

Integrating Electronic Equipment and Power Into Rack Enclosures

Optimized Power Distribution and Grounding for Audio, Video and Electronic Systems

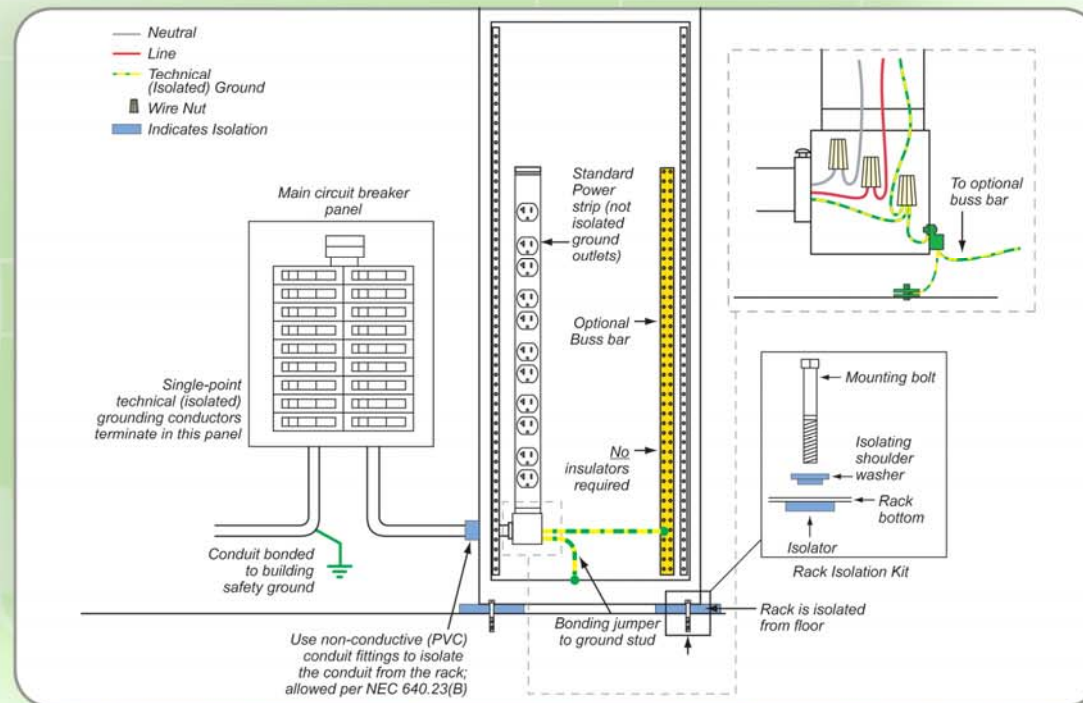


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Preface

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 noise and safety 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 2008 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 In addition many rules refer to, and are superseded by, several other sections of the NEC.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) Safety Comes First: The NEC Code must be adhered to at all times.
- 2) Bypassing or lifting equipment safety grounds may reduce hums and buzzes; but this is dangerous, violates the NEC and should never be done!
- 3) Ground loops are an entirely normal occurrence. Their severity depends on many factors. They may cause significant noise problems when safety grounds of interconnected equipment in enclosures are not connected at a common point.
- 4) Untwisted signal conductors inside the equipment rack should not be installed in parallel (within 2") of untwisted 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.
- 5) When it is necessary to install untwisted signal conductors, and untwisted power conductors or speaker wires in close proximity to each other, coupling is minimized when the cables cross at 90-degree angles.
- 6) 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.
- 7) 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"), and shield current induced noise (SCIN) in signal cables. Both are beyond the scope of this paper and are well documented elsewhere (please see references listed at the end of this paper – page 42).
- 8) 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 electrical safety and power distribution, as far as wiring and associated wiring methods are concerned. For the most part, they are only concerned with 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: 110.12/640.6/720.11/725.24/760.24/800.24/820.24/830.24.
- 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: 220/210.19
- 3) *Ensure low voltage wiring is not installed in the same raceway or conduit, or in close proximity to the power wiring - NEC 725.136 (unless exempted by this article)*
- 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”, “UL Pending” or “Made With UL Recognized Components”

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 ETL and 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

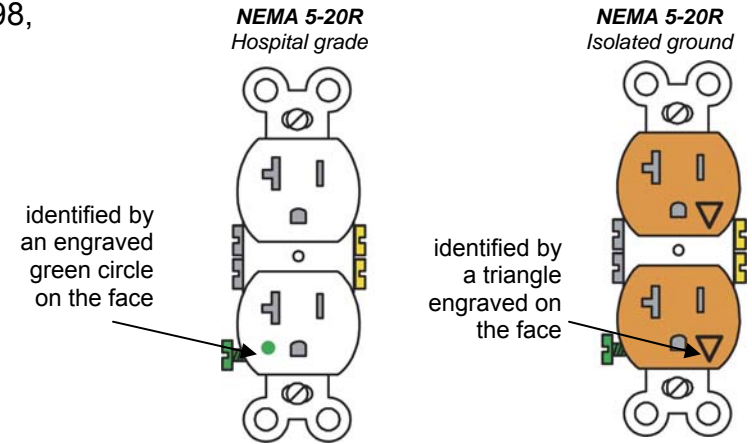
Receptacles have specific prong configurations indicating the voltage and amperage of the circuit for which they are designed. These receptacles and the corresponding circuit must match the plug that is attached to your equipment.

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.

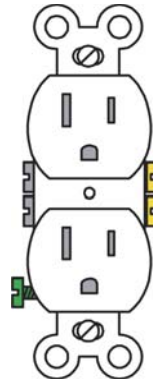
Hospital grade receptacles must pass additional UL testing, per UL Standard 498, including:

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

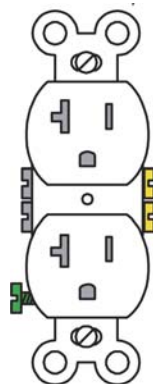
Do not modify the plug on your equipment to match a receptacle that is not intended to work with your equipment. (NEC-406.7)



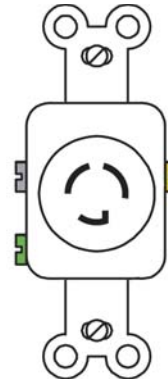
NEMA 5-15R
15 amp circuit
Accepts NEMA 5-15P plug



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



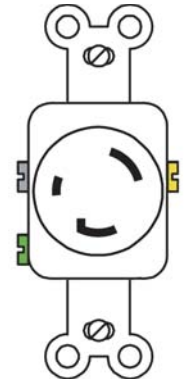
NEMA L5-15R
15 amp circuit
Accepts NEMA
L5-15P plug



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



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



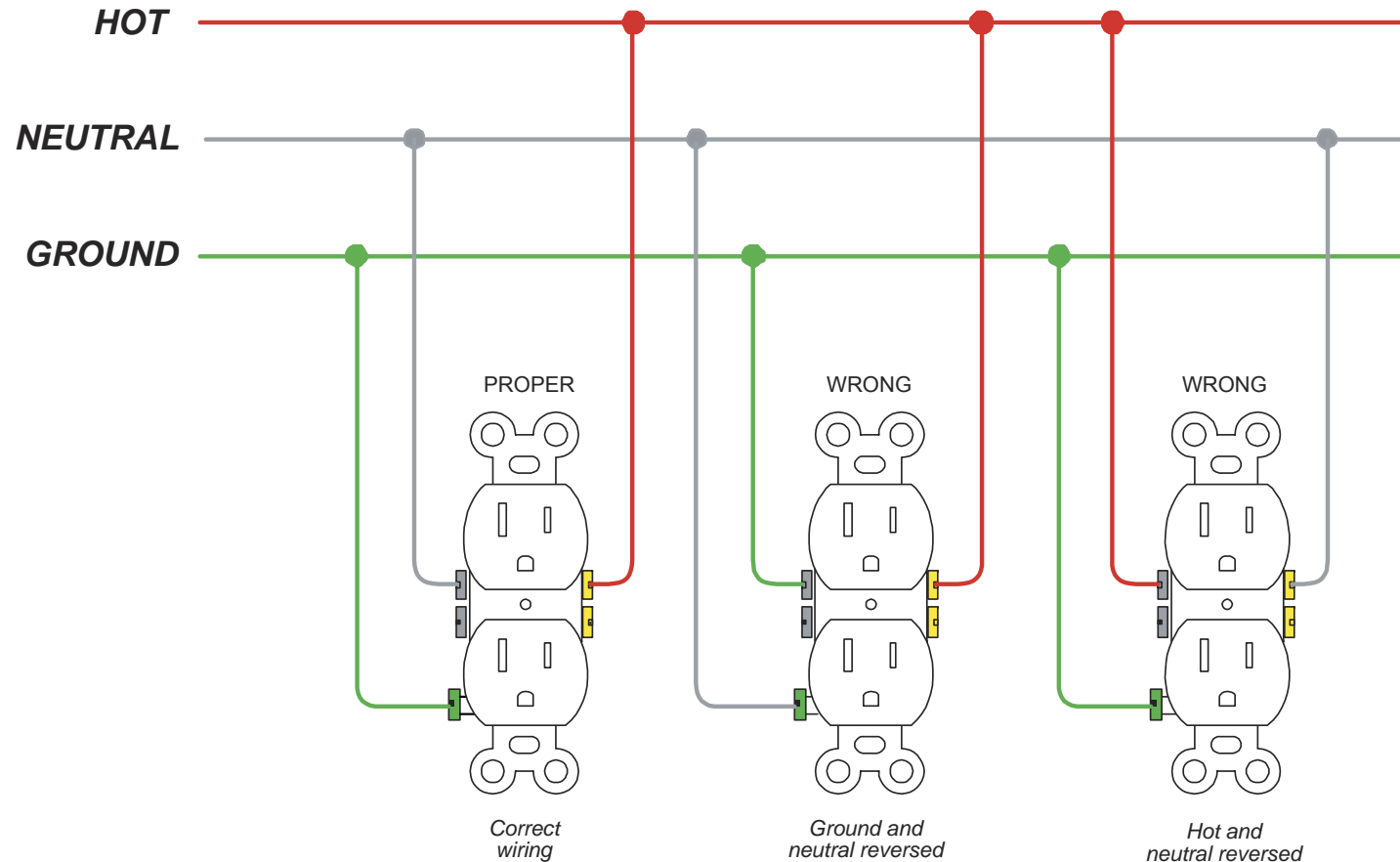
Common Receptacle Wiring Errors

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.**



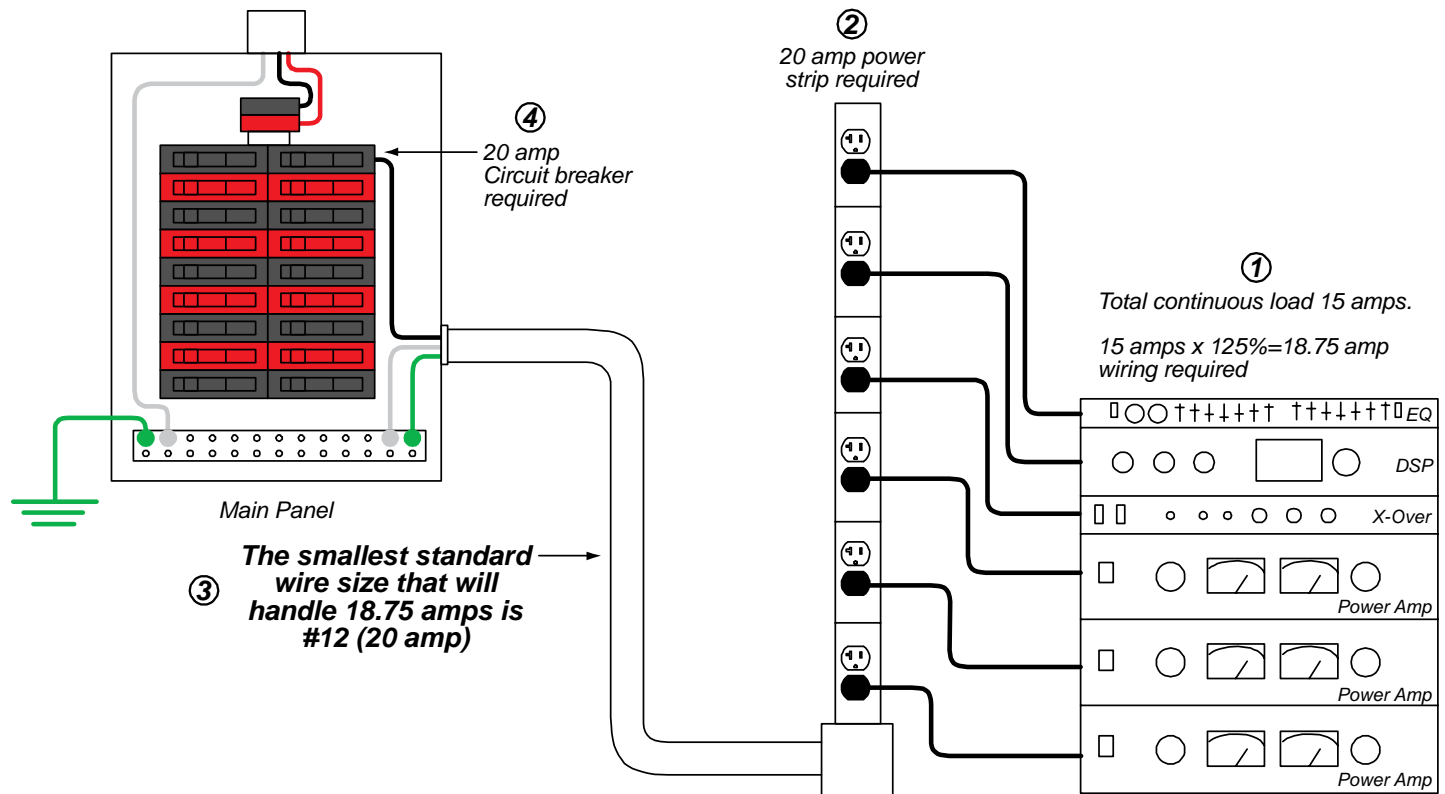
Calculating System Load

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 (NEC 210.19). 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 in the case of audio power amplifiers due to the 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)



Calculating Amplifier Circuit Requirements

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 over-current 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.

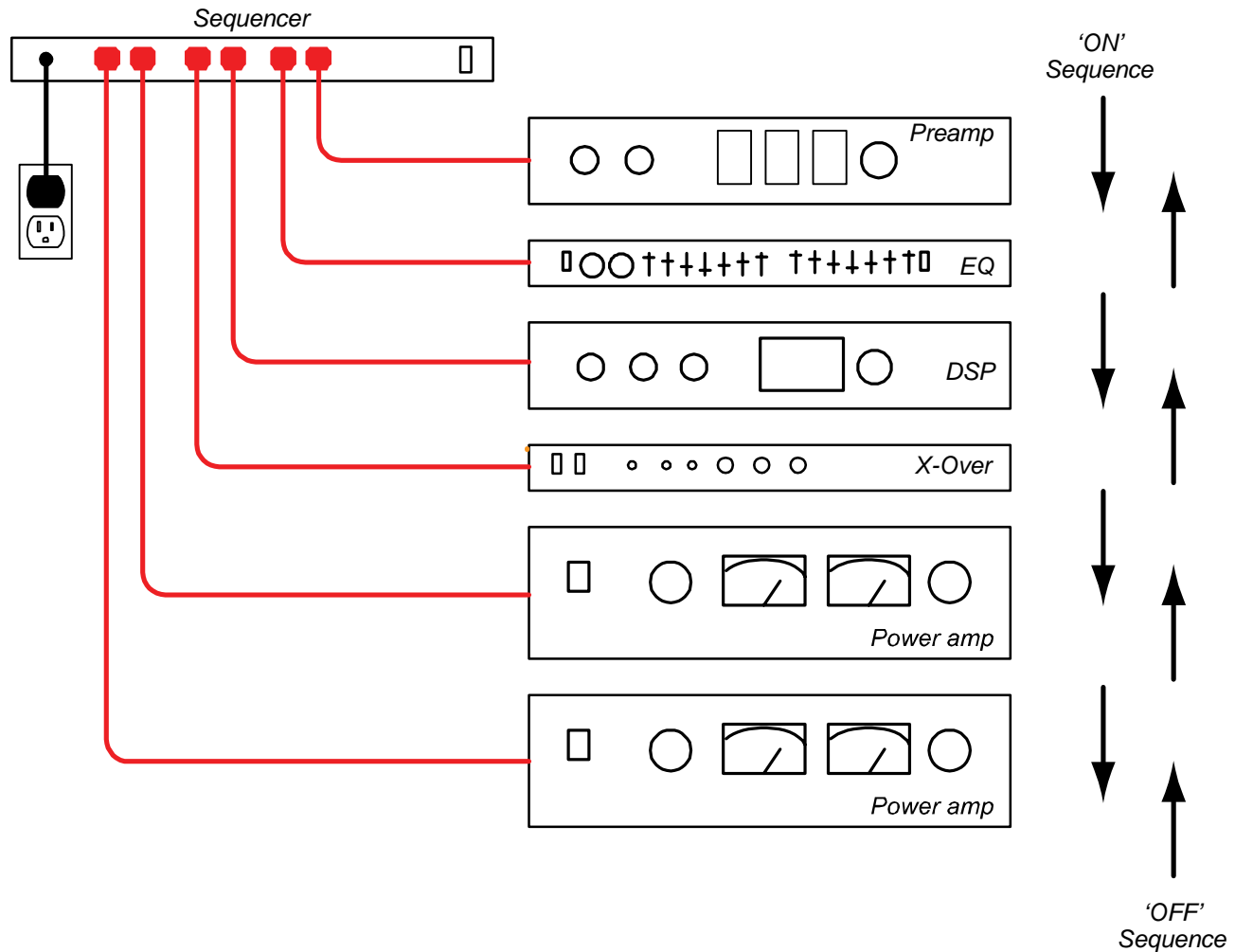


Single Circuit Sequencer Systems

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 amplifiers must switch on last and switch off first.

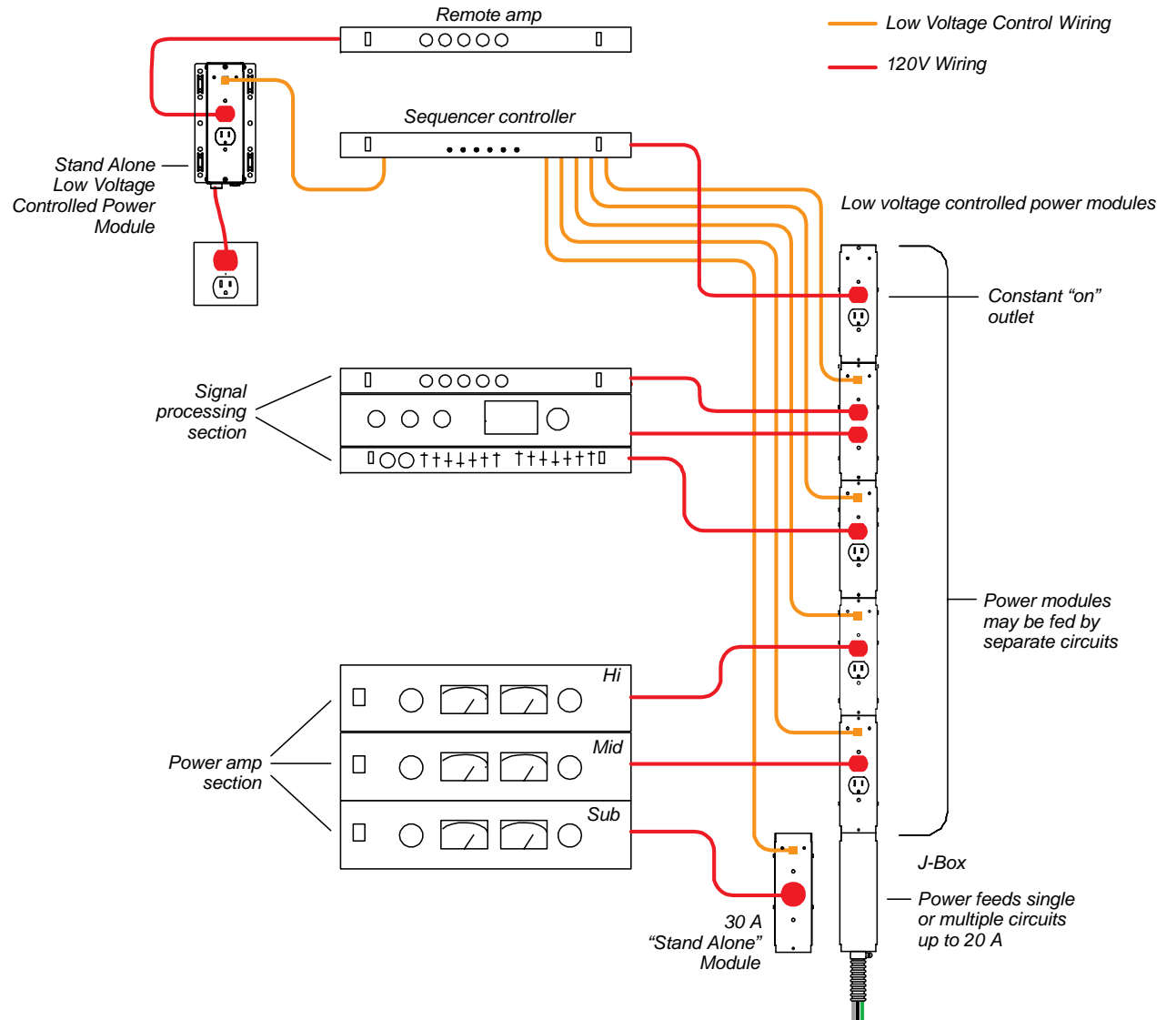


Sequencer Systems (Multiple Modules)

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



Surge Suppression

Under normal conditions an MOV (Metal Oxide Varistor) connected between two conductors will act as an open circuit i.e. no current (other than leakage current) will flow through the MOV. At a pre-determined voltage level an MOV will however start to conduct, shunting potentially damaging surges away from connected equipment.

Without any form of surge suppression power line surges pass straight through to connected equipment.

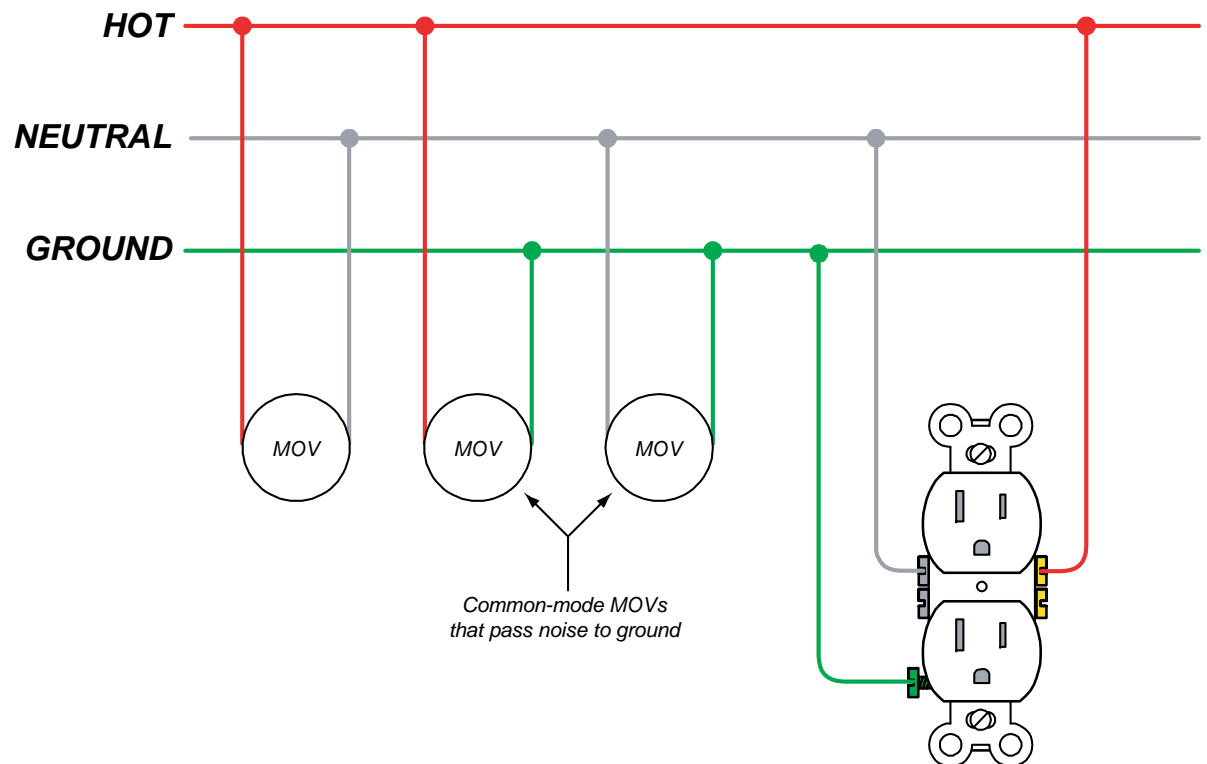
Note: the ability of MOVs to absorb multiple surges is permanently diminished when they are subjected to surges above their rated capacity

- **Example of a Branch Circuit Surge Suppressor Design that **Can Pass Noise** to Ground**

This design provides both common-mode and differential-mode surge protection.

A disadvantage with this design is that the MOV's capacitance couples higher frequency line noise to the ground circuit.

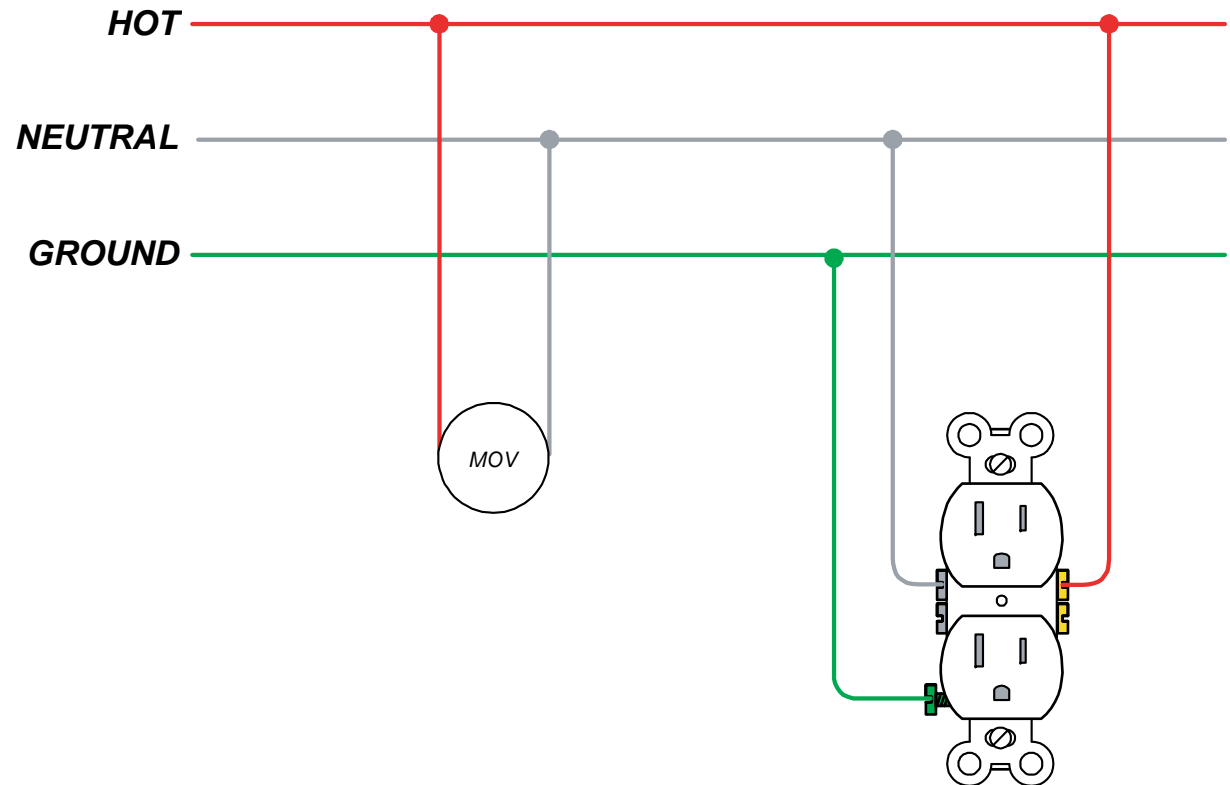
Also, the use of this type of surge suppressor at outlets can actually increase the risk of equipment damage as during a large surge or spike, very high voltage differences may be created in the safety ground system. These differences can appear across the signal wires interconnecting equipment and damage input and output circuitry.



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

Since the MOV is not connected to ground, this design eliminates the possibility of high frequency noise coupling to ground.

This design provides differential-mode surge protection only and is adequate in the majority of cases.



Note: Equipment signal interfaces (e.g. input and output connections) are the points most often damaged by voltage anomalies such as nearby lighting strikes and surges. Power inputs are rarely damaged.

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 on page 42.
- **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 only in specific cases if the conductors of both cables are twisted tightly. 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, power 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 (see page 14) all safety grounds must terminate at only one point.**

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.

The primary 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.

NEC 250.94 requires any intersystem bonding connection to be accessible at the electrical service equipment. In new construction, an electrical contractor must provide accessible means to this connection.

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 most 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 (page 42).



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

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. When installed in a metallic conduit, the conduit can act as the grounding conductor (as shown on page 17).

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 (metallic conduit, boxes, etc.) 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 (page 42).

Isolated Ground Receptacles

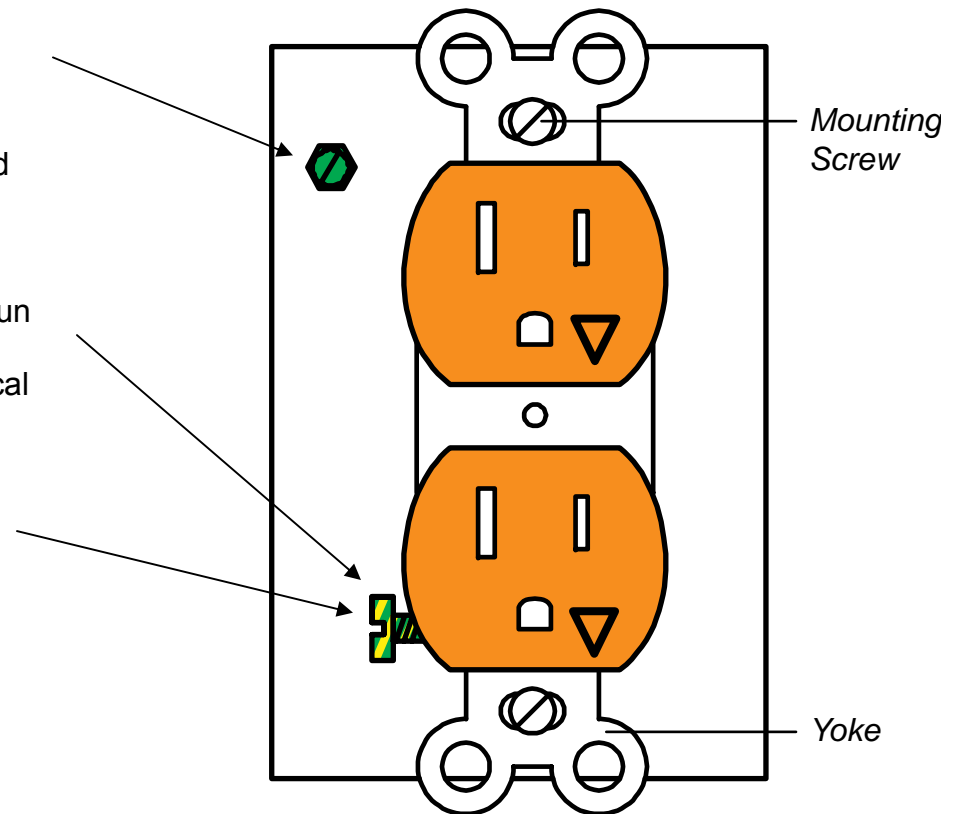
Mounting screws and yokes of isolated ground receptacles are not electrically bonded to the outlet ground screw. The outlet ground screw is only connected internally to the ground prong on the outlet. This separates the isolated (technical) ground conductor from the building ground.

The electrical box must still be bonded to the building ground. If a supplemental (auxiliary) 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 at the system neutral-ground bonding point **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. An isolated ground is also commonly referred to as a Technical Ground.

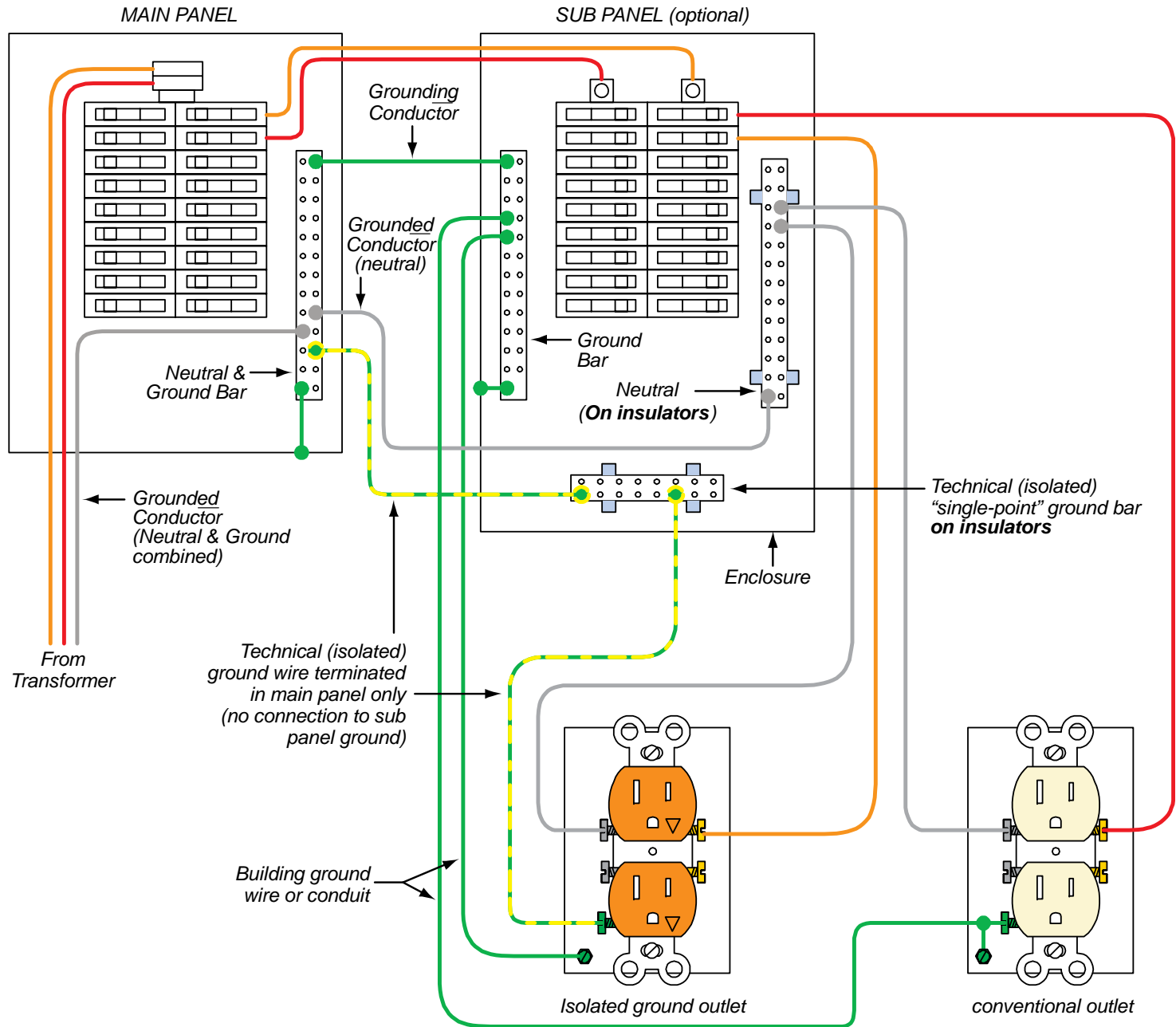
DO NOT BOND THE OUTLET GROUND SCREW TO THE ELECTRICAL BOX WHEN USING ISOLATED GROUND RECEPTACLES

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



Wiring Isolated Ground Outlets and Conventional Outlets when using a Sub Panel

The grounding conductor (ground) and the grounded conductor (neutral) 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.

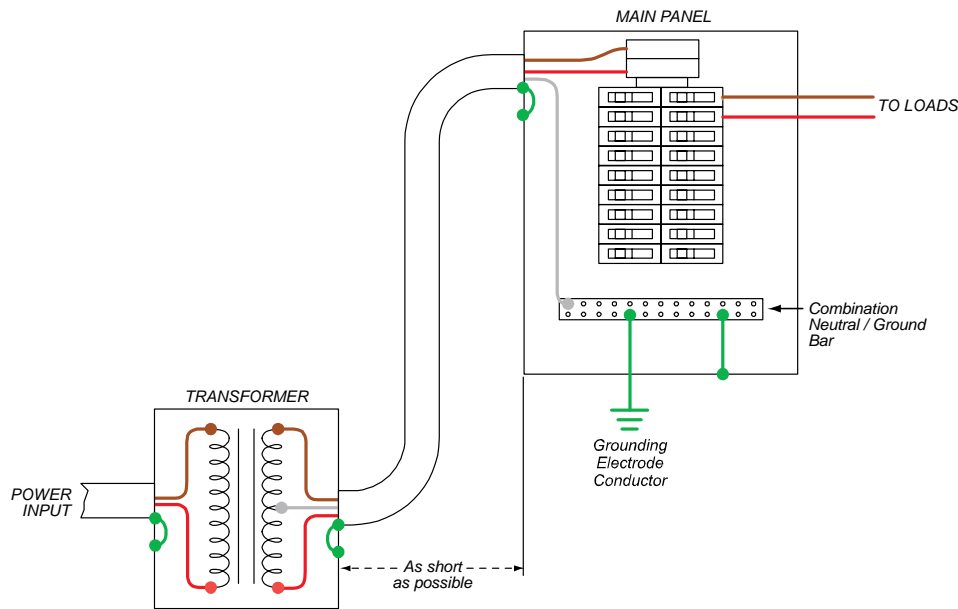


Wiring Methods for Separately Derived Systems (Isolation Transformers)

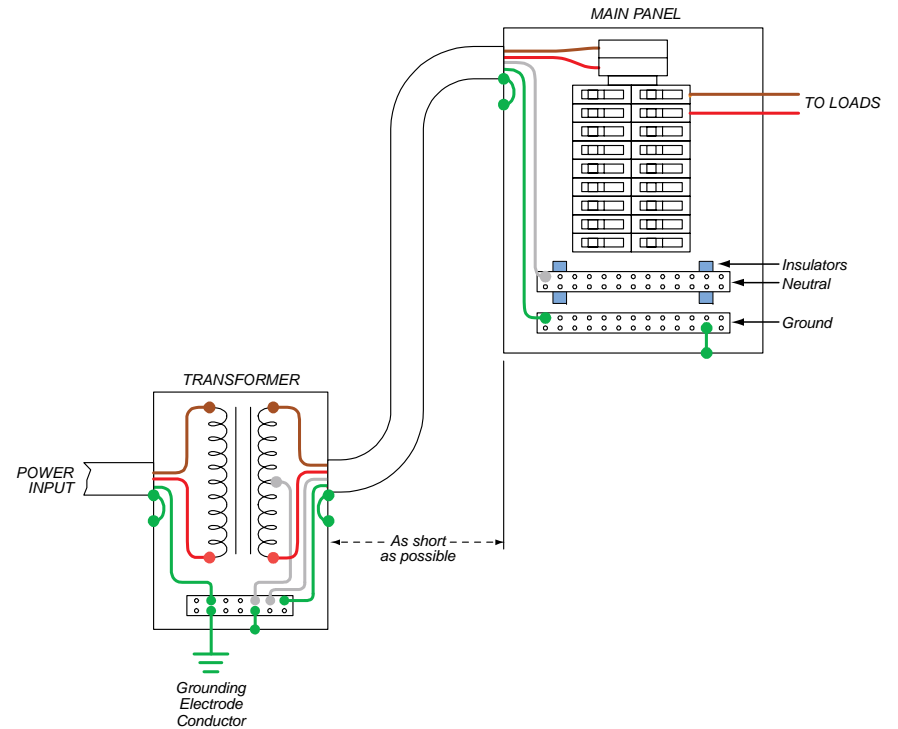
Common-mode noise is generated in facilities by many devices, including elevator motors, lighting dimmers, etc. This noise is present on the AC wiring system. To greatly reduce common-mode noise, an isolation transformer should be used. This provides a new neutral/ground point, and at that point there 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



NEC Approved & Recommended for AV Systems



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 its 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 3rd harmonic current; 10% of the fundamental as 5th; 7% of the fundamental as 7th; 5.5% of the fundamental as 9th; and smaller percentages through the 25th 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:

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

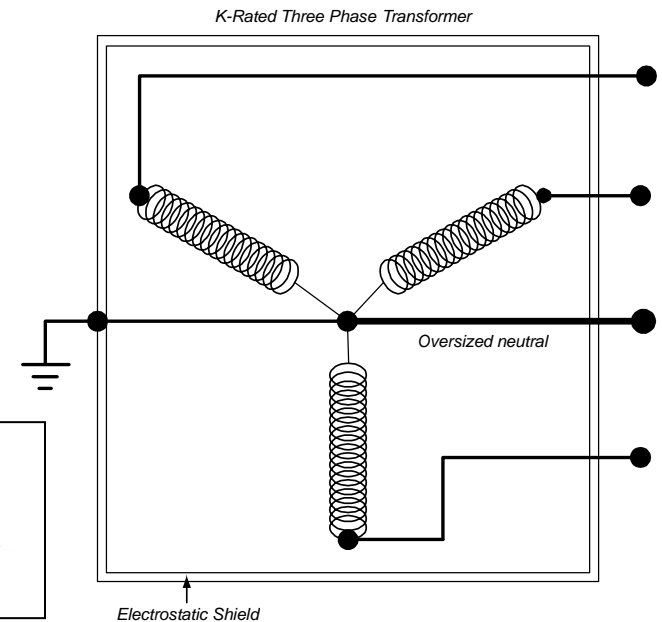
Some problems created by harmonic currents are:

- Over-heated neutrals
- Over-heated transformers
- Malfunctioning generators
- Burned-out motors
- 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:

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



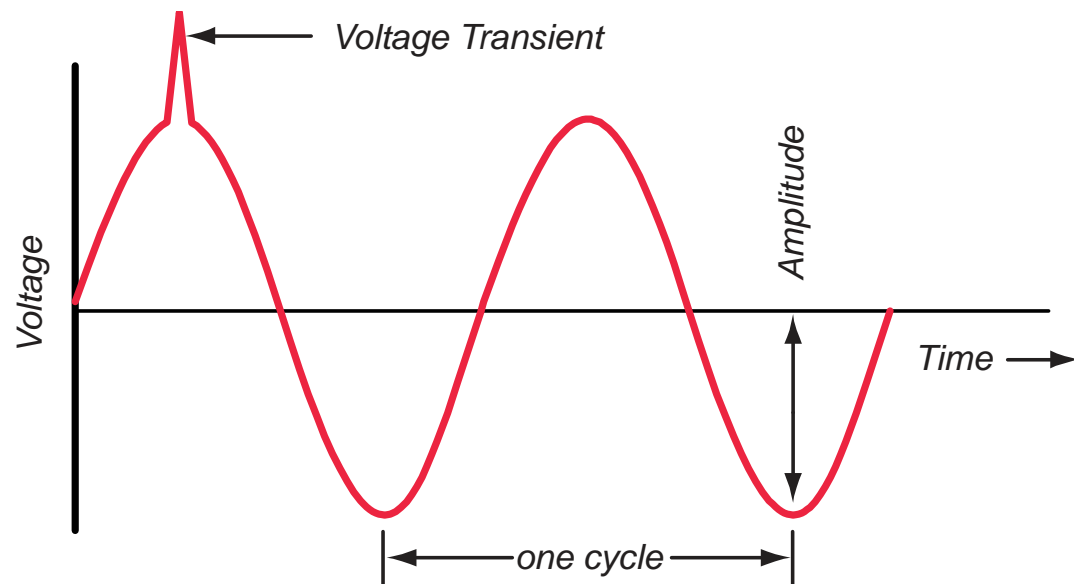
The Specifics of Transformer Action on Transients

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

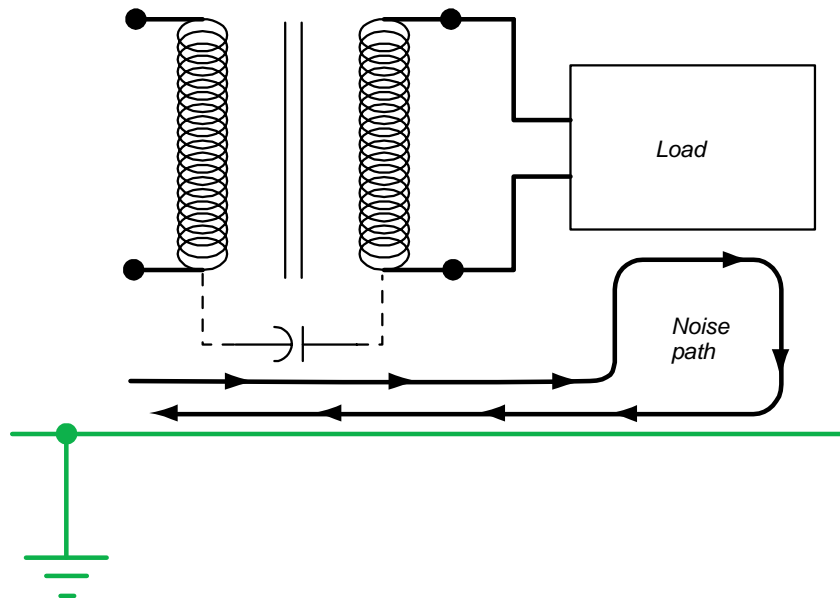
Common mode transients are generally defined as undesirable voltages appearing equally on the hot and neutral conductors with respect to the grounding conductor. These transients may be coupled through the transformer's inherent inter-winding (primary to secondary) capacitances but are usually small.

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.

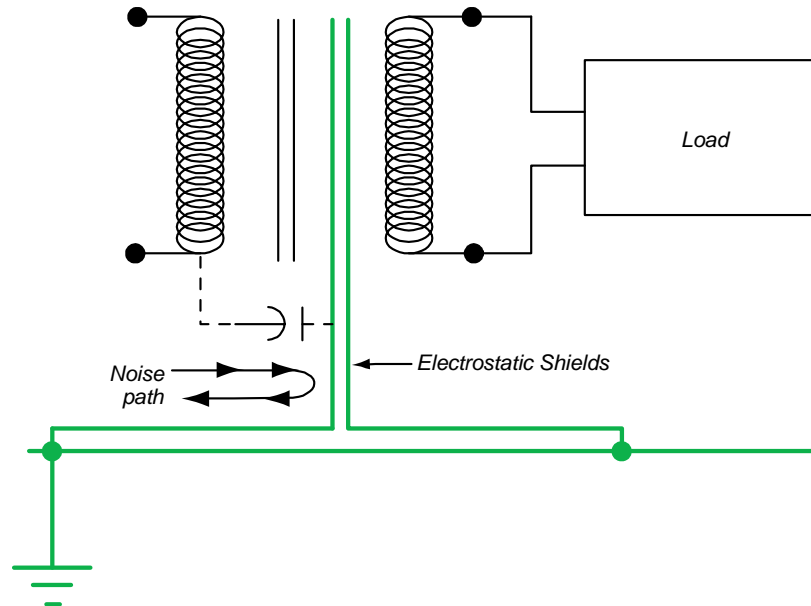


Electrostatic (Faraday) Shielding in Power Transformers

Standard Power Transformer



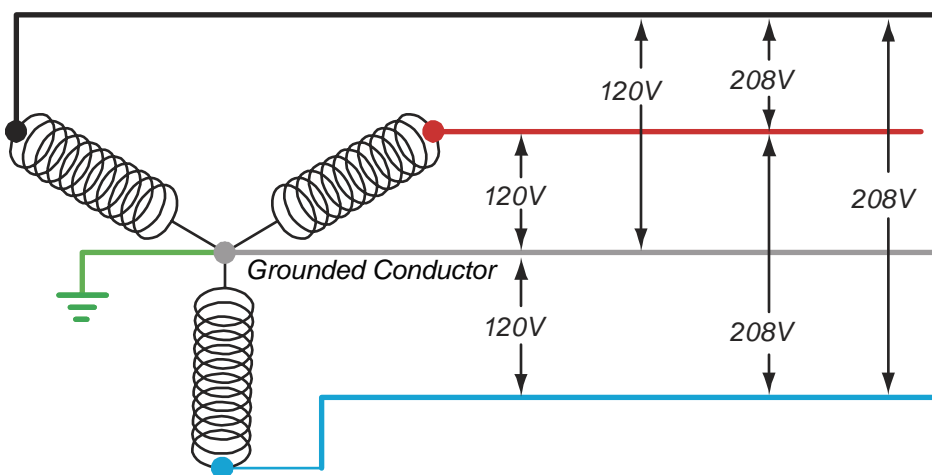
Power Transformer with 2 Electrostatic Shields



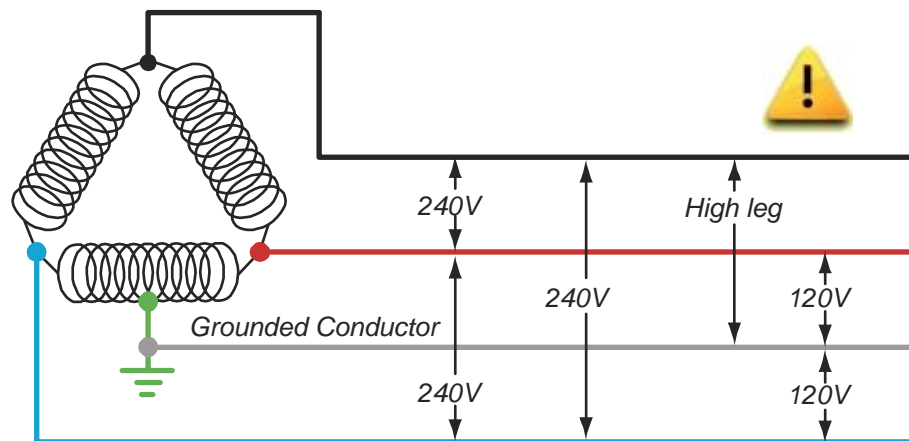
Electrostatic (Faraday) shields reduce common-mode noise coupling between the primary windings and the secondary windings, improving the isolation.

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 grounded conductor (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.

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 grounded filter capacitors found in most equipment, loads on each phase usually couple a small amount of noise onto the ground circuit. Any device that draws a pulse of current for less than the entire voltage wave generates harmonics. Because the phase conductors are separated by 120 degrees, some of the harmonic current in the neutral conductor is tripled. The additive 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 key advantage that single phase has over three phase is that while harmonic currents are still present, it is not possible for the “triplen” components to add in the neutral. 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:

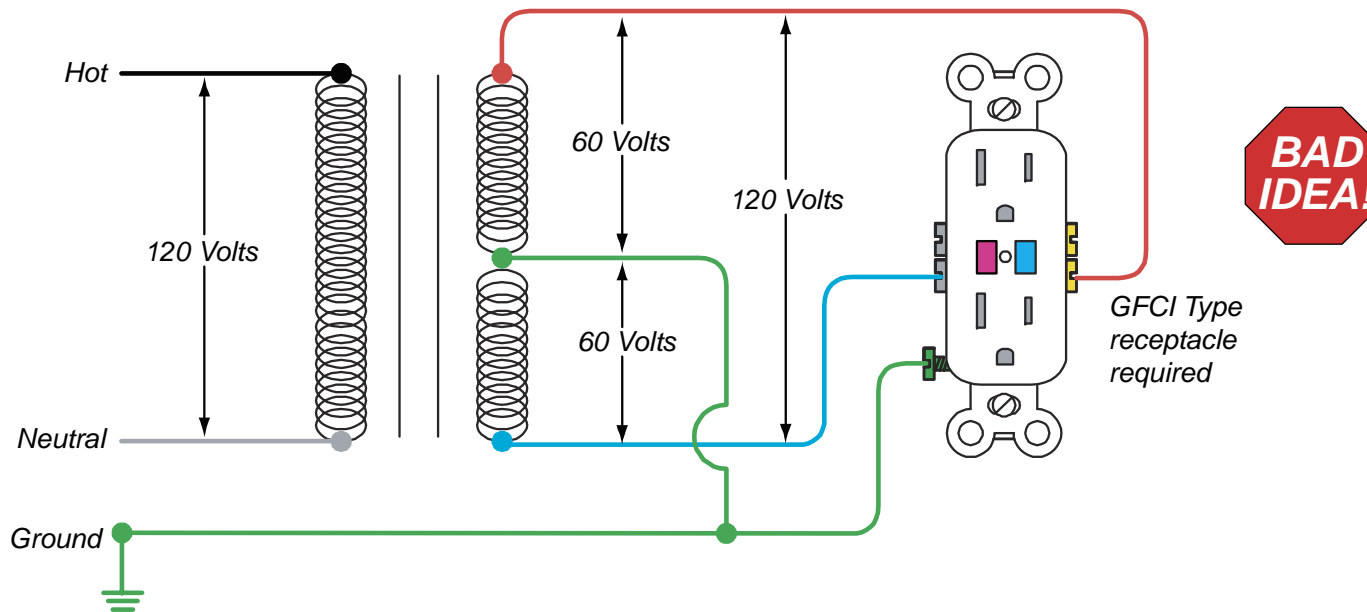
Video equipment is usually connected using unbalanced shielded cables, and is therefore very sensitive to ground loops. In an installation where the remote cameras are mounted to grounded building structures, the cameras will likely be at a different ground potential than the ground at the monitoring 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.

Symmetrical (Balanced) Power Systems

Per NEC 647.1 (2008) the use of a separately derived 120 volt, single phase, 3-wire system with 60 volts between each of the two ungrounded conductors and ground is permitted for the purpose of reducing objectionable noise in sensitive equipment locations, **providing the following conditions are met:**

1. The system is installed **only in commercial or industrial occupancies**
2. The system's use **is restricted to areas under close supervision by qualified personnel**
3. **All** other requirements in NEC 647.4 through 647.8 are met

In a 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.



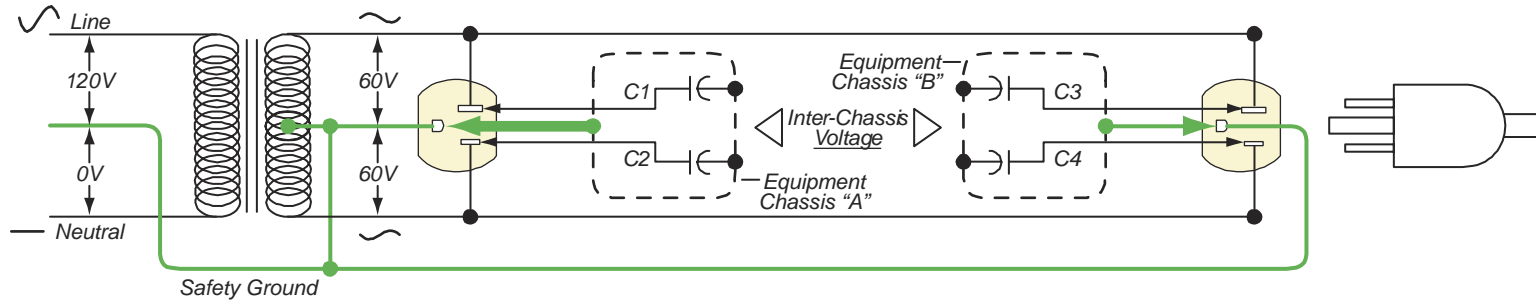
Symmetrical (balanced) power transformers **do nothing** to eliminate differential-mode noise found on the power line

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.

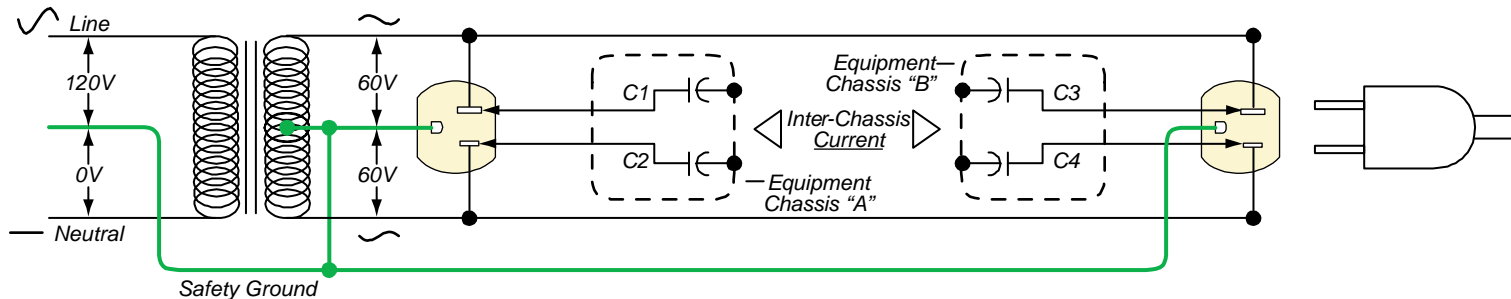
Symmetrical (Balanced) Power Transformer (cont.)

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.

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



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



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.

For reducing 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.

Ground 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 (auxiliary) ground rod is a place where “noise” wants to go.

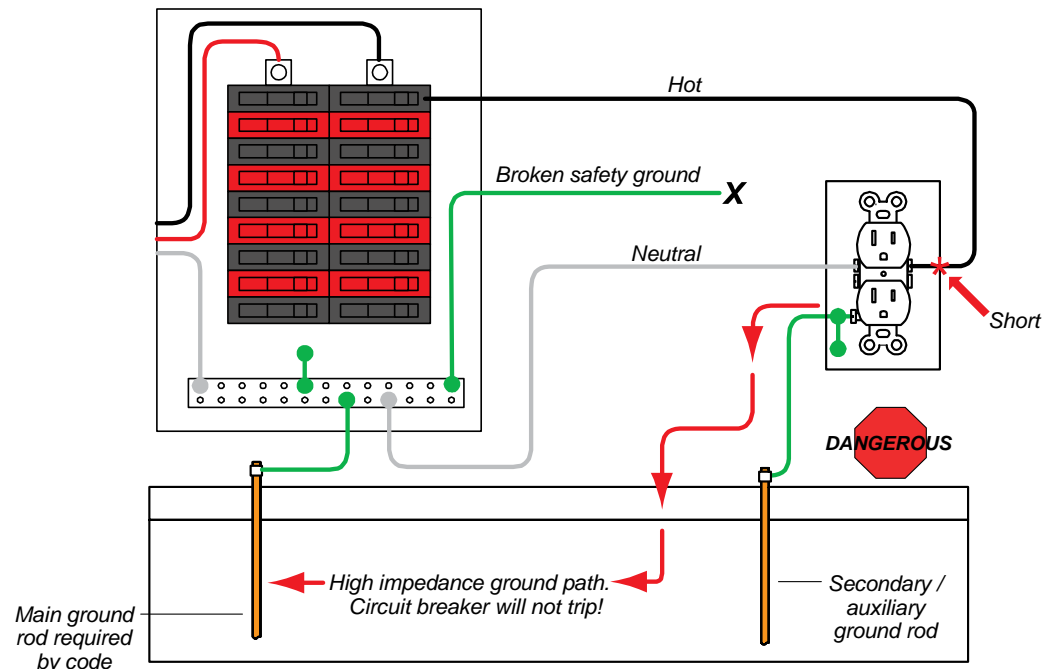
MYTH BUSTED! Noise will always flow back to the source; noise does not want to flow to ground (earth). In addition the NEC mandates that any supplemental (auxiliary) ground rod be bonded to the neutral/ground bond of a separately derived system, the main service neutral/ground bond or the grounding electrode system. Improper bonding of a supplemental (auxiliary) ground rod is dangerous! Any attempt to use a supplemental (auxiliary) ground rod as a magical sink for “noise” will most likely result in circulating currents flowing in the ground wires, most likely adding to noise 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. Driving independent, un-bonded ground rods into the earth does 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 = 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 – page 42).



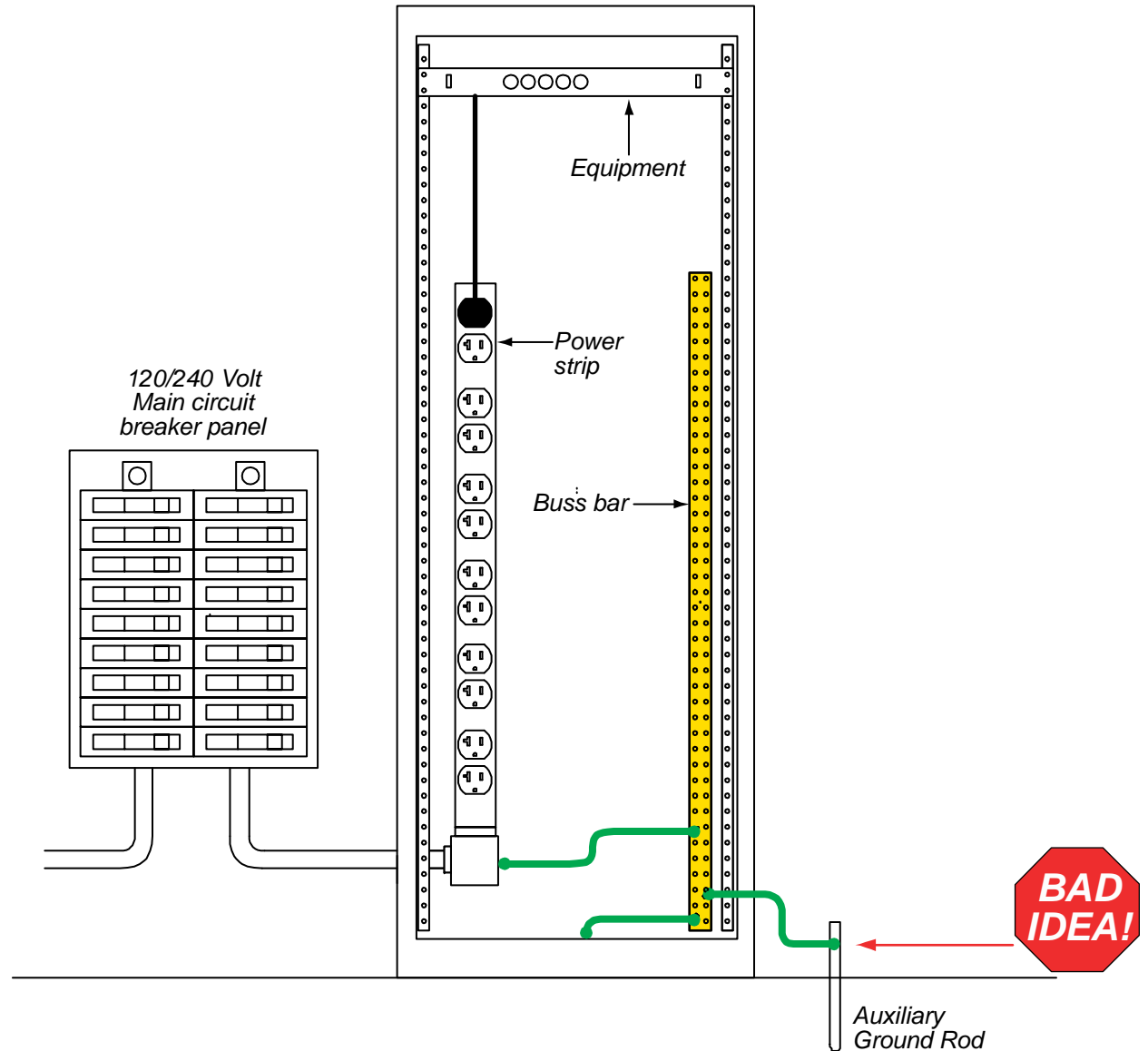
Grounding Gone Bad

Supplemental (auxiliary) grounding electrodes (building steel, ground rods, etc.) are not required or recommended because they 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 (auxiliary) 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 wire to a ground rod or building steel. The grounding conductor (ground) and the grounded conductor (neutral) are bonded together only at the main service panel, at a separately derived transformer or immediately after a separately derived transformer. No further connection of the neutral and ground is allowed on the load side of the main panel or the separately derived system transformer.



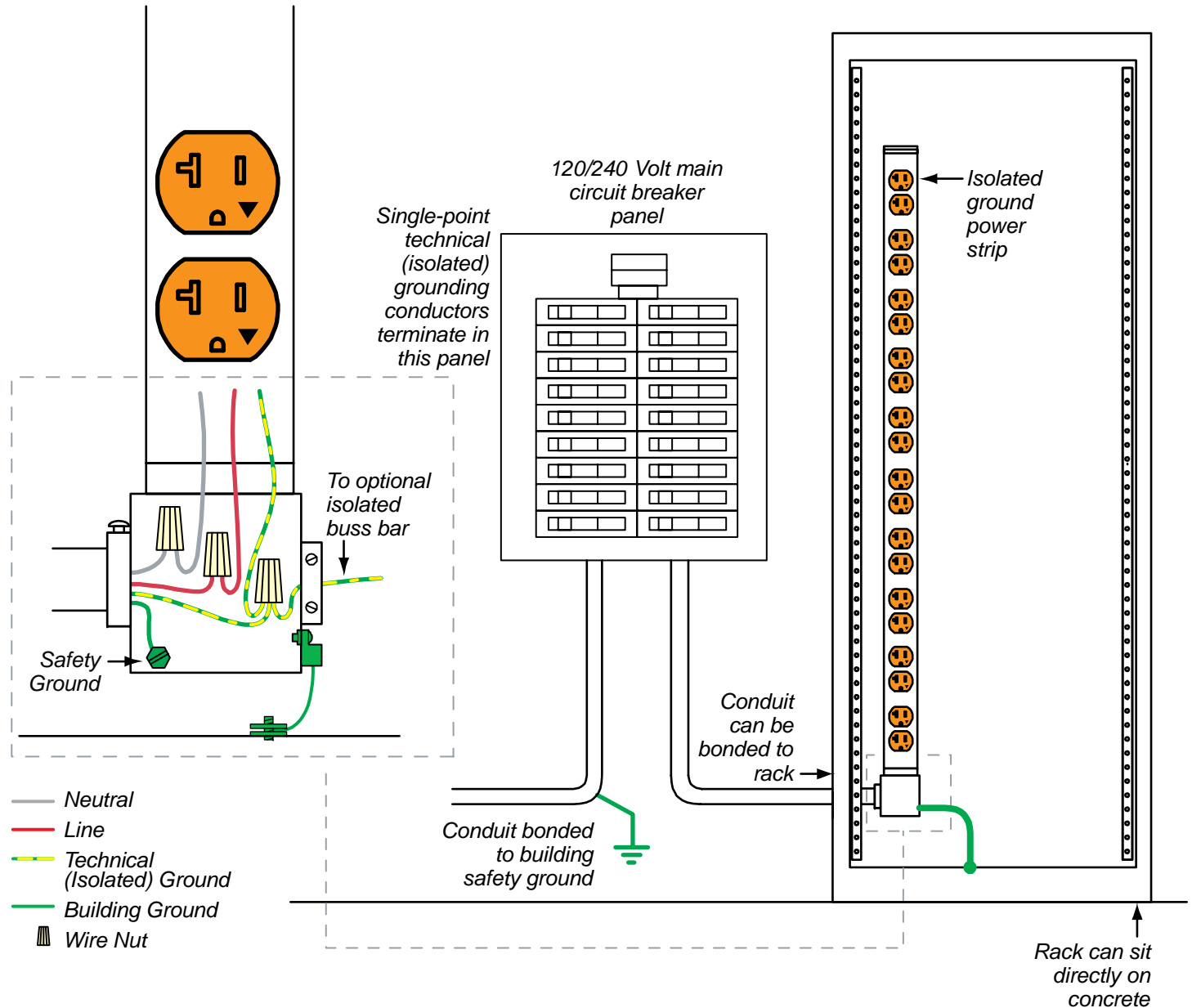
Isolated Ground Power Strip in a Non-Isolated Rack

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. When an isolated grounding system is breached, current will flow in the shields of the signal interconnect cables, inducing noise into the signal conductors.

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



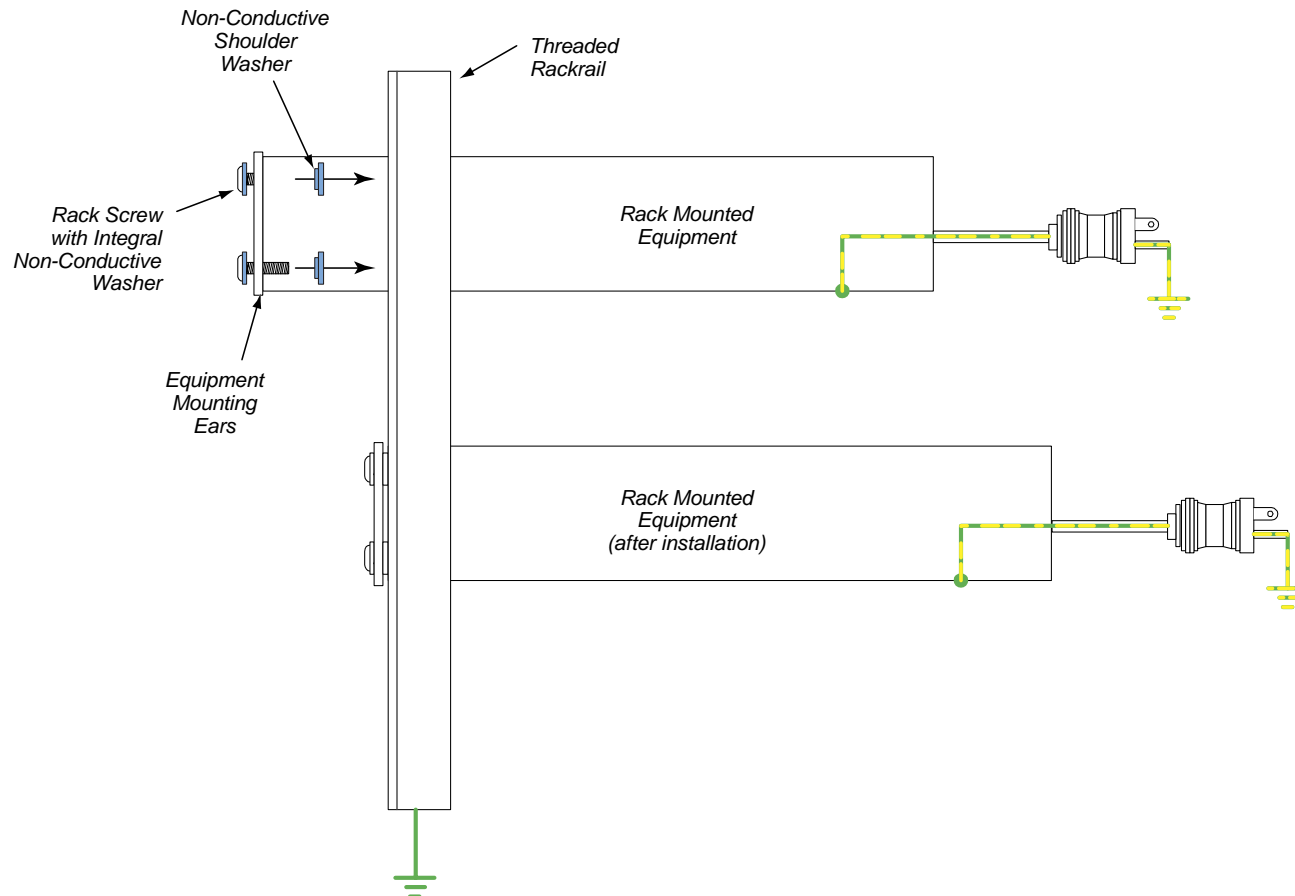
Isolated ground power strip in a non-isolated rack (cont.)

A problem will 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 this rackmounted equipment is screwed to the rackrail, an inadvertent ground connection will be present, defeating the isolation!

To avoid these problems 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 behind the equipment faces, as shown below. **This scheme is hard to implement and is easily rendered ineffective.**

Note: Technically, even when using isolating washers, higher frequencies will couple through the capacitance of the washer.

Rack Ear Insulators



Isolated Rack with Standard (not isolated) Power Strip

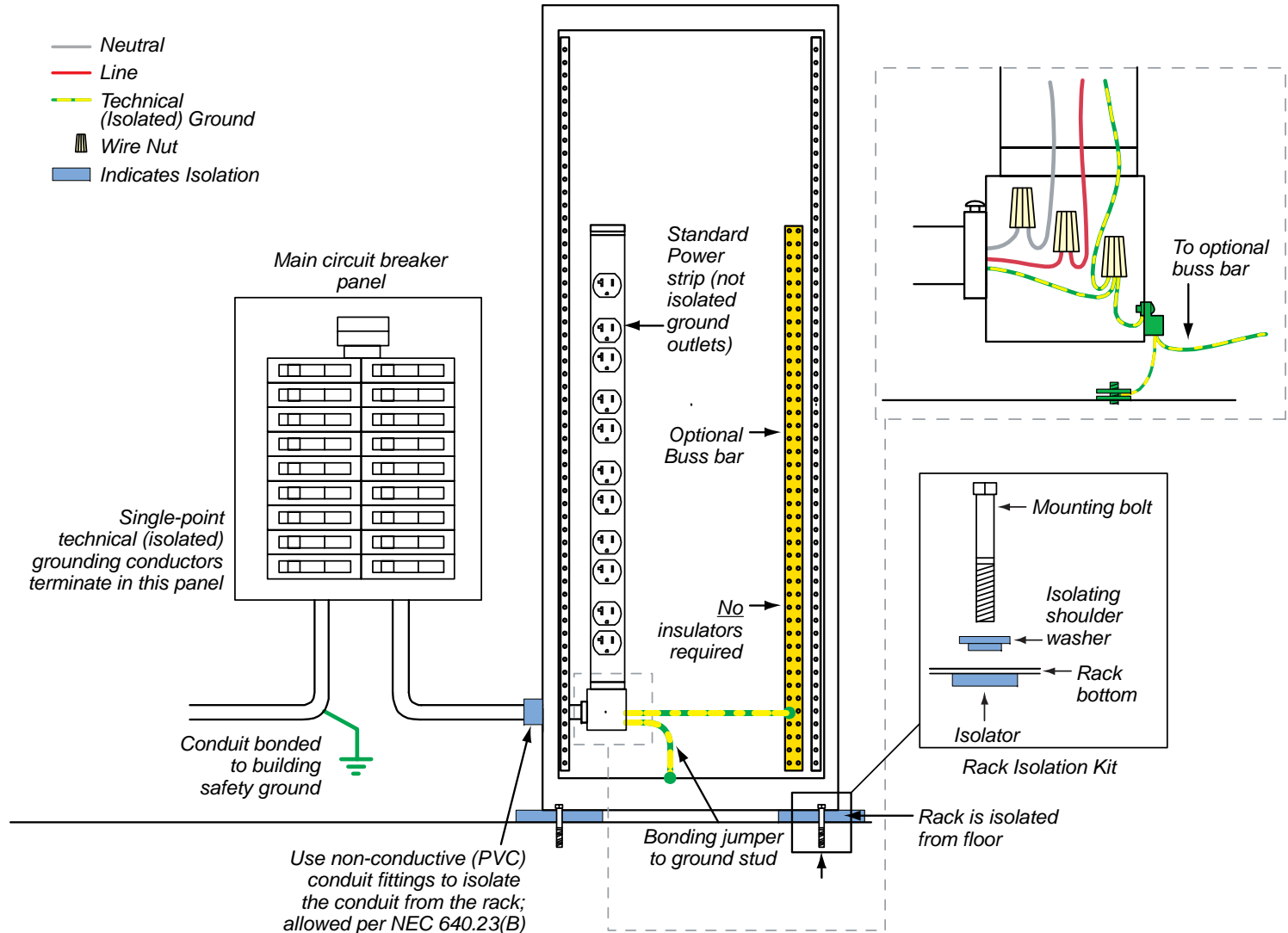
*This is highly effective and is recommended**

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.

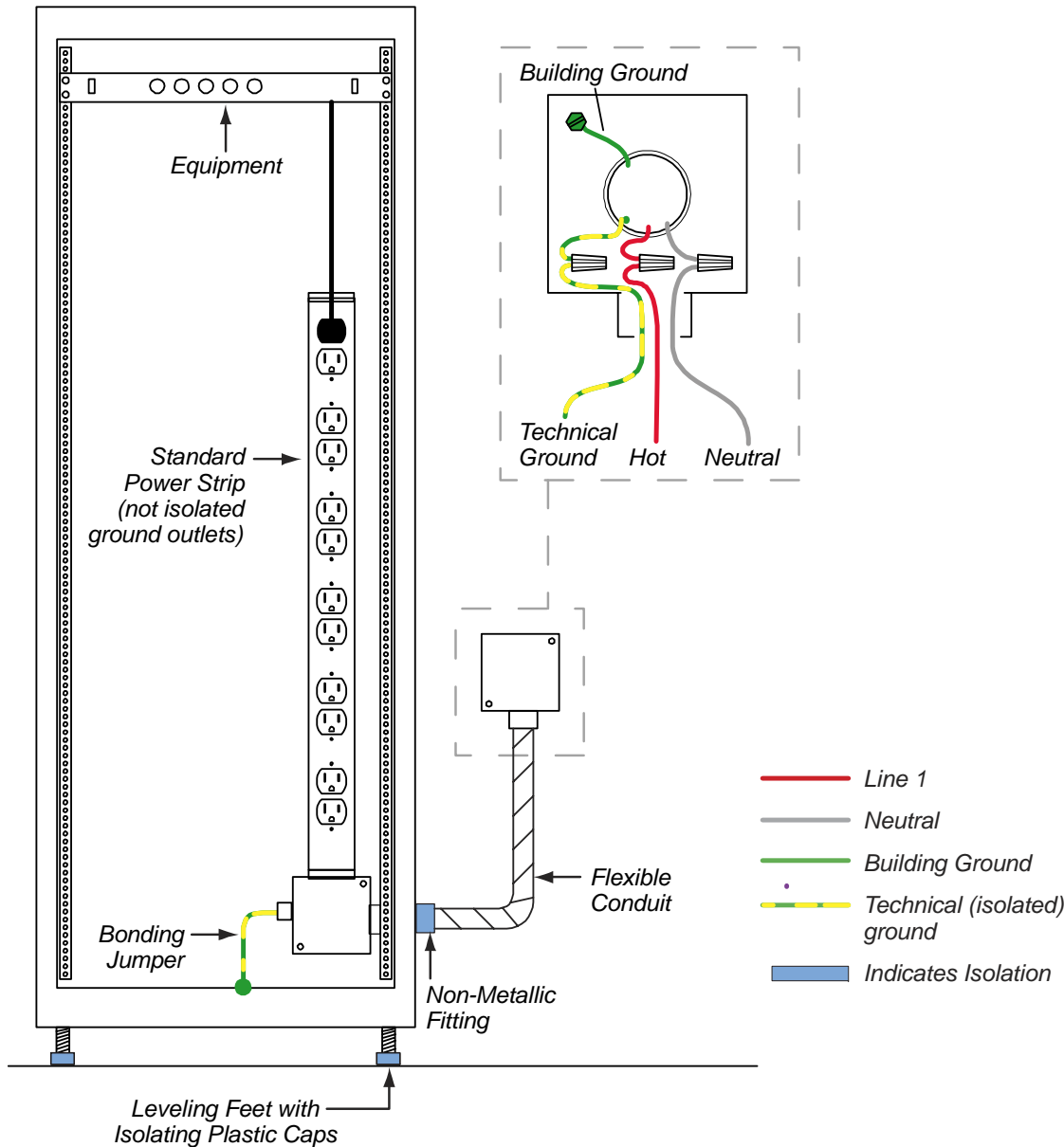
An "isolated ground" power strip may be substituted for the standard one, but there is additional cost and no additional benefit.



* 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 (page 42).

Flexible Connections to Isolated Equipment Racks

Example #1



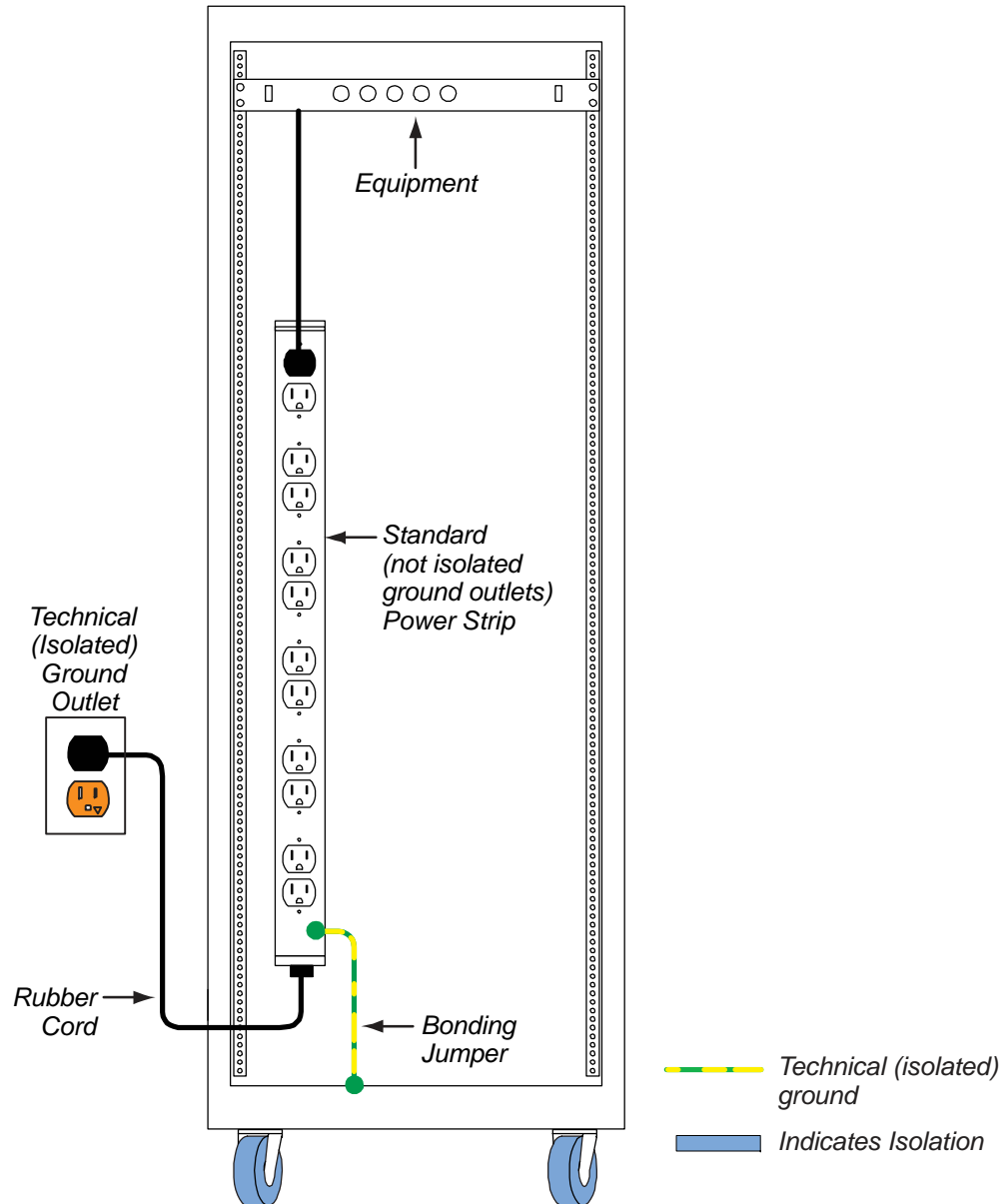
In the following examples, the racks are grounded via a technical (isolated) ground, and isolated from the building safety ground. Additionally, these racks are isolated from the floor by use of insulated leveling feet (example 1), and rubber or plastic wheels (example 2, next page).

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 technical (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.

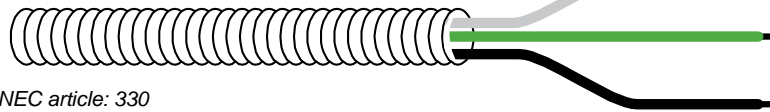
AC Wiring Types

The NEC does not require a supplemental (auxiliary) equipment grounding conductor in metallic conduit (raceway). However, it is highly recommended to add an insulated grounding conductor. Without a supplemental (auxiliary) grounding conductor the integrity of the ground is dependent on all of the conduit fittings in series. If one fitting is loose or corroded, the safety ground system is compromised. Additionally, noise may be induced into the signal path.

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

1. 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.

Metal-clad cable, commonly known as “MC”.



NEC article: 330

While the NEC allows the use of a bare ground wire, the best wire for AV installations is MC with an insulated ground wire. The outer sheath is not to be used as the primary ground; it is supplemental to the ground wire.

2. Electrical metallic tubing (commonly known as “EMT” or Thin-Wall)
3. Intermediate metal conduit (commonly known as “Threaded Thin-Wall”)
4. Rigid metal conduit (commonly known as “Rigid”)

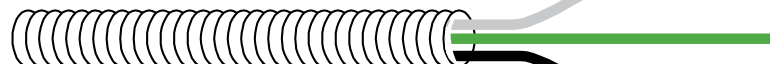


*NEC article: 358 (EMT)
NEC article: 342 (IMC)
NEC article: 344 (RIGID)*

Conduit must be installed as a complete system before the wiring is installed. The conduit is considered a “grounding conductor”. A supplemental grounding conductor may be installed.

For AV installations it is recommended to use an insulated ground wire when metallic conduit is required or specified.

5. Flexible metallic tubing
6. Flexible metal conduit (commonly known as “Greenfield”)
7. Liquidtight flexible metal conduit (commonly known as “Liquidtight” or “Sealtight”)



*NEC article: 360 (FMT)
NEC article: 348 (FMC)
NEC article: 356 (LFMC)*

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.

For AV installations it is recommended to use an insulated ground wire when metallic conduit is required or specified.

AC Magnetic Field Strengths from Different Wiring Types & 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 and Buzz

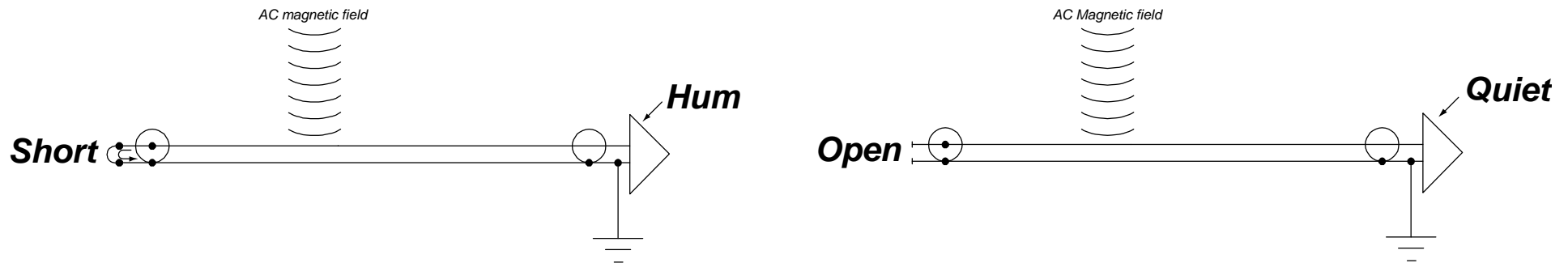
Cable shields do not protect against low frequency AC magnetic fields.

When diagnosing signal problems caused by low frequency AC electromagnetic fields, it is helpful to short the source end of the signal cable. If a signal cable with a shorted source end hums and the hum goes away when the short is lifted then the interfering field is likely to be an AC magnetic one. AC magnetic fields generally sound like “hum,” electrical fields and high order triplen harmonics generally sound like “buzz.”

Note: stationary permanent magnets cannot affect the signal path.

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 untwisted signal and power conductors
2. Use tightly twisted signal wire and twisted AC power cables



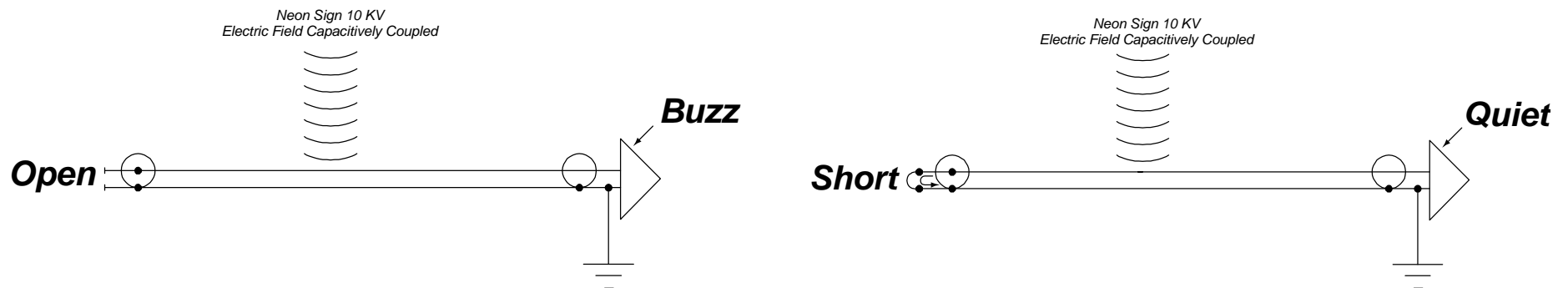
Electric Fields & Their Effect on Signal Wiring

Properly grounded cable shields protect against electric fields.

Diagnosing Hum & Buzz: When diagnosing hum & buzz caused by electric fields, it is helpful to open the source end of the cable. 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 that electric fields cause current flow in the signal path; one example is shown below.

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

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



For more information on good signal path design refer to the following published works*:

- "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 the above listed articles (and other published documents) can be found in the References section (pages 43-45).

Signal Wiring: Unbalanced & Balanced Interfaces

Long runs of unshielded and untwisted conductors are susceptible to external noise coupling 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, since the electromagnetic field is confined to the small space between the signal conductor and the 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 the majority of 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

Signal Wiring: Unbalanced & Balanced Interfaces (cont.)

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 (<http://www.iso-max.com/as/as032.pdf>)
- ▶ 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

Henry Ott has published a thorough and insightful analysis of both balanced and unbalanced interfaces. The paper – Balanced vs. Unbalanced Audio Interconnections – examines the practical application of both types of connection, and provides installation best practices in each case. The paper is available at: http://www.hottconsultants.com/pdf_files/Audio%20Interconnections.pdf

Furthermore, 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.

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.

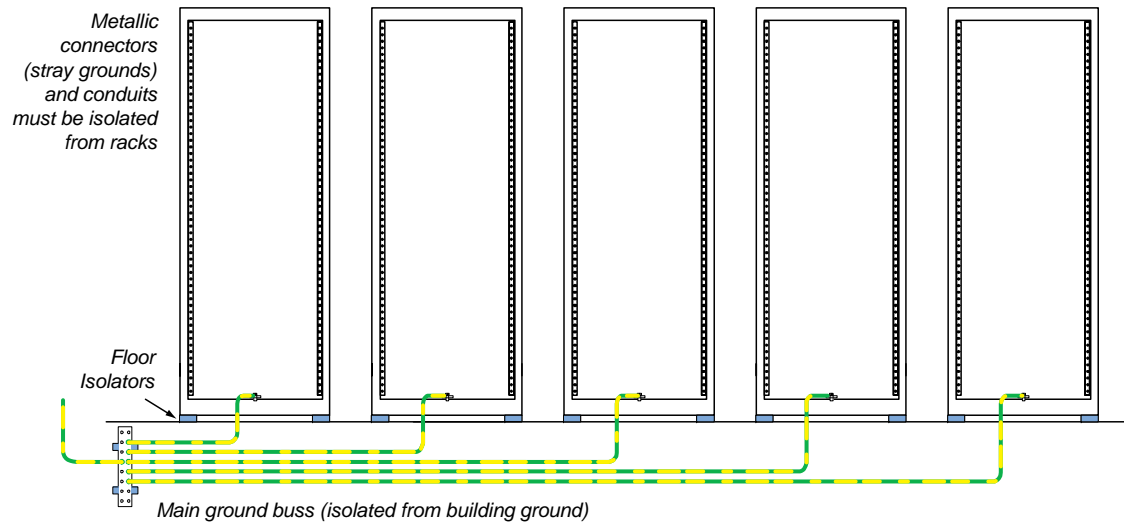
NEVER LIFT, OR OTHERWISE BYPASS THE POWER CORD GROUND... IT COULD BE FATAL!!



Single-Point Technical (Star) Ground vs. Daisy-Chain Grounding of Racks

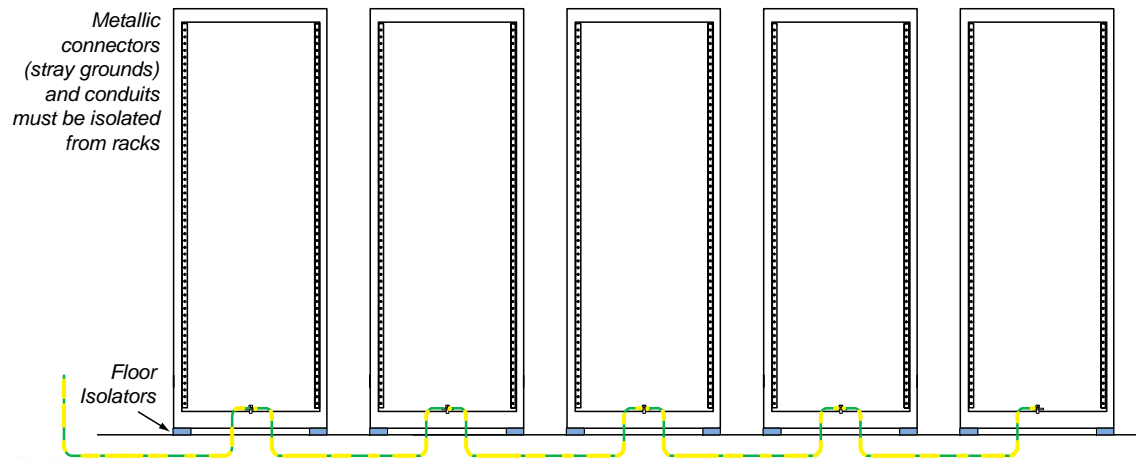
Two common methods of bonding racks together with equipment grounding conductors are known as “star” grounding and “daisy chain” grounding.

“Star” Grounding (isolated or technical ground)



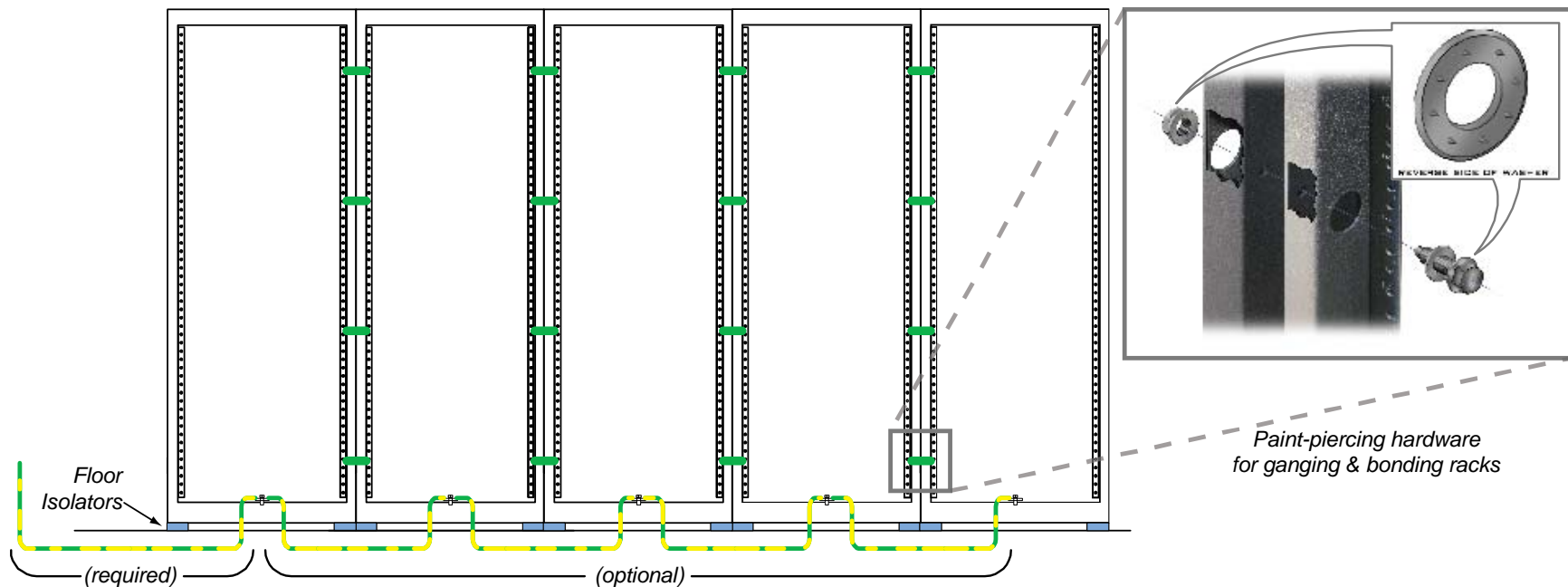
When properly configured, an isolated ground (also known as a technical ground or single-point ground) system is arranged electrically in a “star” pattern. Each rack is bonded to a common single point ground with separate equipment grounding conductors, reducing voltage drop. If paint-piercing hardware 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 (page 42).

“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.

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 minimized. 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.

Note: Daisy-chain grounding can be used in conjunction with paint-piercing hardware, as shown in the above diagram.

Introduction to Star Grounding, Signal Reference Grids & Mesh Grounding

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 as 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 together through a low impedance system, effective at all frequencies. This would minimize any potential difference between points.

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

1. Single Point Ground
 - a. 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.
 - b. 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.
2. Multi-point Ground
 - a. Mesh / Plane: In these systems all points are, effectively, connected to each other.

Star/Isolated Grounding

In a star connection, ground points are all connected to a single point. The resistance (and the low frequency potential difference) between a rack and the ground point is the minimum, since the connection is direct. The resistance between two racks will, however, not be the 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.

To eliminate signal interconnection ground loops the grounded shields of the interconnecting cables are often lifted at one end. In balanced interfaces however, lifting one end of a signal cable shield (also done to circumvent a pin 1 problem) can cause the shield to act as an antenna providing entry for voltage anomalies as well as RF interference. To provide a safe path for RF noise it is recommended to put a .01uF to .1uF capacitor (creating a hybrid ground) between the ungrounded end of the shield and ground. Some connectors with in-built RF bypass capacitors are available - see the EMC Series connectors at www.neutrik.com for examples.

Signal Reference Grids

One way to implement a low impedance ground that is effective over a wide frequency range is to use a copper floor, with all racks and equipment bonded directly to it.

Unfortunately, solid copper floors are impractical for many reasons (cost, manufacturability, etc.), so grounding grids are used instead. This topology is commonly known by a few names: signal reference grid, signal reference ground, and a zero signal reference ground (ZSRG).

The grounding grid approximates a copper ground plane using a mesh of interconnected copper bars or conductors. These conductors are often installed just under a raised floor surface. The grounding grid is then connected to the building safety ground.

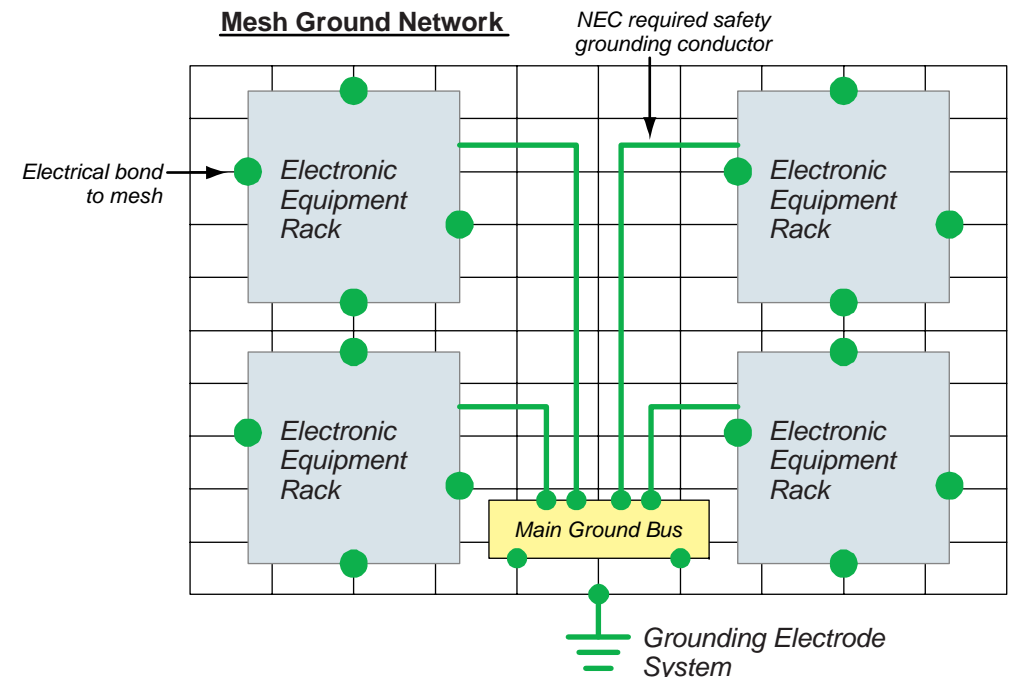
Mesh Grounding

The figure to the right illustrates the topology of an effective mesh ground network.

In a mesh connection, whether it is produced by a grounding grid or by ground wire interconnections, the impedance between any two points is minimized. Since there are multiple paths between any two racks, the ground current (and therefore, the potential voltage 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.

Note that creating a set of mesh connections can be logistically difficult and may increase the cost of an installation.

For a more detailed insight consult: Lewis, Warren H. Handbook of Electromagnetic Compatibility. Chapter 8, Grounding and Bonding. Edited by Reinaldo Perez: Academic Press, Inc. 1995



Good engineering practices should always be used to properly ground an installation. EMC 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, 10th Edition

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

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Notes

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