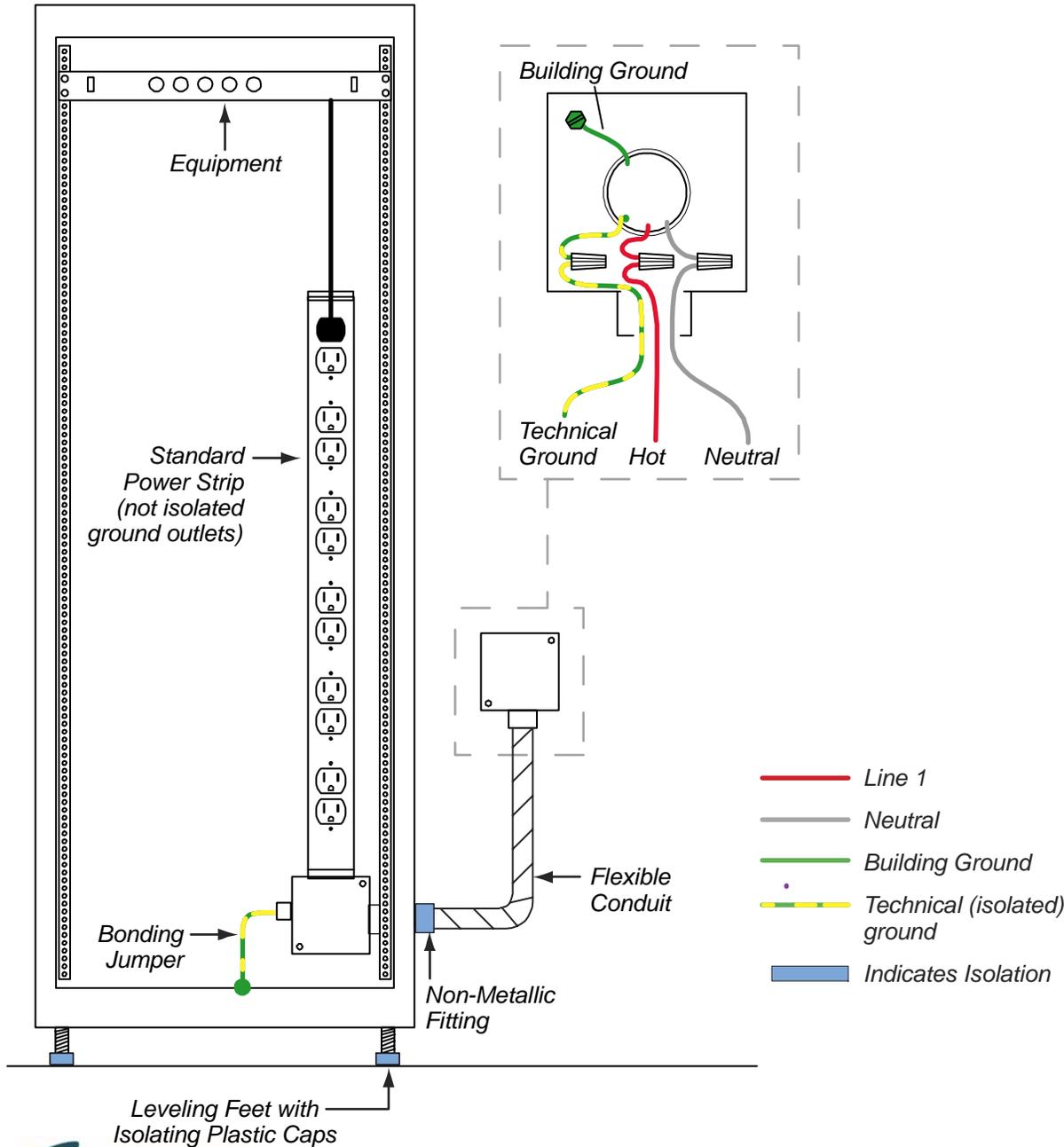
*This is highly effective and is recommended\**



\* If the installation is in close proximity to RF sources (i.e. radio or TV transmitters), mesh grounding may be the best design. Please see the "mesh grounding" section of this white paper.

# Flexible Connections to Isolated Equipment Racks

Example #1



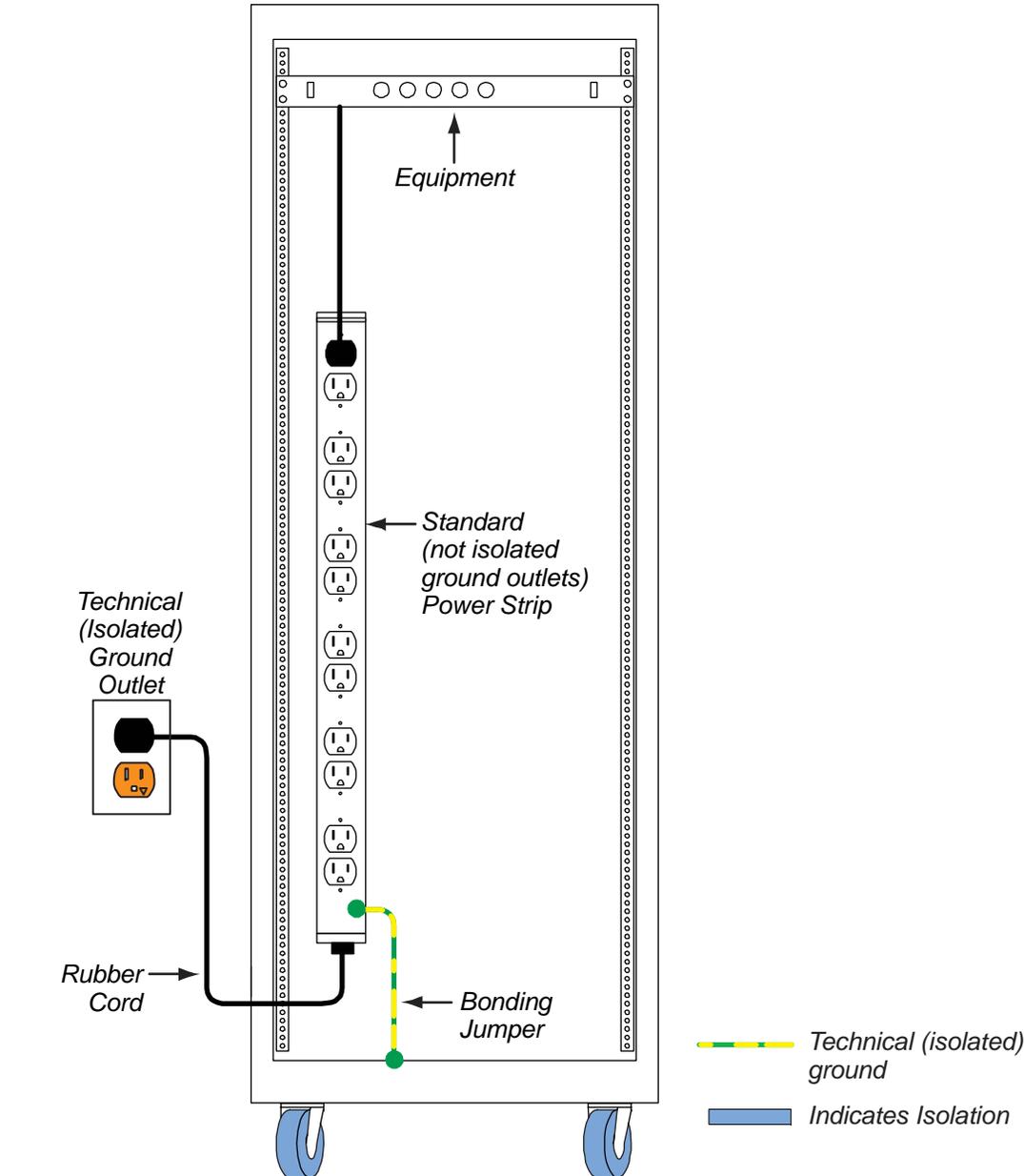
In the following examples, the racks are grounded via a technical (isolated) ground, and isolated from the building safety ground. Additionally, these racks are isolated from the floor by use of insulated leveling feet (example 1), and rubber or plastic wheels (example 2, next page).

Since power strip mounting hardware cannot be relied upon to conduct fault current, a bonding jumper must be installed between the power strip chassis and the rack.

Example 1: With this “hardwired” power strip the bonding connection is between the isolated grounding conductor, in the junction box, and the rack.

## Flexible Connections to Isolated Equipment Racks (cont'd)

Example #2

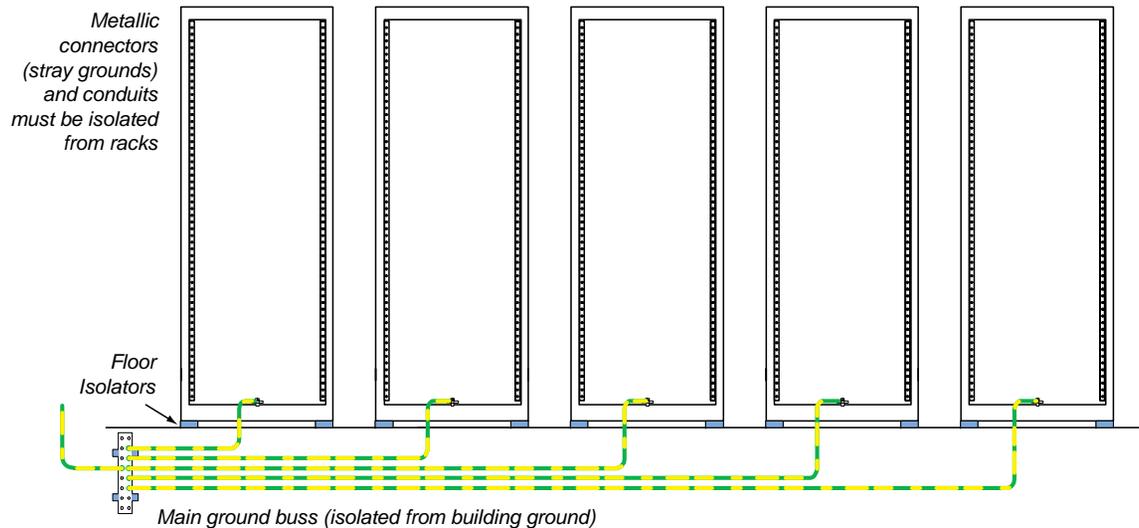


Example 2: With this "cord connected" power strip the bonding connection is between the power strip chassis and the rack. Note: since the power strip is plugged into an isolated ground style outlet the power strip chassis is grounded via an isolated ground.

# Single-Point Technical (Star) Ground vs. Daisy-Chain Ground

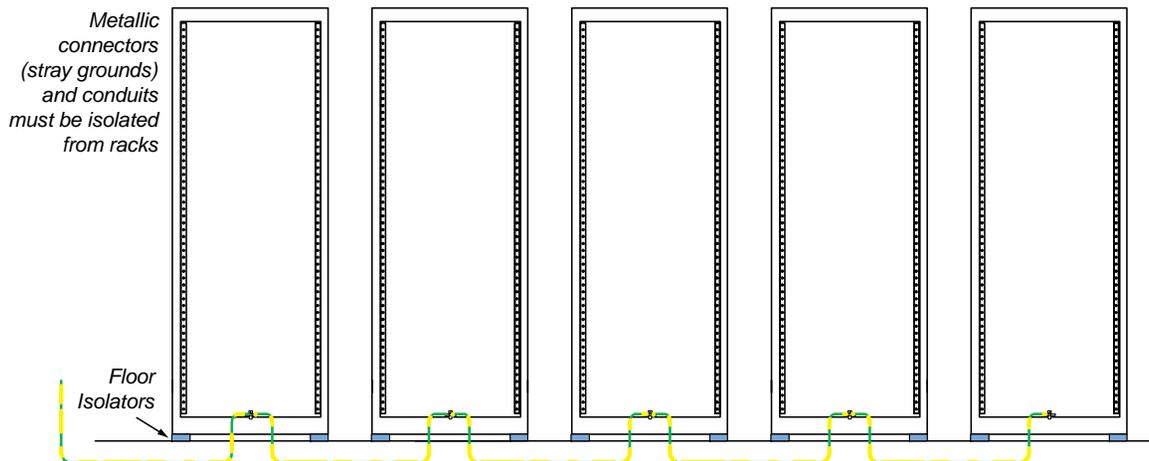
Two common methods of bonding racks together with equipment grounding conductors are known as “star” grounding and “daisy chain” grounding.

## “Star” Grounding (isolated or technical ground)



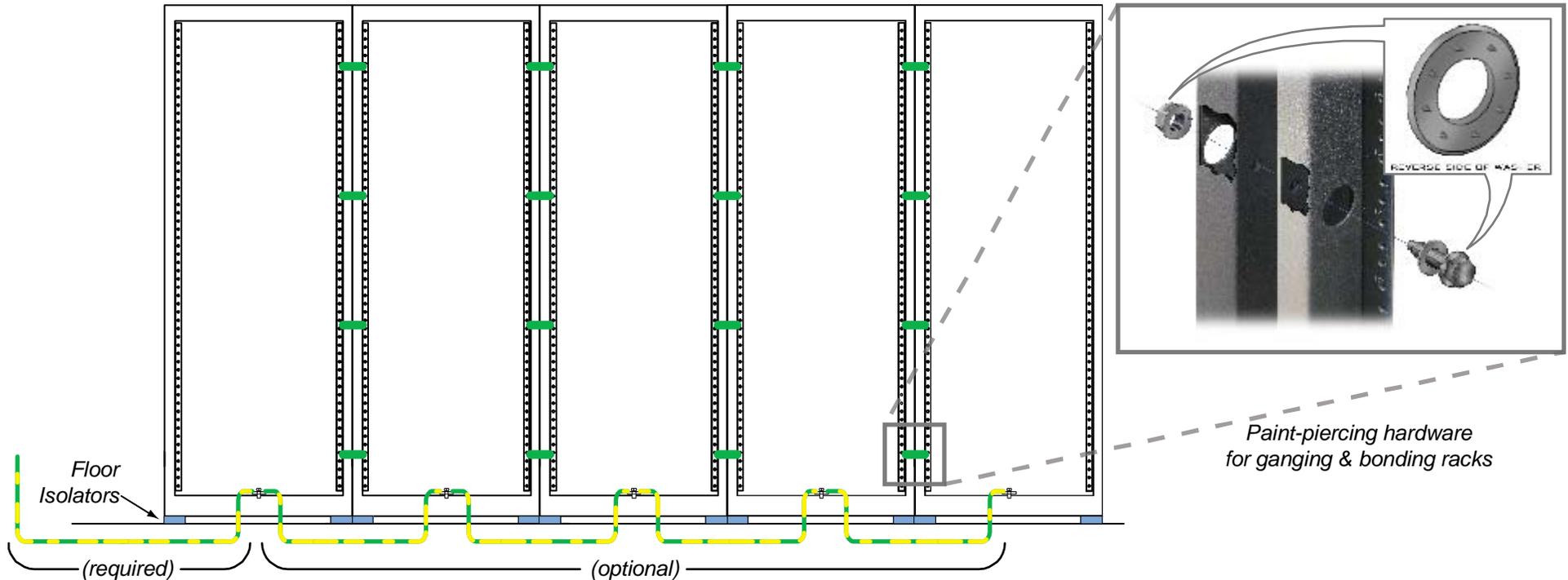
When properly configured, an isolated ground (also known as a technical ground or single-point ground) system is arranged electrically in a “star” pattern. Each rack is bonded to a common single point ground with separate equipment grounding conductors, reducing voltage drop. If paint-piercing hardware is not utilized while ganging racks together, “star” grounding is the recommended design. If the installation is in close proximity to RF sources (i.e. radio or TV transmitters), mesh grounding may be the best design. Please see the “mesh grounding” section of this white paper.

## “Daisy Chain” Grounding



When racks are connected in a “daisy chain” fashion, series resistances in the equipment grounding conductors can increase at each bond point. This can lead to potential differences between racks, which may lead to ground loops that interfere with the system’s performance. This is not recommended unless paint-piercing hardware is used to gang the racks together.

## Enhanced EMC Rack Bonding



Routing signal conductors adjacent or close to a ground plane is a very effective and proven method of reducing the undesirable effects of EMC in signal conductors (since the electromagnetic field is confined to the small space between the signal conductor and the ground plane). The greater the surface area of the ground plane, the lower the impedance and the more effective the protection, especially at higher frequencies.

Metal chassis of racks are required by code to be bonded to ground for safety. One of the most effective ways to create a large surface area ground plane is to bond these grounded equipment racks together in a mesh-type configuration.

One method is to grind the protective paint (or powder coat) from the ganging points where the racks join, and subsequently bolt the racks together. However, grinding exposes the base metal, which will then be subject to corrosion, defeating the intended purpose.

When "paint-piercing" hardware is used to gang racks together, the opportunity for corrosion is eliminated. Daisy-chain grounding techniques between the racks can then also be used without the possible associated disadvantage of additive resistances. Most electrical inspectors in the United States want to see bonding wires connected to the rack's grounding lug, so the elimination of the daisy-chain depends on the field requirements.

# INTRODUCTION TO MESH GROUNDING (SIGNAL REFERENCE GRID)

Paragraph 5.3.2 of CEI/IEC Technical Report 61000-5-2 states *“The earthing network is generally designed and implemented by the facility builder to have an impedance as low as possible in order to divert the power fault currents as well the HF currents without passing through the electronic apparatus or systems. Different earthing network layouts exist and may give satisfaction to their users.”* Note that there is no one “right way” to develop an earthing/ground network.

Ideally, we would want all points in the earthing network connected to the same potential. This would eliminate any potential difference between points.

There are three specific methodologies that are often used to create this earthing network:

1. Daisy-Chain. If racks are bonded together in a daisy chain fashion (i.e., Ground A is connected to Ground B, Ground B is connected to Ground C, Ground C is connected to Ground D, etc.), resistances can add at each bond connection.
2. Star (isolated). In this method, all ground connections are joined at a single point. The resistance between each ground connection and that point is minimized. Longer runs of cable will, however, have higher resistance than shorter runs.
3. Mesh. In a mesh system, all points are, effectively, connected to each other.

## **Star/Isolated Ground**

In a star connection, ground points are all connected to a single point. The resistance (and the potential difference) between a rack and the ground point is minimum, since the connection is direct. The resistance between two racks will, however, not be minimum since the length of the connection from one rack to another is the sum of the resistance from one rack to ground, added to the resistance from ground to the second rack. In addition, Star systems can act as antennas. This is a significant problem in a facility that is near a source of RFI (such as a radio station), where the RF signal can cause large potential differences. Connecting endpoints in the star to each other would reduce the resistance but would, again, create a ground loop.

Often, ground shield on signal interfaces are lifted at one end in order to eliminate ground loops. Signal interfaces (e.g., input and output connections) of equipment are the points most often damaged by voltage anomalies, such as nearby lighting strikes and surges. Power inputs are rarely damaged. In balanced interfaces, lifting one end of a signal cable shield, in order to circumvent a pin 1 problem, for example, causes the shield to act as an antenna providing entry for such voltage anomalies as well as RF interference.

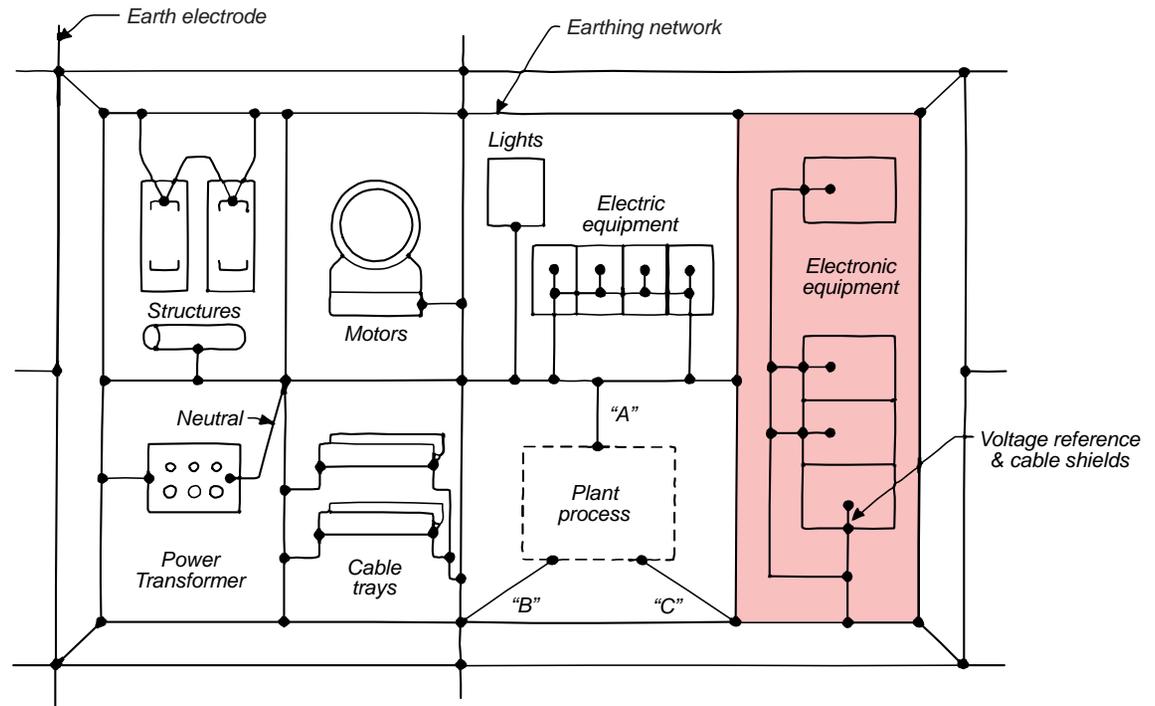
## Mesh

An effective way to implement a low impedance ground is to use a copper floor, with all racks and equipment bonded directly to it. This topology is known as a ground plane.

Solid copper ground planes are impractical for many reasons (cost, manufacturability), so grounding grids are used instead. The grounding grid approximates a copper ground plane using a mesh of interconnected copper bars. These bars are often installed just under a raised floor surface. The grounding grid is then connected to the building safety ground at only one point. In this type of a setup, all points are connected to each other with minimum resistance. Therefore, there is little potential difference between all points in the system.

In a mesh connection (whether it is produced by a grounding grid or by ground wire interconnections), the resistance between any two points is minimized. Since there are multiple paths between any two racks, the ground current (and therefore, the potential drop) in any one path is minimized. Mesh grounding may be required for sensitive digital and RF equipment found in telecom and other critical industries where higher frequencies are present.

The figure to the right (*Figure 8 on IEC 61000-5-2, page 39*) illustrates the topology of an effective combined star/mesh network. Note that creating a set of mesh connections can be logistically difficult and may increase the cost of an installation.



Good engineering practices should always be used to properly ground an installation. Directive 2004/108/EC of the European Parliament states “It should be possible to use harmonized standards for fixed installations in order to demonstrate conformity with the essential requirements covered by such standards.” Further, “A fixed installation shall be installed applying good engineering practices and respecting the information on the intended use of its components, with a view to meeting the protection requirements ...” Generally, Star/Isolated Ground connections, which are recognized as good engineering practices in the US, are not usually recognized by the European regulatory agencies as good engineering practices. However, when properly employed Star/Isolated Ground connections or Mesh connections are effective means of minimizing ground currents and noise in electrical systems.

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BICSI Telecommunications Distribution Methods Manual, 10<sup>th</sup> Edition

IEC 61000-5-2 Electromagnetic Compatibility (EMC) Part 5: Installation and Mitigation Guidelines – Section 2: Earthing and Cabling

K-Rated Transformer, I-Trap, Shielded Isolation Transformer material was provided by Acme Electric Corporation.

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