

Integrating Electronic Equipment and Power into Rack Enclosures

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

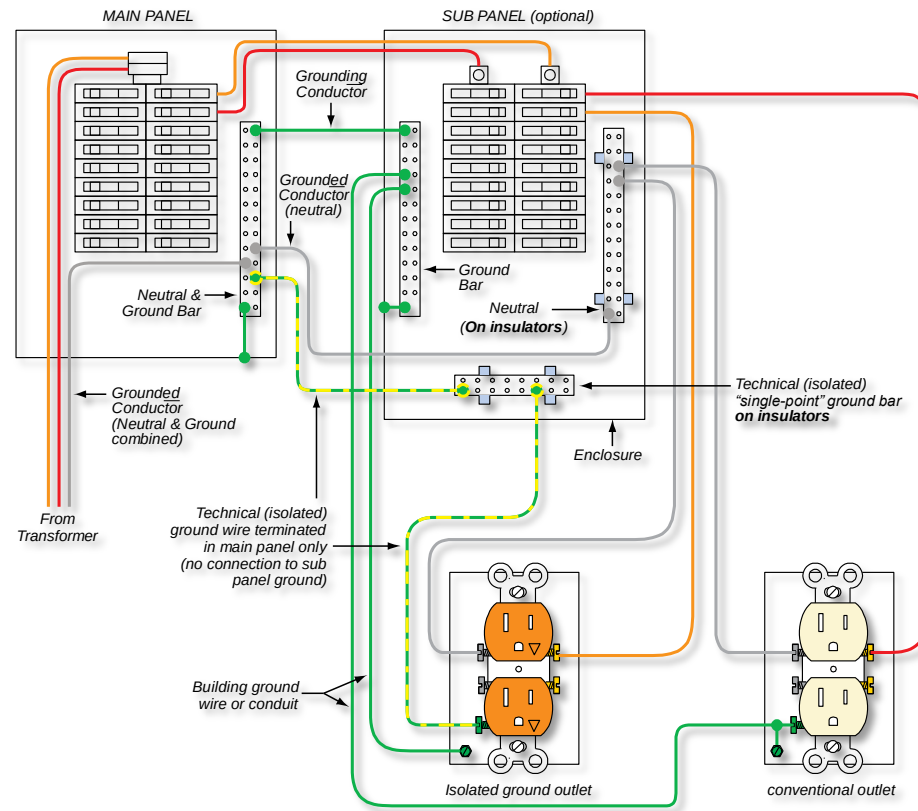


Table of Contents

Preface	1
A Note about Signal Paths	2
Ground Loops and Signal Interconnections	2
Signal Wiring: Unbalanced & Balanced Interfaces	3
AC Magnetic Fields & Their Effect on Signal Wiring	4
Electric Fields & Their Effect on Signal Wiring	5
Radio Frequency Interference (RFI)	5
Important Things to Remember When Designing & Installing Audio/Video Systems	6
North American Product Safety Certification	7
Dealing With Electrical Inspectors and Electrical Contractors	8
Typical 120-Volt Receptacles Used For Electronic Equipment	9
Receptacle Wiring - Common Errors and the Correct Way	10
AC Power Wiring Types	11
AC Magnetic Field Strengths from Different Wiring Types	13
Calculating System Load	13
Calculating Amplifier Circuit Requirements	15
Single Circuit Sequencer Systems	16
Multiple Circuit Sequencer Systems	17
Simplified Grounding Guidelines for Audio, Video and Electronic Systems	18
Isolation Transformers (Separately Derived Systems): Benefits and Wiring Methods ...	19
Isolation Transformer Neutral-Ground Bonding Methods	20
Electrostatic (Faraday) Shielding in Power Transformers	22
K-Rated Three Phase Power Transformers	23
Typical Three Phase Services	24
Phasing of Supply Conductors	25
60/120V Symmetrical (Balanced) Power Systems	26
Ground Myths	28
Neutral-Ground Reversals and Bootleg Grounds	29

Neutral-Ground reversals	30
Steps to Troubleshoot Bootleg Grounds and Neutral-Ground Reversals	32
Auxiliary Ground Rods	34
Intersystem Bonding (Cable TV, Satellite TV, Telephone)	35
Power Quality Problems	36
Power Quality Problems: Voltage Regulation	36
Other Power Quality Problems	36
Electrical Noise	37
Power Conditioning	38
The System Approach to Power Quality	39
Ground Voltage Induction (GVI)	40
Isolated (Technical) Ground vs. Safety & Building Ground	43
Isolated Ground Receptacles	45
Wiring Isolated Ground Outlets and Conventional Outlets when using a Sub Panel	46
Isolated Ground Power Strip in a Non-Isolated Rack	47
Isolated Rack with Standard Power Strip (not isolated ground receptacles)	49
Flexible Connections to Isolated Equipment Racks	50
Main Considerations When Implementing Surge and Spike Protection	52
Surge and Spike Protection Technologies	53
Surge Suppressors and Noise on Safety Ground Wires	55
Single-Point Technical (Star) Ground vs. Daisy-Chain Grounding of Racks	56
Enhanced Rack Bonding	57
Introduction to Star Grounding, Signal Reference Grids & Mesh Grounding	58
Star/Isolated Grounding	58
Signal Reference Grids	59
Mesh Grounding	59
Authors	60
References	60

Preface

Note on the Rev. 4b Edition:

Since its initial publication, Integrating Electronic Equipment and Power into Rack Enclosures has been periodically reviewed for accuracy. This document undergoes frequent maintenance and will continually be modified to include the most current industry thinking and consensus.

The primary changes in this edition are focused on AC power wiring and ground voltage induction, isolation transformer wiring methods, surge/spike protection technologies, and troubleshooting bootleg grounds and wiring errors. Many clarifications have been included, and some typos have been corrected.

In providing this information, the intent is not to make audio/video system professionals into electricians. They do however need a basic understanding of proper design and installation of power distribution and grounding to avoid potential noise and safety problems.

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. 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 as it relates to audio and video systems.

A Note about Signal Paths

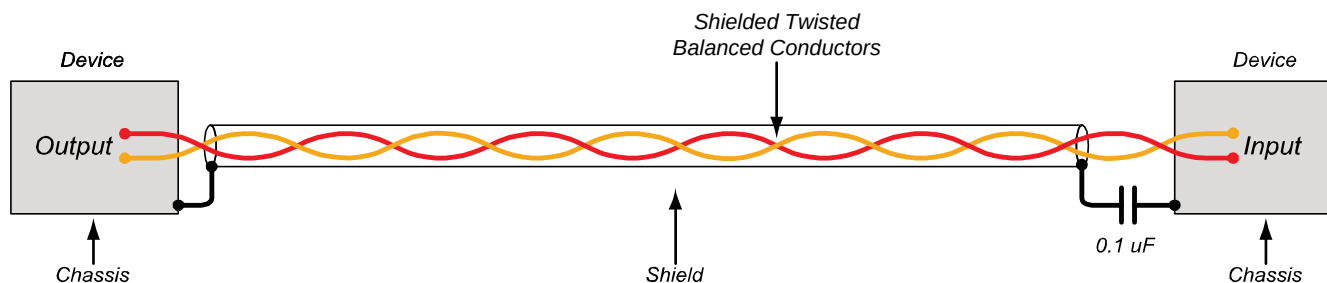
Although the focus of this paper is on electrical power distribution and grounding, the impact of noise on the signal path is ultimately what we see or hear. When designing or troubleshooting audio & video systems it's important to have a basic understanding of how the electrical and grounding system can adversely impact the signal path. The following few pages are simply a high-level overview of signal-related topics including SCIN, CMRR and Pin 1 problems that are well covered by many authors and industry organizations (see references section of this paper).

Ground Loops and Signal Interconnections

Low-current ground loops are entirely normal and may or may not create problems in AV systems. Unbalanced interfaces will always be susceptible to low-current ground loops. When using balanced interfaces, problems are caused by ground loops only in conjunction with improper signal wiring and/or signal equipment with low common-mode rejection ratio (CMRR) or Pin 1 problems.

Audio systems that require low noise floors and wide dynamic range need (among other things) balanced signal interconnections, good cables, good equipment (no Pin 1 problems, adequate common-mode noise rejection) and proper grounding. There is no single “right way” to wire an AV system optimally. The equipment chosen has a profound impact on noise immunity. Many so-called “balanced inputs” only marginally reject common-mode noise. **Note:** The communication and data industries are generally not affected by ground loops and have a very different set of requirements for proper operation.

Long runs of signal wire having “SCIN” (shield current induced noise) susceptibility are affected by ground loops. To eliminate signal interconnection ground loops on balanced interfaces, the shields of the interconnecting cables are often lifted (disconnected) at the **receiving** (input) end. This addresses one common cause of noise, although lifting one end of a balanced signal cable shield (also done to circumvent a Pin 1 problem) can cause the shield to act as an antenna, allowing RF interference to capacitively couple onto the signal conductors within the cable. To prevent this, it is recommended to put a 0.1 uF capacitor with short leads (creating a “hybrid” ground) between the now ungrounded **receiving** (input) end of the shield and the equipment chassis (see diagram below).



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 (sometimes referred to as crosstalk) to adjacent conductors running in close proximity. Telecommunications network cabling can also conduct Electromagnetic Interference (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 power-line related *voltages* will always exist between pieces of grounded equipment, and
2. Tiny power-line related *currents* will always flow in signal cables connecting grounded 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.

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

Unbalanced signal interconnections should be avoided whenever possible because they’re extremely vulnerable to ground loop currents. Even at a shield resistance of 0.5 ohm, 0.3 milliamps of loop current can impact the lower 30 dB of a CD’s 95 dB dynamic range. **Note:** When a high level of dynamic range is not required, it may be acceptable to use very short unbalanced cables with very low shield resistance.

Signal Wiring: Unbalanced & Balanced Interfaces (cont.)

BALANCED interfaces are widely used in professional audio equipment and generally use XL or screw terminal connectors.

Balanced interfaces have substantial immunity to noise currents! Since the impedance (with respect to ground) of the two signal conductors is the same, noise from any source is coupled to them equally and can be rejected by the receiving input. Power line ground noise current will harmlessly flow in the cable shield, if present. However, some equipment and some cables are of poor design and can still give rise to 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” or “SCIN” problem, disconnect the shield only at the receive end of the cable. If RF noise is encountered after disconnecting the shield, a capacitor may be installed as described in the Ground Loops and Signal Interconnections section
- ▶ Use cables without shield drain wires to reduce Shield-Current-Induced-Noise (SCIN)

If noise rejection is still 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.

AC Magnetic Fields & Their Effect on Signal Wiring

Cable shields do not protect against low (power and audio) frequency AC magnetic fields.

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 pair signal wire and AC power cables with twisted conductors

Electric Fields & Their Effect on Signal Wiring

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

1. Use cables with properly grounded cable shields (only effective against electric fields, not magnetic fields)
2. Use low-impedance balanced signal connections
3. 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 of this paper.*

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!!

Radio Frequency Interference (RFI)

Radio frequency interference (RFI) in systems can arise from many sources, including transmissions from nearby radio transmitters. All conductors act as antennas at certain frequencies, including speaker wires. Twisting speaker wires is one way to prevent them from acting as differential mode antennas; this prevents RFI coupling from the amplifier's output to the amplifier's input via its feedback-loop components. Twisting wires greatly reduces their susceptibility to both RFI and AC magnetic fields.

Although using signal interface cables and balanced interconnects can be effective at reducing the severity of RFI problems, the most effective solutions must be designed into the equipment by the manufacturer in the form of appropriate filtering, shielding, and proper shield terminations.

Important Things to Remember When Designing & Installing Audio/Video Systems

- 1) There are many possible causes of signal path noise, including equipment that does not comply with the AES48 standard ("Pin 1 Problem"), inadequate CMRR (Common-Mode Rejection Ratio) on input stages, signal wiring that does not comply with the AES54 standard (Grounding and EMC Practices of Signal Wires) and shield current induced noise (SCIN) in signal cables. 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. With the exception of grounding, these topics are beyond the scope of this paper and are well documented elsewhere (please see references listed at the end of this paper).
- 2) Ground loops are an entirely normal occurrence. The amount of current in the loop is determined by many things, including jobsite conditions and the design of the power and grounding system. Whether a ground loop becomes a problem depends on the equipment and cabling vulnerabilities mentioned above.
- 3) Large printed circuit trace loop areas are susceptible to voltage induction (as a result of close proximity to transformer-based power supplies). This is usually found on poorly designed equipment. These circuit trace loops can cause hum even when there is no ground loop present, and even when there is no power to the equipment.
- 4) Best practices of good signal path design include good cable management inside the rack. With the exception of well-constructed coaxial cable (which is inherently immune to low-frequency AC magnetic fields), it is recommended that signal cables are placed a minimum of 2" away from AC power conductors when run parallel. It is, however, acceptable to install signal cables in close proximity to power cables if the conductors of both cables are twisted tightly.
- 5) Some equipment is designed to pass leakage currents onto the ground circuit. This current may manifest itself as a hum or buzz in poorly designed AV systems.

North American Product Safety Certification

The Nationally Recognized Testing Laboratory (NRTL) program is mandated by the Occupational Safety and Health Administration (OSHA) and recognizes organizations that provide product safety testing and certification services to manufacturers (further information on OSHA can be found on its website at <http://www.osha.gov>). There are a number of well known NRTL organizations that act as third parties, evaluating thousands of products, components, materials and systems.

Under U.S. law, all NRTLs that are accredited to test similar types of products must be equally acceptable to inspectors or Authorities Having Jurisdiction (AHJs). Some of the more common include:

ETL - The ETL Listed Mark is the fastest growing product safety certification mark in North America with more than 50,000 product listings.

UL - Underwriters Laboratories, Inc. is currently the most recognizable NRTL.

TÜV - TÜV SÜD America Inc. is a globally recognized testing, inspection & certification organization offering the highest quality services for a wide range of industries worldwide.



This symbol represents a product that has passed ETL's certification to comply with both U.S. and Canadian product safety standards.

This symbol represents a product that has passed UL's NRTL tests, in both the U.S. and Canada.

This category is for UL Recognized COMPONENTS only. Generally UL Listed products are manufactured using all "Recognized" components; however, this does not mean that the product is "UL Listed" to meet NRTL requirements.

This symbol represents a product that has passed TÜV's certification to comply with both U.S. and Canadian product safety standards.

* On a regular basis, NRTL Inspectors also visit the factories where the NRTL listed products are manufactured to ensure products are manufactured according to NRTL safety standards.

In advertising, labeling or marketing products, all NRTLs specifically **forbid** the use of the following terms:

"Approved" "Pending" "Made With Recognized Components"

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

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 electrical inspectors (who are usually very experienced electricians) don't know much about audio, video or communications design and 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 and not performance. For example, while an electrical inspector may consider an incorrectly installed isolated (technical) ground system safe, it 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) *NRTL 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)

Typical 120-Volt Receptacles Used For Electronic Equipment

All 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. Hospital grade receptacles are identified by an engraved green circle on the face. Both symbols may appear on the same receptacle. The color of the receptacle itself has no bearing whatsoever, i.e. orange colored receptacles with no engraved designations only mean that they are colored orange.

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

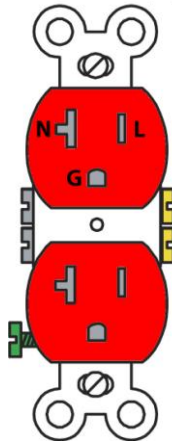
- Abrupt Plug Removal Test
- Ground Contact Overstress Test
- Impact Test
- Assembly Security Test

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

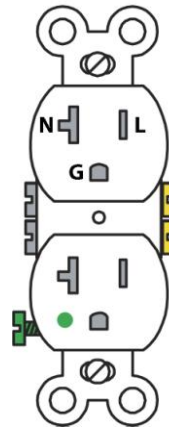
Twistlock Terminal Identification	
X,Y	Phase Legs
L	Line
W	Neutral
G	Ground

Receptacle Terminal Identification	
Yellow	Brass
White/Silver	Hot Leg
Green	Ground

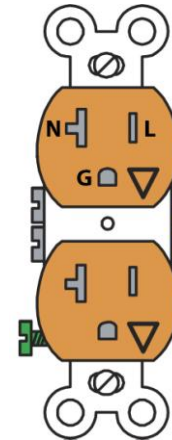
NEMA 5-20R
Red typically indicates emergency power



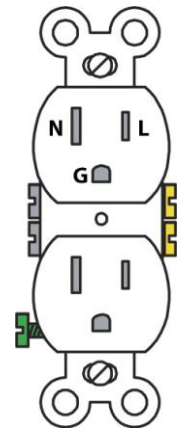
NEMA 5-20R
Hospital Grade



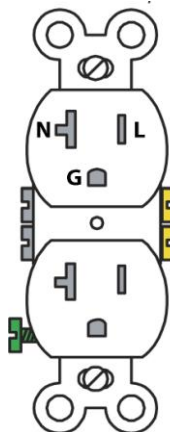
NEMA 5-20R
Isolated Ground



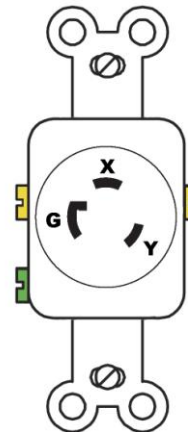
NEMA 5-15R
15 amp circuit accepts NEMA 5-15P plug



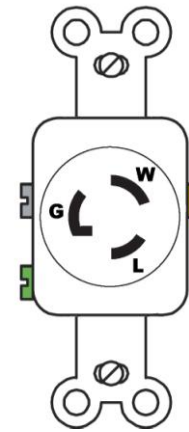
NEMA 5-20R
20 amp circuit accepts NEMA 5-15P or NEMA 5-20P plug



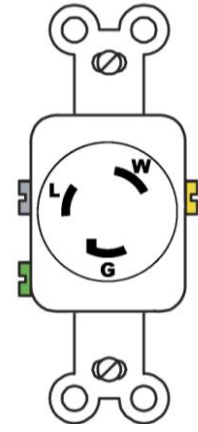
NEMA L5-15R
15 amp circuit accepts NEMA L5-15P plug



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



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



Receptacle Wiring - Common Errors and the Correct Way

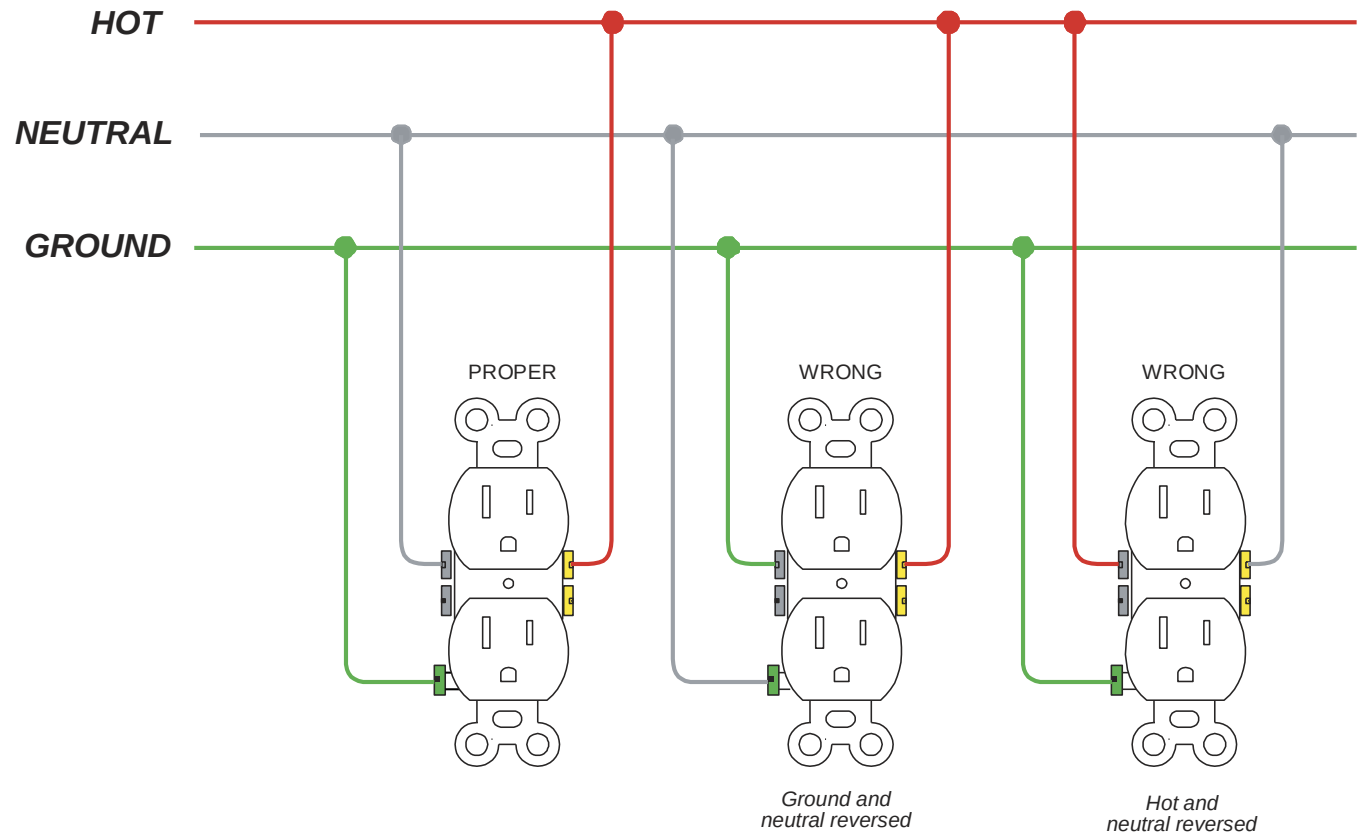
Receptacle wiring errors are more common than some may realize. Some wiring errors can negatively impact AV system performance. Some can result in safety hazards. Be sure to verify power system wiring before connecting equipment.

Receptacle wiring errors may not be detected by simply plugging in your equipment, which may seem to work ok. For example, a hot-neutral reversal will not affect the equipment operation, nor will it create hum and buzz in the system unless other wiring errors are present.

The most common way to detect receptacle wiring errors is with a three-prong receptacle tester. However, “three prong” receptacle testers (like that shown below) **cannot detect a neutral-ground reversal or a bootleg ground**. A reversal or bootleg ground can be a significant cause of system noise and can only be detected by using an amp meter as detailed in the Neutral-Ground Reversals and Bootleg Grounds section of this paper.



Note: The NEC 200.6(A) designates neutral conductors to be colored white or light gray. To facilitate printing we use light gray to represent neutral colors throughout this paper.



AC Power Wiring Types

The NEC does not require a supplemental (auxiliary) equipment grounding conductor in metallic conduit (raceway). However, it is highly recommended to install one and ensure that it is insulated (not bare). Without a supplemental (auxiliary) equipment 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.

Installing a supplemental (auxiliary) equipment grounding conductor, along with the power conductors, assures a low impedance ground path for fault current and may reduce ground voltage differences between interconnected equipment. The supplemental (auxiliary) equipment grounding conductor must be installed in the conduit with the power conductors.

Flexible Metallic Tubing/Conduit – Commonly called “Greenfield” after the name of its inventor, 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.

NEC Definitions

Flexible metallic tubing (NEC article: 360 FMT)

Flexible metal conduit, commonly known as Greenfield (NEC article: 348 FMC)

Liquidtight flexible metal conduit, commonly known as “Liquidtight” or “Sealtight” (NEC article: 356 LFMC)

Armor Clad – Designated (AC) by the NEC, and sometimes called “BX”, its original manufacturer’s trade name. While it is the least expensive, is the least desirable for AV systems due to the fact that there is no supplemental grounding conductor (wire). The metal jacket, along with its aluminum bonding strip, is the safety grounding conductor and is detrimental to AV performance due to its higher comparative impedance than a solid piece of copper wire. Without a supplemental grounding conductor, the ground impedance and integrity is dependent on the length of the sheath and all the connectors and fittings (in series). BX cannot be used with isolated ground receptacles.

Non-Metallic Sheath - designated (NM) by the NEC and commonly called Romex, is not permitted in places of assembly or in buildings of 3 or more floors. Romex cannot be used with isolated ground receptacles.

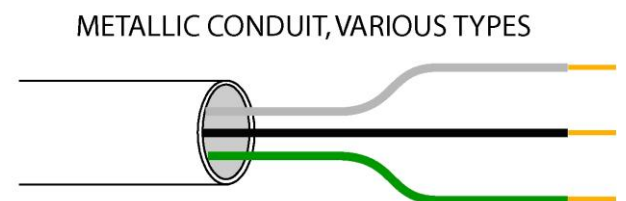
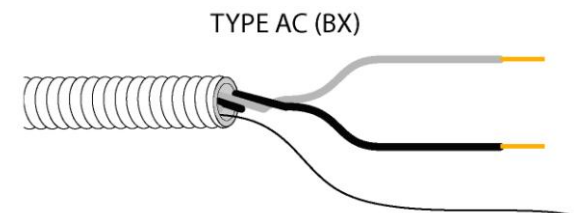
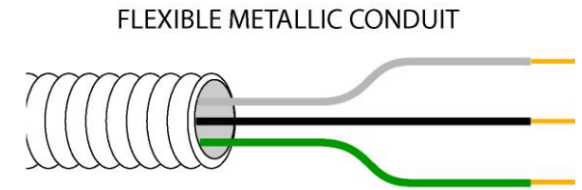
Metallic Conduit must be installed as a complete system before the wiring is installed. The conduit is considered a “grounding conductor.” A supplemental grounding conductor may be installed. For AV installations it is recommended to use an insulated ground wire when metallic conduit is required or specified.

NEC Definitions

Electrical metallic tubing, commonly known as “EMT” or Thin-Wall (NEC article: 358 EMT)

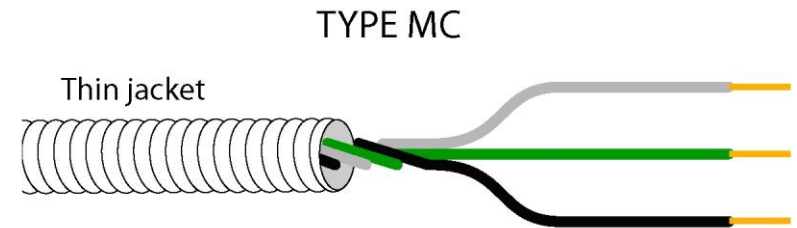
Intermediate metal conduit, commonly known as “Threaded Thin-Wall” (NEC article: 342 IMC)

Rigid metal conduit, commonly known as “Rigid” (NEC article: 344 RIGID)



AC Power Wiring Types (cont'd)

Metal Clad (MC) is manufactured in both steel and aluminum with twisted conductors that help reduce AC magnetic fields. Although the steel jacket helps reduce AC magnetic fields, the twisting of conductors has the greatest effect on reducing these fields. Another benefit is the constant symmetry of the phase conductors with respect to the grounding conductor which greatly reduces voltage induction on the grounding wire. (NEC article: 330)

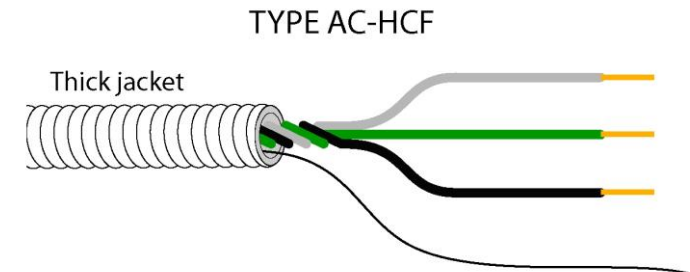


Two conductor plus 1 ground MC (Metal Clad) is a good choice for Non-Isolated Ground A/V systems. MC cable contains a safety grounding conductor (wire). The three conductors in the MC cable (Line, Neutral and Ground) are uniformly twisted, reducing both induced voltages on the ground wire and radiated AC magnetic fields. The NEC article 250.118 (10)a prohibits the use of this cable for isolated ground circuits because the metal jacket is not considered a grounding conductor, and it is not rated for fault current.

Two Conductor plus 2 ground MC (Metal Clad) may be used in an Isolated Ground installation, because the cable contains two grounding conductors (one for safety ground and one for isolated ground). The conductors are twisted, but the average proximity of the hot conductor and the neutral conductor with respect to the isolated grounding conductor is not equal. Under load, this will induce a voltage along the length of the isolated ground wire, partially defeating the intent of isolation (see Ground Voltage Induction section of this paper).

Armor Clad for Healthcare Facilities (AC-HCF)

Aluminum Armor Clad for Healthcare Facilities (AC-HCF) is the **best choice** for Isolated Ground A/V systems. Like MC, it contains an additional grounding conductor, although with this type of cable it is permissible to use the metal jacket as the safety grounding conductor, as required with isolated ground installations. The biggest benefit is that the average proximity of the hot conductor and the neutral conductor with respect to the isolated equipment grounding conductor is nearly equal, virtually eliminating ground voltage induction (GVI), even on long runs.



Steel Armor Clad for Healthcare Facilities (AC-HCF)

Similar to aluminum armor clad AC-HCF, but does not address ground voltage induction as effectively as aluminum (see Ground Voltage Induction section of this paper). Two other problems are that steel clad is not readily available and is cumbersome to transport and install.

AC Magnetic Field Strengths from Different Wiring Types

AC current flowing through a conductor will create an AC magnetic field along the entire length of the wire, the magnitude of which will vary in proportion to the amount of current. This field may inductively couple noise voltage to signal wires running parallel, which can result in hum and buzz. The longer the run of these parallel wires, the greater the inductively coupled noise voltage will be.

Cable shields, whether braid and/or foil type, cannot attenuate AC magnetic fields, they ONLY attenuate electric fields.

The only ways to reduce the effect of AC magnetic fields are through physical separation (distance), tightly twisting the conductors, or encasing them in ferrous tubing such as steel.

As evidenced by the chart below, tightly twisting the conductors is far more effective at shielding AC magnetic fields than placing the conductors in heavy steel conduit. This is why steel clad “MC” type or “AC-HCF” type flexible cable is recommended for use in proximity to signal wires; it has twisted conductors that greatly reduce the AC magnetic field.

Field strength, in milligauss, is a unit of measurement of AC magnetic fields. AC magnetic fields are produced by AC electrical current flow and are a component of electromagnetic fields (not to be mistaken for static magnetic fields like the souvenir magnet on the fridge at home). AC magnetic fields can inductively couple into the signal paths of sensitive AV systems, often resulting in hum in high gain systems. 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 conductors reduces both emitted, and the effect of received electromagnetic fields, the more twists per unit length, the greater the reduction.

Wire Type	Test Subject	Current Draw, using a Resistive Load @120V	Milligauss		
			1/2" Away	2" Away	
Single #12	Conductor only (loose, not in conduit)	7.5A (900 watts) not in proximity to return conductor	180	135	↑ Worst Best ↓
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 MC	7.5A (900 watts)	0.6	0.1	
12-3	SignalSafe™ Cord*	7.5A (900 watts)	0.2	0.0	

*SignalSafe™ is a trademark of Middle Atlantic Products, Inc.

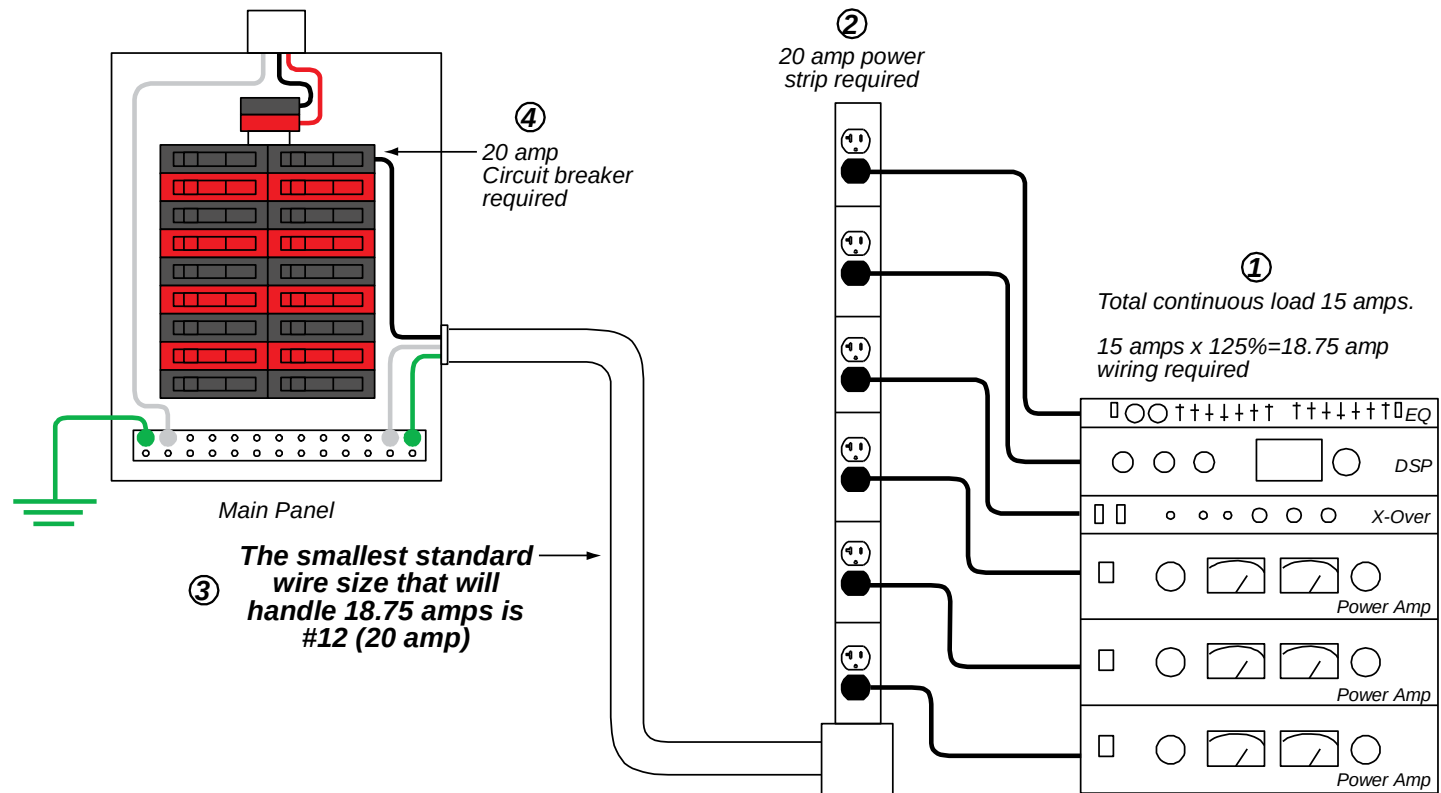


Calculating System Load

If an electrical load is operated for three hours or more under usual and customary conditions, 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 operated for less than three hours, the wiring may be sized at 100% of the load. General Rule: The load (1) determines the power strip rating (2) and wire size (3); the wire size determines the circuit breaker size (4), as shown in the figure below.

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) De-Rating: the number of conductors allowed in conduit based upon amperage and 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 to the same amplifier can change the overall current draw.

Program Type	Speaker Impedance	AC Current Draw
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 impedance of the load(s) that it is driving. Although the NEC allows 100% circuit sizing for non-continuous loads, when sizing an amplifier AC 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 minimizes resistive voltage drop when the amplifier is required to reproduce peaks in program material.

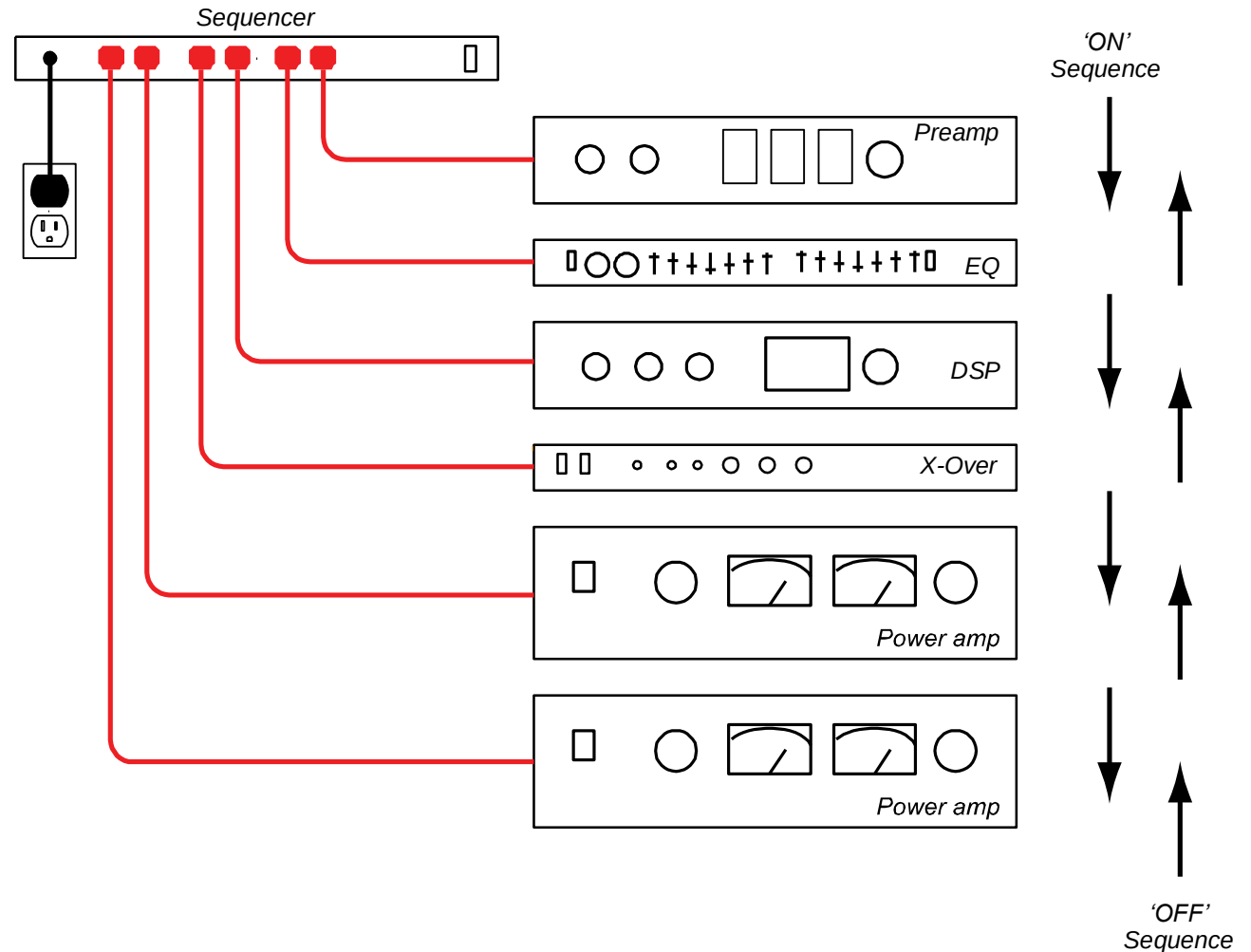
Calculation Example: If the calculated load is 17 amps, the minimum size conductor would normally be #12 copper (20 amps), however, when the 125% factor is applied ($17 \text{ amps} \times 125\% = 21.25 \text{ amps}$), the next standard wire size is #10 (30 amps).

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 NRTL listing and the product warranty if it is done in such a manner that is inconsistent with the amplifier installation instructions.

Single Circuit Sequencer Systems

Without sequencing, two common problems can occur when a sound system's power switches on and off. Loud "pops" may result from source or processing equipment that is turned on after power amplifiers (putting speakers at risk) and the circuit may overload from the simultaneous in-rush current drawn by multiple power amplifiers.

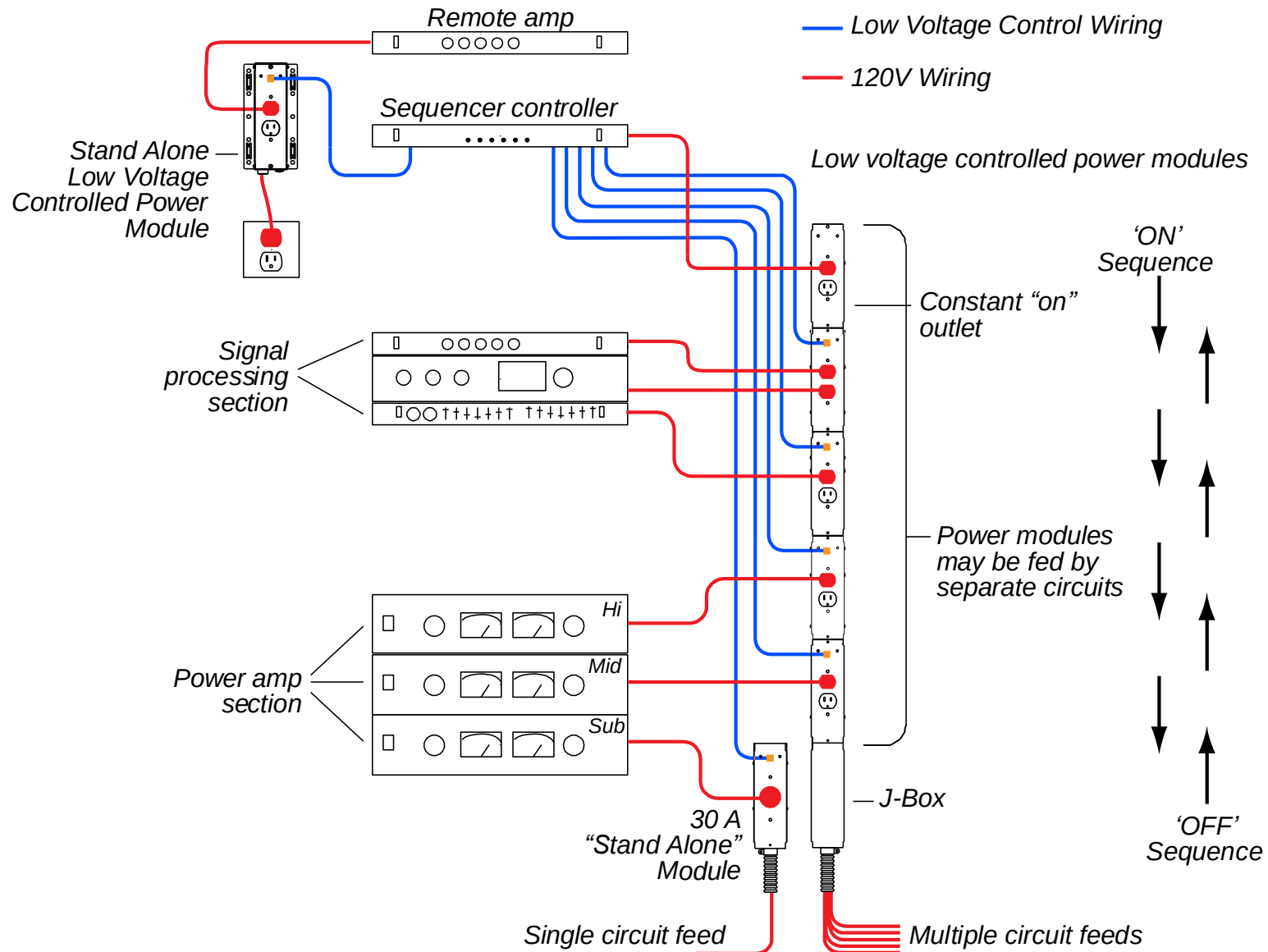
These problems can be solved with a sequencing system. Single circuit sequencers are to be used when the total electrical load of all the controlled equipment does not exceed 80% of the capacity of the sequencer. Power amplifiers must switch on last and switch off first, as indicated in the figure to the right.



Multiple Circuit Sequencer Systems

Multiple circuit sequencer configurations are used when the total electrical load of all the controlled equipment exceeds the current handling capacity of a single circuit, or if remote sequenced locations are required.

Power amp section must switch on last and switch off first, as shown in the figure below.



Simplified Grounding Guidelines for Audio, Video and Electronic Systems

- **Safety Comes First:** The NEC Code must be adhered to at all times, including its interpretation by the Authority Having Jurisdiction (AHJ).
- **There are several meanings of the word “ground”** which contributes to confusion and misunderstanding. Most commonly, ground refers to a return path for fault and leakage 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 all exposed surfaces at the same potential as the soil. Building safety grounds provide a return path specifically for fault and leakage currents. The safety ground for audio, video, and other electronic systems must be connected to the building (facility) safety ground. When safety ground connections or the neutral connection at the service entry panel are loose or corroded it will be hazardous and cause system noise.
- **Proper grounding** reduces only ONE source of noise (common-mode). Both the primary electrical system grounds and the signal interconnection system grounds need to be properly designed and installed to achieve a “hum and buzz free” system.
- **Electrical safety 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. Bypassing or defeating a safety ground to reduce noise is illegal, violates the NEC, is dangerous and should never be done!
- **Best practices dictate that equipment racks must be bonded together.** Per the NEC (Article 640) or Authority Having Jurisdiction, it is best to bond ganged racks together with paint-piercing hardware and purchase racks with pre-installed ground studs for convenience and to ensure good conductivity.

Isolation Transformers (Separately Derived Systems): Benefits and Wiring Methods

Properly designed and installed shielded isolation transformers can significantly reduce AC line noise that affects AV systems. There are two types of AC line noise: differential-mode and common-mode.

Differential-mode noise on the power line is defined as voltage appearing between the hot and neutral conductors. Isolation transformers do not prevent differential-mode noise from passing between the primary and the secondary. The job of a power transformer is to magnetically couple 60Hz as efficiently as possible, but frequencies up to 1kHz can couple quite well. Depending upon the construction of the transformer, most frequencies above 1kHz are attenuated, more significantly as the frequency increases. Common-mode noise on the power line is defined as the voltage measured equally between hot and safety ground, and neutral and safety ground. This noise can couple into audio/video signal paths through poorly-designed safety ground systems, equipment and cabling. Common-mode noise is capacitively coupled through the transformer while differential-mode noise is magnetically coupled through the transformer.

Common-mode noise arising within a facility can be caused by many devices, including motors, lighting dimmers, etc. It can also be caused by high resistance ground connections. As the length of the circuit 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 double conversion online uninterruptible power supply (UPS), it is termed “separately derived” (NEC Article 250.30). High frequency common-mode noise can capacitively couple between the primary and the secondary windings of a transformer. A separately derived system power isolation transformer eliminates common-mode noise between neutral and safety ground because these are bonded together immediately after the transformer. The use of an electrostatic (Faraday) shield, which reduces the capacitive coupling between the primary and secondary windings, provides additional isolation at high frequencies. The shield is also very effective at suppressing fast rise time voltage spikes.

Most AV installations benefit from a dedicated shielded isolation transformer with a single ground reference point. The transformer will be a buffer between the utility company and facility electrical system and the protected electronics systems such as AV equipment, control electronics, dimmers and data devices.

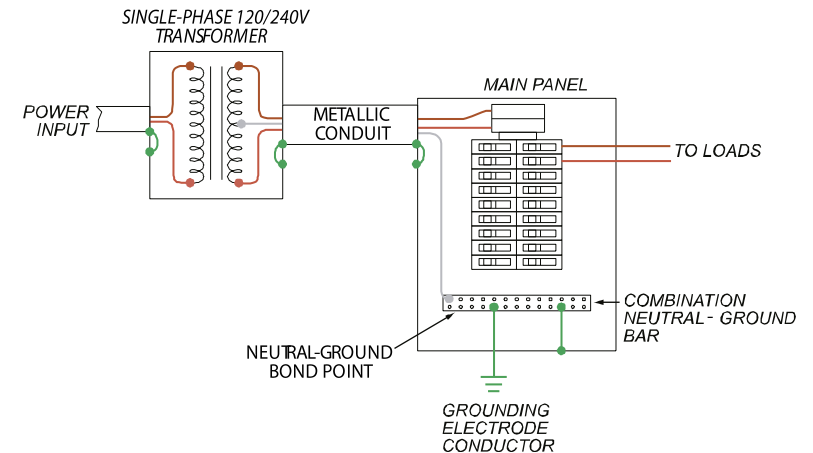
Isolation Transformer Neutral-Ground Bonding Methods

All separately derived systems are required by the NEC to have a neutral-ground bond point on the secondary side of the transformer. The location of this bond point can have a significant impact on the performance of an AV grounding system. The following diagrams are all approved by the NEC for safety, but have varying degrees of performance for AV systems.

Not Ideal for AV Systems:

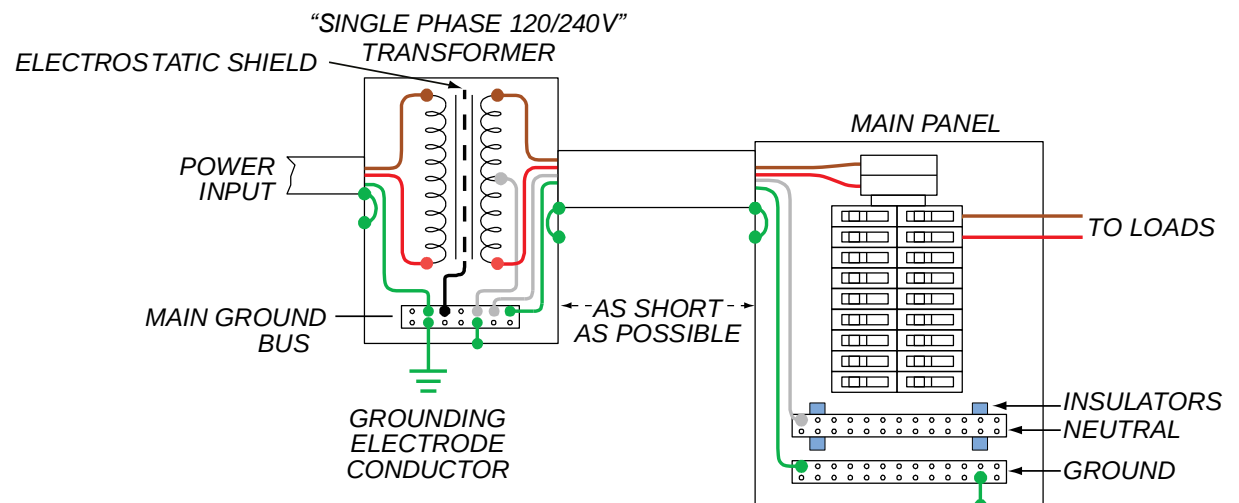
The “neutral-ground bond” in this type of wiring arrangement is at the first circuit breaker panel after the transformer. The busbar in the circuit breaker panel is a “combination” neutral / ground connection point, and ALL return current (i.e. neutral, fault, and system leakage current) flows through this busbar on its way back to the source of supply (the transformer).

This current flow causes slight voltage differences along the length of the busbar. Since the busbar is the primary ground reference, these voltage differences will be seen as ground voltage differences between the chassis of interconnected equipment, and may manifest themselves as hum and buzz in the system (through the system cable shield interconnects).



Better for AV Systems:

The “neutral-ground bond” in this type of wiring arrangement is at the transformer. The circuit breaker panel after the transformer contains a separate isolated neutral busbar AND a separate ground busbar. Return current on the neutral busbar has no effect on the grounding system.

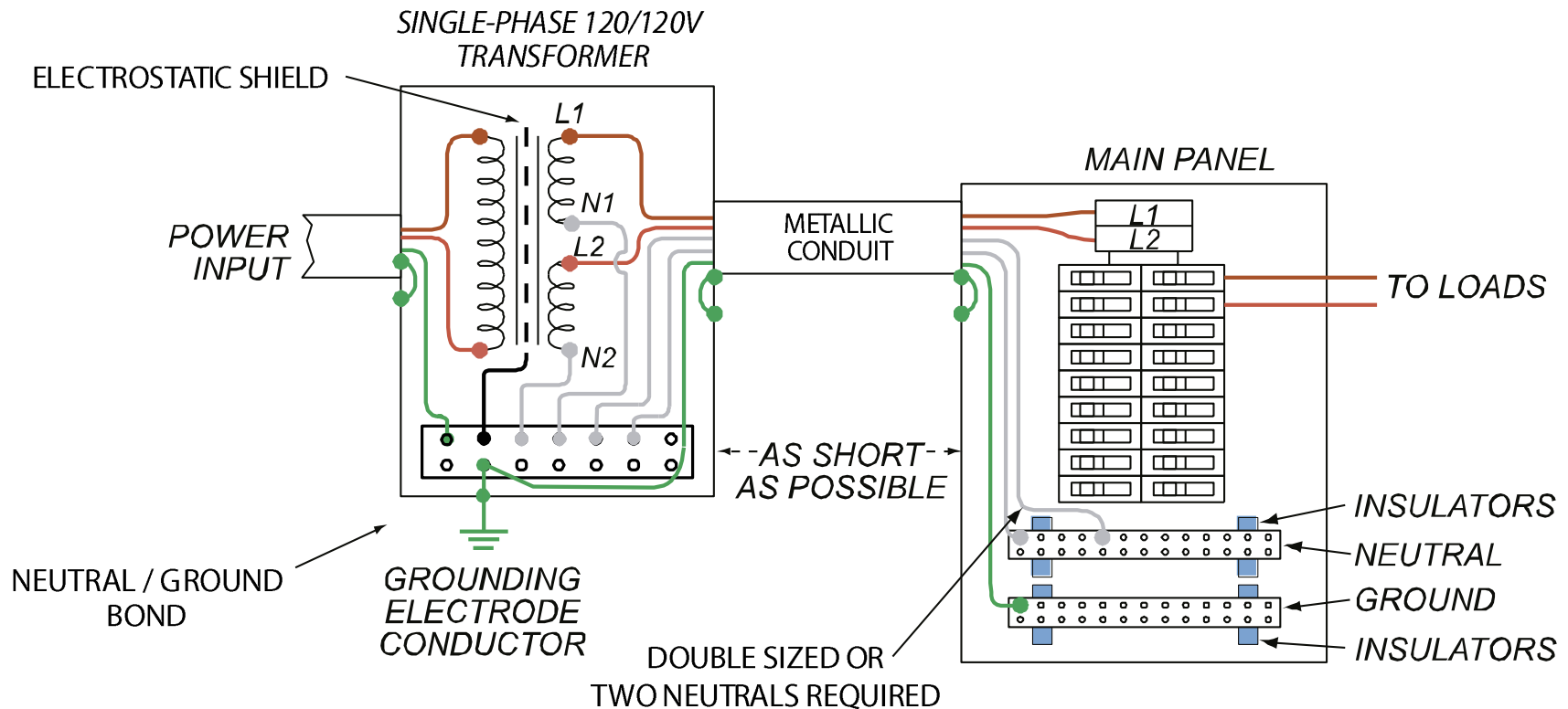


Isolation Transformer Neutral-Ground Bonding Methods (cont'd)

Best for AV Systems:

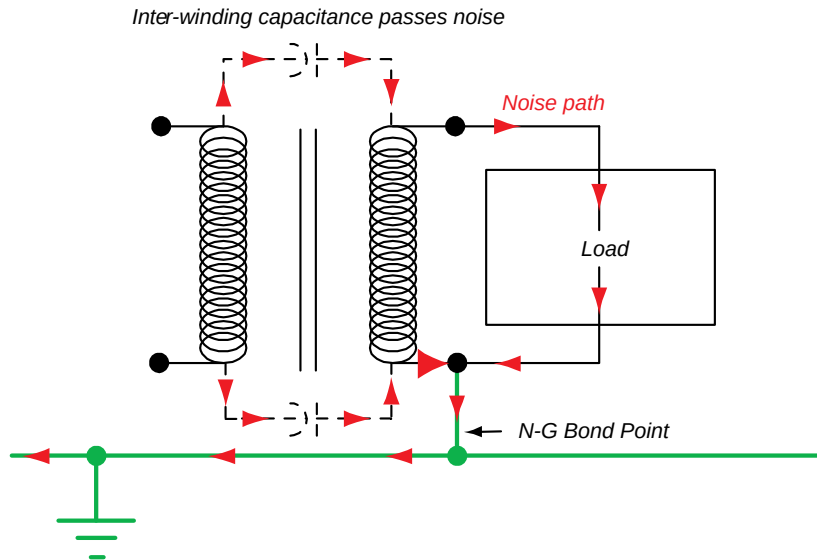
Commonly available single-phase transformers can have their secondary windings field-connected in one of two ways: 120/240V (as shown in the previous 2 drawings) or 120/120V (shown below). AV systems can benefit from 120/120V because all load circuits get their power from the SAME PHASE, thereby minimizing the effect of cross-phase leakage currents.

In a 120/120V wiring arrangement (pictured below), the neutral conducts ALL of the return current, not just the imbalance, as with a 120/240V single phase system. Since the neutral bar on a typical panel board is sized to handle the full load of only one hot leg, a panel with double the current rating must be specified to handle the combined load of both secondary windings. The two separate neutral conductors between the transformer and panel are also required in order to handle the full load of the separate hot legs. Note: a 200 amp panel only has a rated neutral capacity of 100 amps.

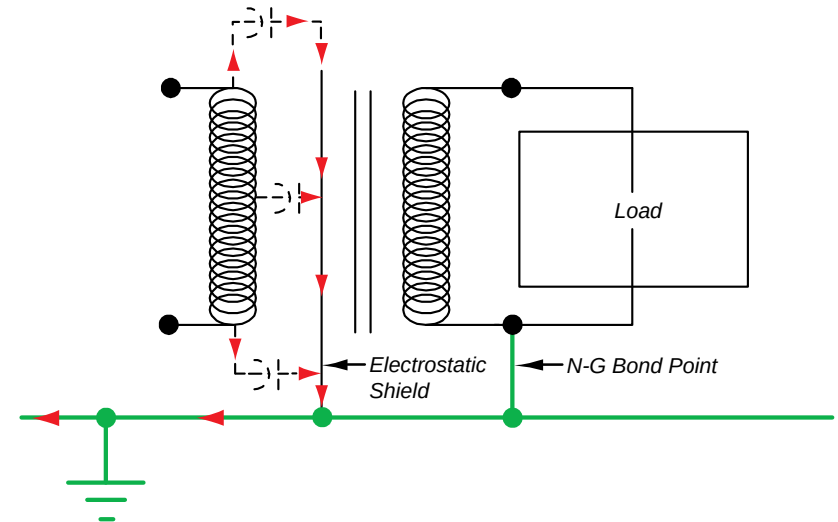


Electrostatic (Faraday) Shielding in Power Transformers

Standard Power Transformer (Unshielded)



Power Transformer with an Electrostatic Shield



All transformers have capacitance between the primary and secondary windings, which allows higher frequencies of common-mode noise to pass – as shown in the diagram above left. Utilizing an electrostatic (Faraday) shield between the windings reduces this capacitance and provides a path for the noise to flow back to its source - as shown in the diagram above right.

K-Rated Three Phase Power Transformers

K-rated transformers are used to deal with harmonic content in three phase systems. Power conductors that feed audio and video equipment often contain harmonics. These harmonics consist of frequencies much higher than 60Hz. Because the voltage phase angle between phases are separated by 120 degrees, some of the 3rd, 9th, 15th and all odd multiples of the 3rd harmonic current in the shared neutral conductor are additive. The additive currents are referred to as “triplen” harmonics. These 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.

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 where a three phase transformer is required.

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

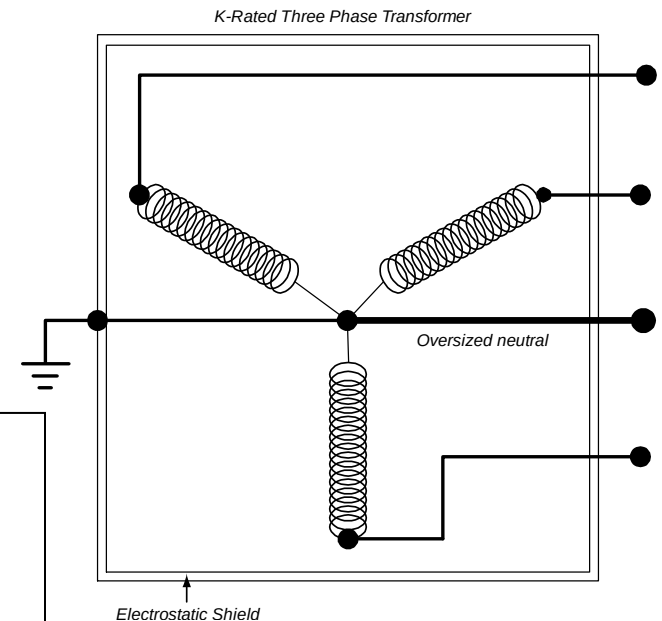
Some problems created by harmonic currents are:

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

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

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, which contains switch-mode power supplies



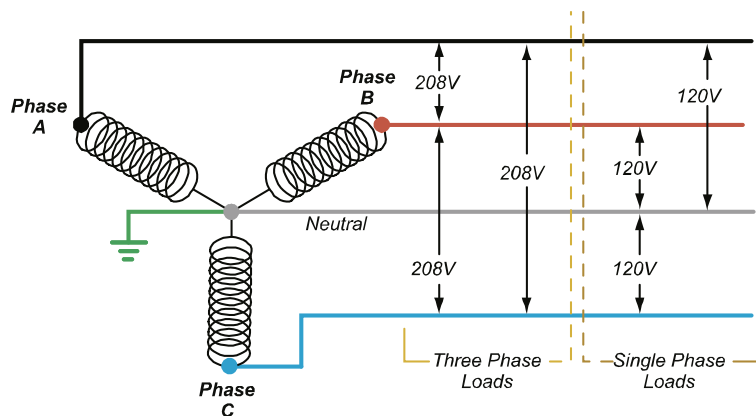
***Note:** single-phase transformers do not need a K-rating, as the harmonics pass through to the primary feeder.

Typical Three Phase Services

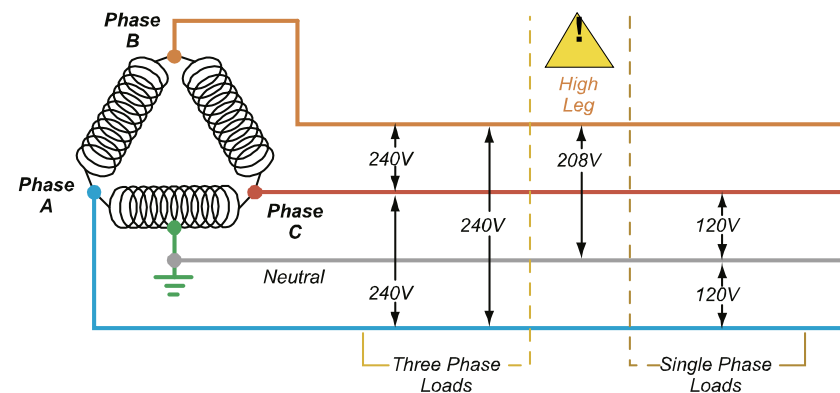
In smaller facilities, single-phase 120/240V service is common. In larger facilities, three phase WYE service may be used (see “WYE” figure below). In some commercial buildings, a High Leg Delta service may be found (see “DELTA” figure below). The below figures compare the single and three phase voltages for 120/208 WYE (below, left) and 120/240 volt High Leg Delta (below, right).

In a High Leg Delta panel board that contains a neutral, every 3rd circuit breaker space should be blank. Use caution when this type of panel is encountered. If a circuit breaker is put in that space, a branch circuit connected to it will be 208 volts, which can easily damage most equipment intended for 120 volts (per diagram below, right). No single phase load can be connected between the B Leg and the neutral. Always check the line voltage on the circuit supplying your equipment before plugging it in.

120/208 Volt “WYE”



120/240 Volt High Leg “DELTA”



In larger commercial and industrial buildings you may find a 277/480 Volt three phase system. In this case, all 120V circuits are from separately derived systems using step-down transformers. There may be several 120V single phase systems throughout the building. Best practices dictate that you designate one of these as your technical power system, using an electrostatically-shielded isolation transformer near your technical power distribution panel.

Phasing of Supply Conductors

When designing power distribution systems, electrical engineers will typically 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 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 combines in phase (adds), rather than canceling, as in the case of the 60Hz fundamental current. The problems with three phase service are mostly from harmonic-generating devices sharing the same neutral as the AV system. A shielded isolation transformer minimizes the coupling of these harmonics to the signal path by deriving a new neutral and neutral-ground bond point.

Single-Phase 120/240V electrical service is most commonly found in residences and smaller commercial buildings, and is commonly used to feed AV equipment. One key advantage that single phase has over three phase is that while harmonic currents are still present, only even order harmonics can add in the shared neutral, and they are uncommon, since the waveform would be asymmetrical. In addition, use of single-phase 120/240V can result in at least a 6dB reduction in noise floor as compared to three phase if the capacitances of the connected equipment are relatively well balanced. Furthermore, if a signal cable is connecting two pieces of ungrounded equipment powered from opposite phases, the leakage current flowing in it will increase (causing more noise) as compared to powering the equipment from the same phase.

Single-Phase 120/120V is a specialty configuration with two 120V secondary windings (not center-tapped) arranged so both legs are in phase with each other. The advantage is that there is no phase difference between any branch circuits, which is beneficial for reducing noise. However, the neutral wire feeding the load center and the load center neutral bar must be double-sized to handle the additional “additive” current.

60/120V Symmetrical (Balanced) Power Systems

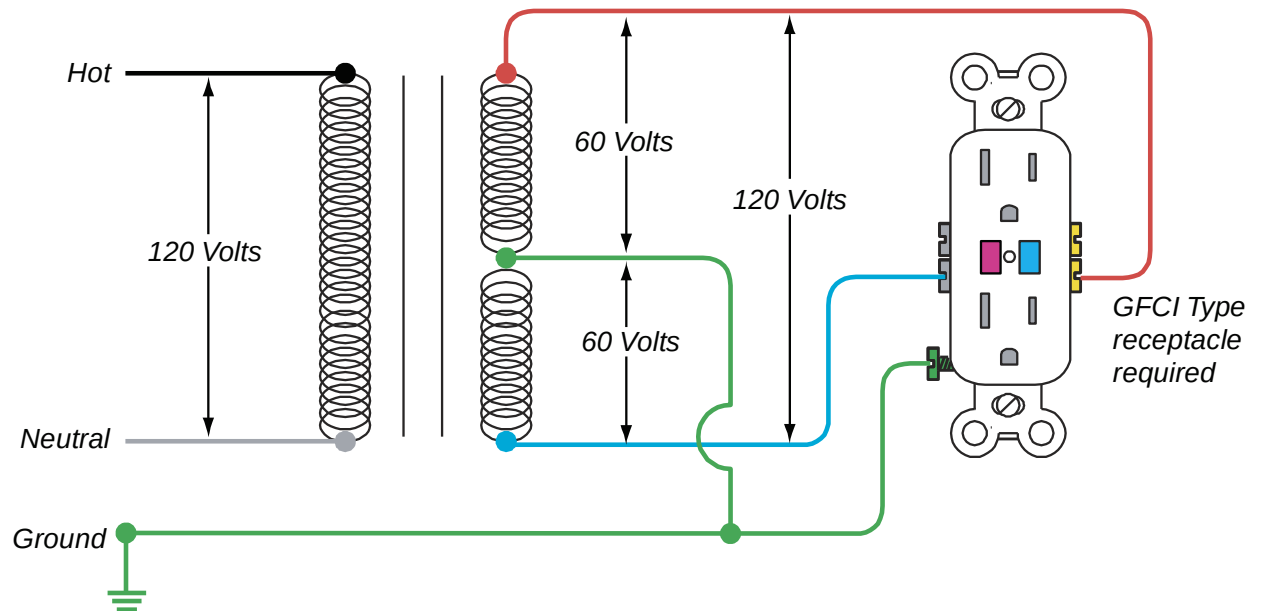
Per NEC 647.1 (2008) the use of a separately derived 120 volt, single phase, 3-wire system with 60 volts between each of the two ungrounded conductors and ground is permitted for the purpose of reducing objectionable noise in sensitive equipment locations, **providing the following conditions are met:**

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.

A major 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.

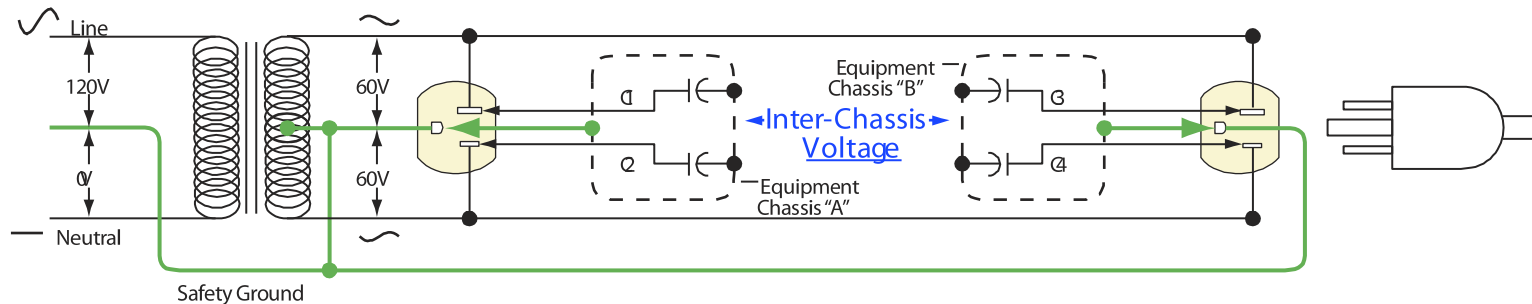
When the GFCI receptacles are disabled or bypassed, the system becomes an electrocution hazard!



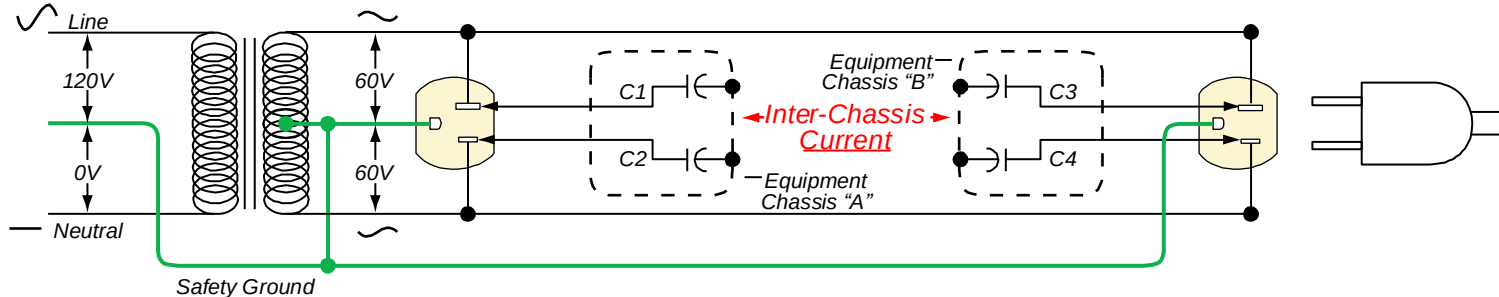
Symmetrical (Balanced) Power (cont'd)

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 can be a significant cause of noise in unbalanced signal interfaces when connecting ungrounded equipment.

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. The primary benefit (reduced common-mode noise) is due to the fact that these systems are inherently isolation transformers, whether the output is balanced or not. A standard, unbalanced shielded isolation transformer will do nearly as well without the disadvantages of a balanced output power transformer.

For reducing noise, it is more cost-effective to use a signal transformer to 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” systems connect to “ground” at the neutral-ground bond point in the main circuit panel, and must be insulated from any other ground connections. If equipment is mounted in a rack, to conductive rack rails, the rack itself must also be insulated from any other grounds, including concrete or conduit, to function as designed.

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

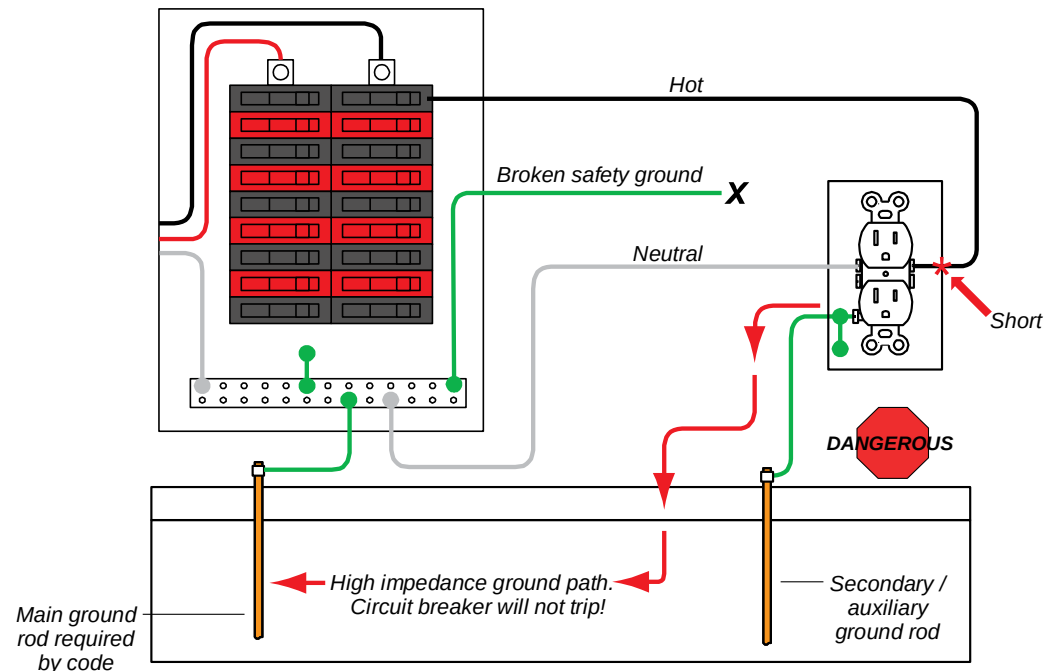
MYTH BUSTED! Noise will always flow back to the source; noise does not want to flow to earth. In addition, the NEC mandates that any supplemental (auxiliary) ground rod be bonded to the neutral-ground bond of a separately derived system, the main service neutral-ground bond or the grounding electrode 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 fail, and result in circulating currents flowing in the ground wires, most likely adding to noise problems. There is no wire from an 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 can 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).



Neutral-Ground Reversals and Bootleg Grounds

The most common cause of AV system noise from wiring errors is unwanted current flowing on the grounding system caused by bootleg grounds. While less common, neutral-ground reversals will also lead to unwanted current flowing on the grounding system. There are many field conditions that determine the impact of these wiring errors on the AV system. The following assumes that the wiring error described is within a system with multiple branch circuits. On a single circuit system, the impact will depend on the location of the wiring error.

Bootleg grounds

Bootleg grounds occur when neutral and ground are improperly connected together downstream of the service entrance or separately derived system, thus violating the NEC [article 250.24 (A)(5)]. All metal objects that are part of the grounding system (beams, conduits, grounding conductors, etc.) will become part of the return path for the neutral current. This will cause excessive current to flow through safety grounds and signal cable shields, which is not only hazardous, but will add noise to the AV system. Bootleg grounds also create large loop area AC magnetic fields which frequently couple to the signal path, creating additional hum and buzz.

Two of the most common ways a bootleg ground is formed:

- Poor workmanship while wiring outlets (i.e. neutral strand touching a grounded metal box, ground wire touching the neutral screw)
- Some electrical contractors, in violation of the NEC, mistakenly install a neutral-to-ground bonding screw in a sub-panel in locations other than a main panel or after a separately derived system

If a branch circuit is under load, a bootleg ground **anywhere** on that branch circuit will **always** cause excessive current to flow in the safety ground system of that circuit and reduce the amount of current being returned on the neutral conductor. This will happen regardless of **any** of the following factors:

- Location of the bootleg ground on that branch circuit
- Which receptacle the load is plugged into on that branch circuit
- Receptacle type
- Box material (metal or plastic)

Neutral-Ground reversals

Although rare, neutral and ground conductors can inadvertently be swapped when wiring a receptacle or wired outlet strip.

If a branch circuit is under load:

- a neutral-ground reversal at a standard receptacle that is mounted in a grounded metal box will act as a bootleg ground and will always cause excessive current to flow in the safety ground system and reduce the amount of current being returned on the neutral conductor, regardless of where the neutral-ground reversal is on that branch circuit, and regardless of what receptacle the load is plugged into on that branch circuit
- a neutral-ground reversal at a standard receptacle that is housed in a plastic box, or at an isolated ground receptacle, is commonly diagnosed by connecting a load to that receptacle and measuring the current as described in the “Steps to Troubleshoot Bootleg Grounds and Neutral-Ground Reversals” section of this paper. This condition can be hard to diagnose, as the receptacle can either have no load plugged into it, a steady load plugged into it or an intermittent load such as a refrigerator, resulting in unintentional current flow on the grounding system only if:
 - a 2-prong or 3-prong current drawing load is connected to that specific receptacle; or
 - any 3-prong grounded device, which is also grounded by another means (e.g. through grounded rackrail), is plugged into that receptacle, even if it is not powered on

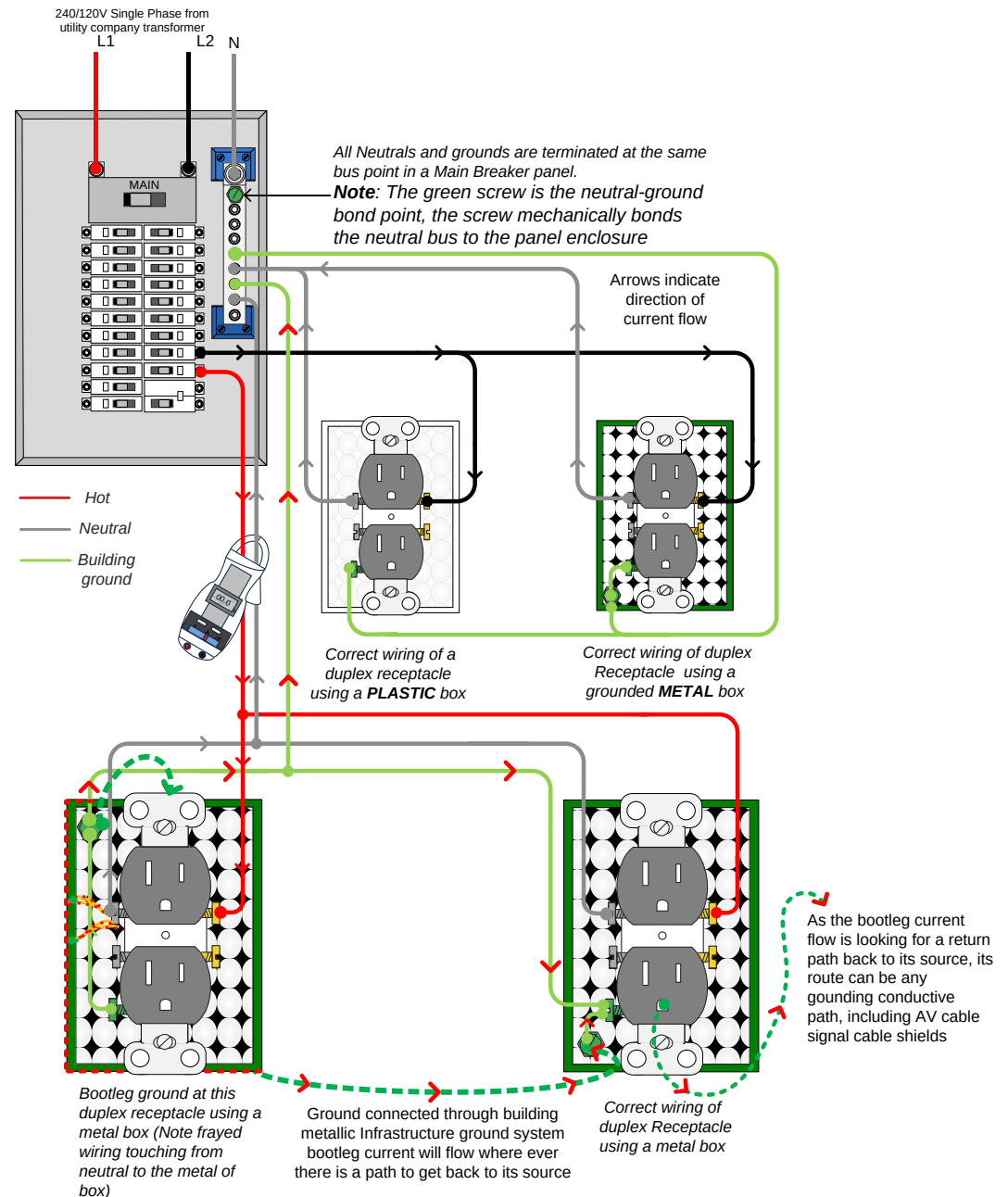
Return current, when flowing on a grounded signal wire (even in part), can add unwanted voltage (noise) to the signal path, resulting in hum and buzz.

Troubleshooting Overview

From the name and definition, it might be thought that the presence of a bootleg ground on a dedicated branch circuit could be verified through the measurement of ground current. A properly bonded grounding system (of which branch circuit ground conductors are simply a part) provides multiple return paths for current to return to its source. The return paths include metal building beams, metal plumbing pipes & conduit **and as such the current measured on a branch circuit ground conductor may be far lower than the total amount of current actually flowing throughout the grounding system overall.**

For these reasons, the most effective way to determine whether or not you have a bootleg ground or a neutral-ground reversal on a branch circuit is to do a direct comparison between the current flowing on the hot, and the respective neutral conductor (see drawing right). The easiest and most fool-proof way to compare the difference in current between line and neutral conductors is to put both conductors (of the branch circuit under test) inside the jaws of a clamp-on ammeter. The current measured should be no more than 20mA (this being normal ground leakage current). If the current measured is more than 20mA, then it is very likely that there is either a bootleg ground on that branch circuit, a neutral-ground reversal or an improperly shared neutral.

To troubleshoot the likely cause, clamp the ammeter around the hot and neutral independently. The current measured on the neutral should never be greater than that measured on the hot conductor. If this is the case then the neutral conductor is being shared by more than one branch circuit on the same phase – this is in direct violation of the NEC (article 100, Branch Circuit, Multiwire) and is hazardous, as the current flowing in the neutral conductor can easily exceed the rated capacity of the wire.

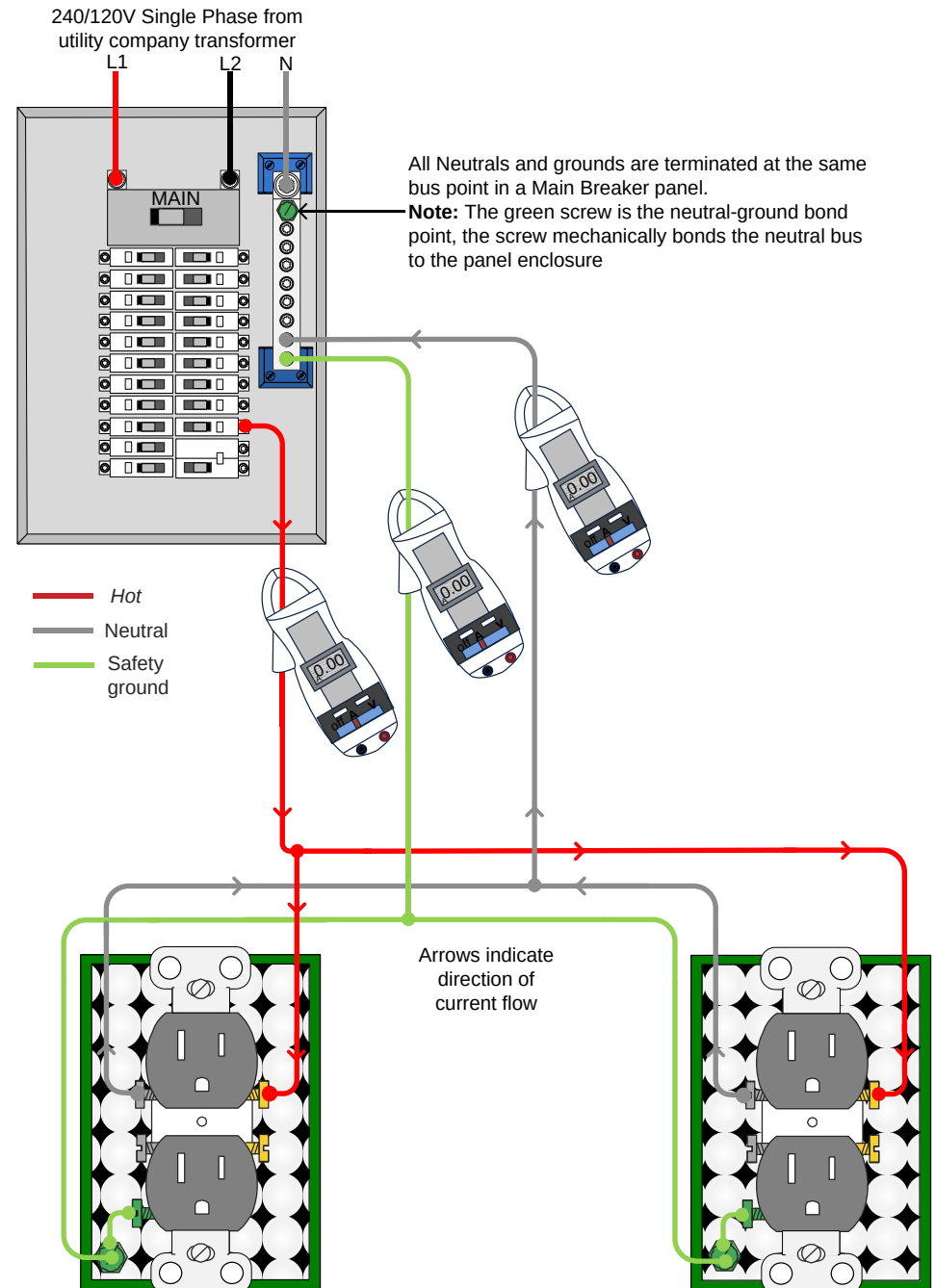


Steps to Troubleshoot Bootleg Grounds and Neutral-Ground Reversals

There is currently no plug-in test device that can detect bootleg grounds or neutral-ground reversals, including three prong receptacle testers (the ones with lights) and voltmeters. The following steps can be taken to identify these problems:

1. Identify all receptacles located on the branch circuit under test and remove all loads from that circuit.
 2. At the panel board (circuit breaker panel) that feeds the branch circuit, separately measure current on ground, neutral and hot using a clamp-on amp meter. There should be no current on any of the conductors (See diagram to the right).
- If any current is measured on the ground, even mA, there may be a problem with the premises wiring. This could be induced ground voltage from a nearby feeder or leakage current from a motor, transformer, etc. or a ground wire shared by multiple branch circuits.
 - If any current is measured on the hot, not all loads have been removed from the circuit. If any current is measured on the neutral, it may indicate that this neutral is shared by another circuit.

Ensure that these preceding problems are addressed before proceeding to the next step (continued on next page).



3. As shown in the diagram on the right, choose one receptacle on the branch circuit, plug a 100 watt light bulb test load into it, and put both hot and neutral conductors (of the branch circuit under test) inside the jaws of a clamp-on ammeter. If all receptacles on the branch circuit under test are properly wired, then the return current on the neutral will be exactly the same as the current on the hot wire and the ammeter will read zero. If it's not zero, then somewhere on this branch circuit there is likely one or more of the following issues:

- a.) a bootleg ground **anywhere** on this branch circuit, including at receptacles, J-boxes, wiring clamps, etc.
- b.) a neutral-ground reversal in a **metal** box **anywhere** on this branch circuit
- c.) a neutral-ground reversal at **the receptacle under load**, and it is housed in a plastic box, or is an isolated ground receptacle

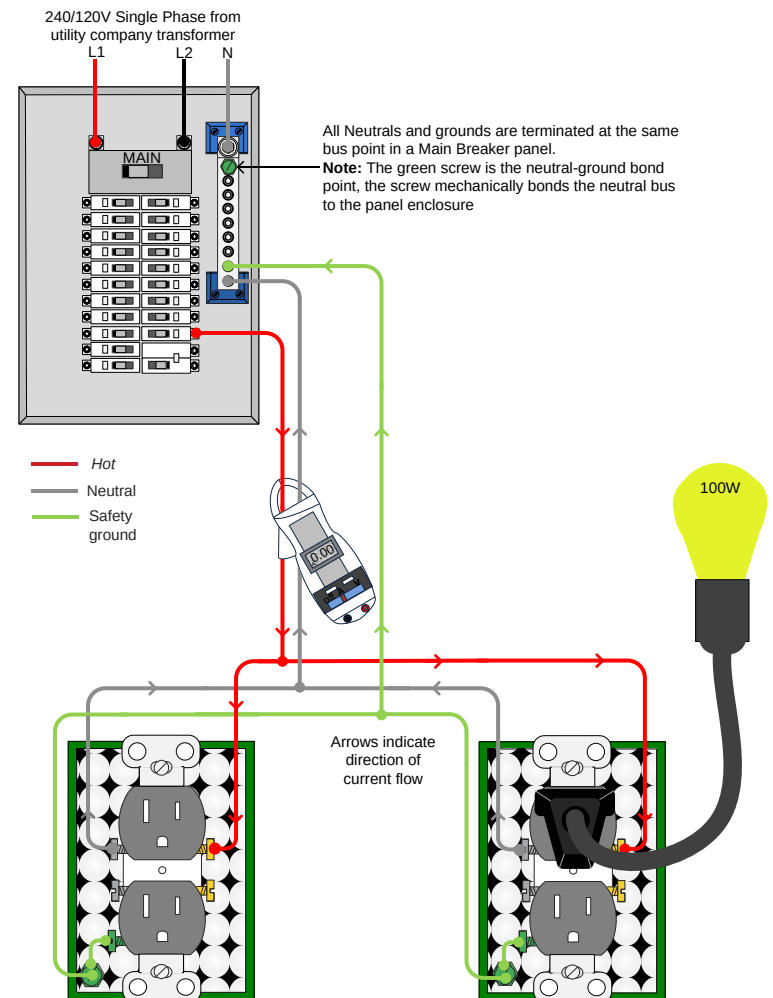
To troubleshoot the likely cause, clamp the ammeter around the hot and neutral independently. If the current measured on the neutral conductor is approximately half that measured on the hot conductor then somewhere on this branch circuit there is either a neutral-ground reversal (in a metal box), or there is a bootleg ground at a receptacle. The current that would normally be returning on the neutral is now shared between the neutral conductor and safety ground system.

If the current measured on the neutral conductor is substantially less than that measured on the hot conductor (close to zero) then condition (c) from above applies. All of the load current will flow on the safety ground conductor instead of the neutral conductor.

4. Repeat this process for each receptacle on the branch circuit in question.

Note: Neutral-ground reversals at a receptacle housed in a plastic box, or at an isolated ground receptacle, will cause excessive safety ground current to flow (and result in intermittent hums and buzzes) only when the receptacle is under a load.

A quick way to detect a “bootleg” ground or neutral-ground reversal, without the need for qualified personnel, is to plug an inexpensive tabletop dimmer using a 100 watt incandescent light bulb into a branch outlet, and while adjusting the dimmer, listen for any change in system noise. If a bootleg ground or neutral-ground reversal is present, part of the neutral current will be flowing in the grounding conductor, adding to the signal path and noise will vary with the amount of neutral current. Note: in some cases, however, there are no wiring errors and this test can be misleading, as buzz can arise due to normal parasitic coupling that exists between multiple branch circuits housed in the same conduit or in close proximity to each other.



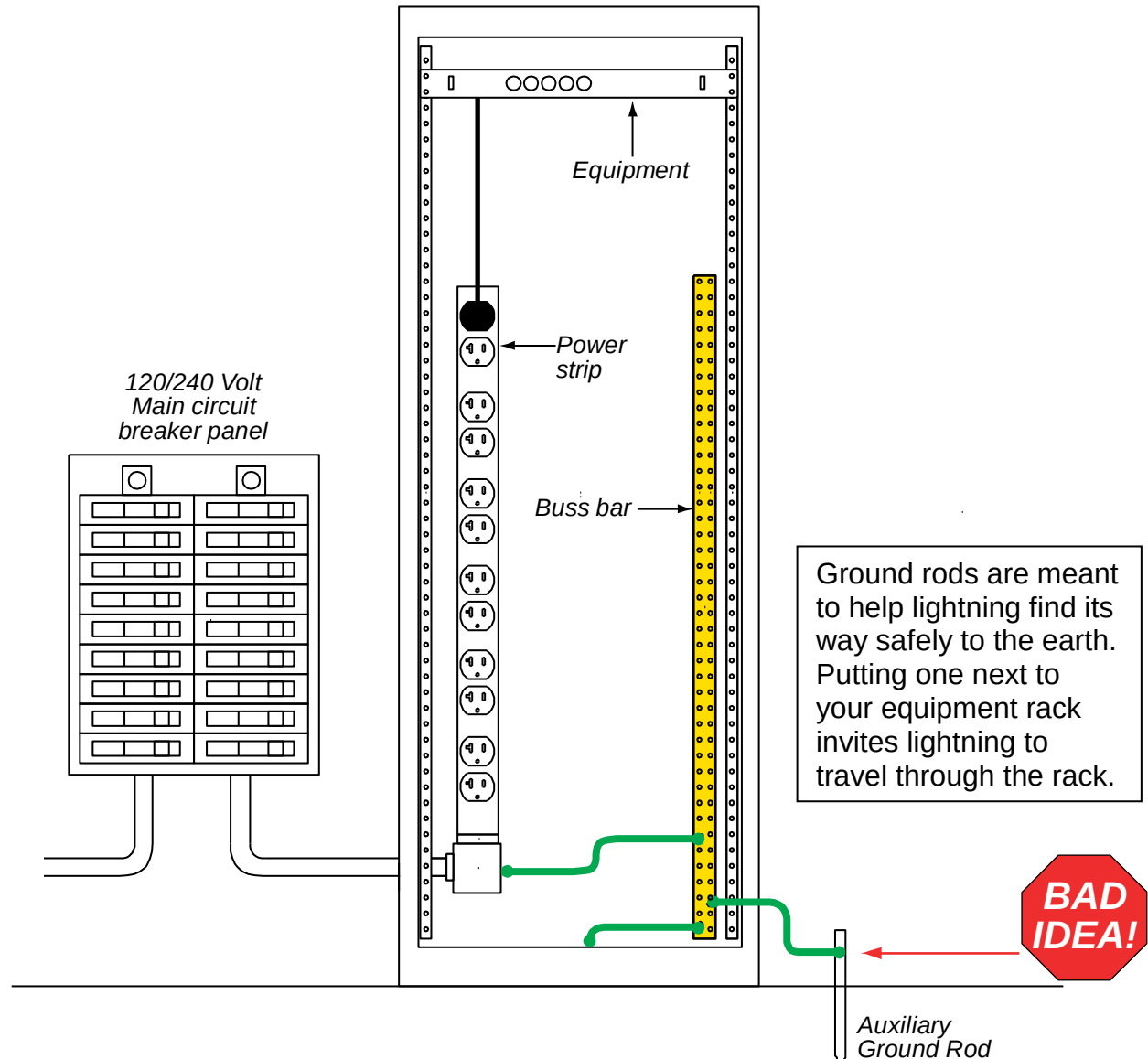
Auxiliary Ground Rods

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.



Intersystem Bonding (Cable TV, Satellite TV, Telephone)

If not bonded properly, signal cable shields of cable TV, and satellite TV systems can be at different ground potentials relative to one another, and relative to the main grounding system.

This condition is undesirable for two main reasons:

1. It may cause audio system hum and video display anomalies, even if all other AV system components share a common ground point
2. It can be hazardous (and expensive) as in the event of a lightning strike very high voltage differences will be developed across improperly bonded power and signal grounds. These voltage differences can cause damage to interconnected equipment, and can cause arcing between adjacent grounded metal enclosures/conductors

To reduce these undesirable risks, signal cable shields of cable/satellite/phone system grounding blocks and the main grounding electrode system must be connected (bonded) together by means of an “intersystem bonding conductor” (see figure below).

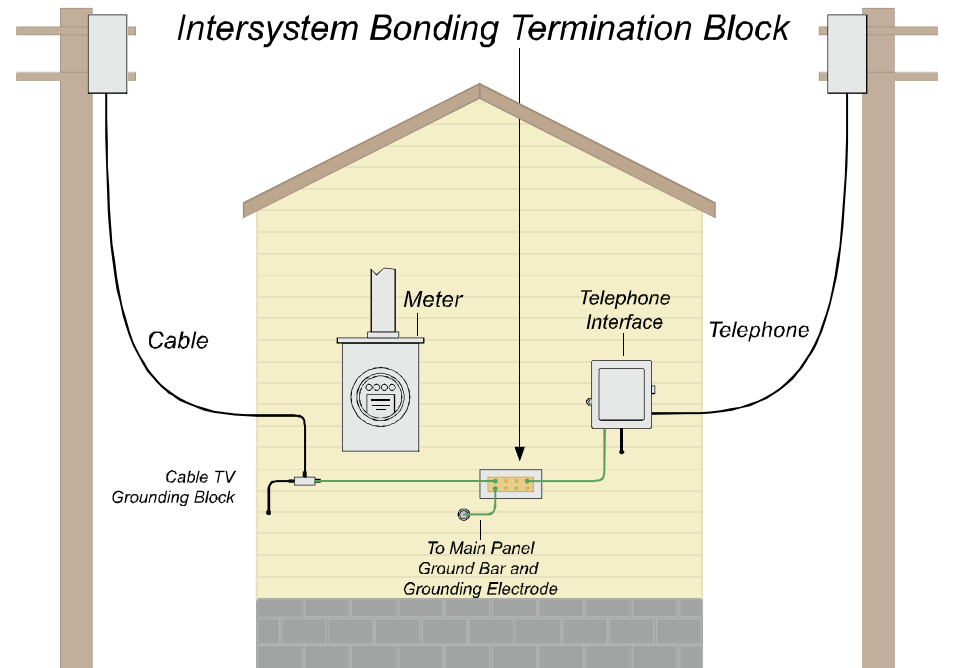
In some instances the electrical service entry and the cable/satellite TV/telephone wiring enter at opposite ends of the facility. If it is impractical to install an intersystem bonding conductor, it is allowed by the NEC (Article 800.100) to establish this bond using the facility’s metallic infrastructure including water piping, building steel, etc. A #6 (minimum) conductor size is required.

It is recommended that the “Intersystem Bond” be connected directly to a terminal block (small busbar), located on or near the service entry main electrical panel (see figure to the right).

- 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.

Note: Ground loops can be easily detected by putting a sensitive (1mA resolution) amp probe* around the cable TV wire; any reading higher than 10mA can cause noise in unbalanced AV system interfaces.

*one example is the AEMC model 565



Power Quality Problems

“As much as 80% of all power quality problems can be attributed to inadequate electrical grounding or wiring, or interactions between loads within the premises.” (Source: Electric Power Research Institute)

Power quality problems can affect sensitive electronic systems and impact operation and reliability. While some troubles such as system re-boots and lockups are an inconvenience, these problems can have greater implications, including damage to integrated circuits and other sensitive electronic components. A number of conditions cause distortions in voltage and frequency that result in poor power quality. These include nearby lightning strikes, transient currents in the facility drawn by loads such as air conditioners and motors, utility company switching, and conducted noise from neighbors connected on the same utility transformer. A properly configured and installed isolating transformer/filter/surge protector will effectively address all these issues.

Power Quality Problems: Voltage Regulation

Voltage regulation is primarily the responsibility of the power utility, which ensures line voltage is maintained with a + or – 10% nominal operating voltage. Voltage swings that fall outside these parameters, commonly known as “swells” and “sags,” can be caused by large loads turning on and off and have caused problems in the past. However, modern switch mode power supplies operate differently than their linear power supply predecessors. Their improved design provides systems with a substantial immunity to such voltage variations, making additional preventative measures like additional voltage regulators mostly unnecessary, except in extreme cases like facilities at the end of a very long utility power run, or very close to a utility substation where the condition is likely permanent. In these cases, re-tapping a power transformer is the best solution.

Other Power Quality Problems

Lightning: Lightning surges are unavoidable in many areas. Inductive coupling from storms miles away can produce harmful transients in any wiring and metallic structures inside a facility.

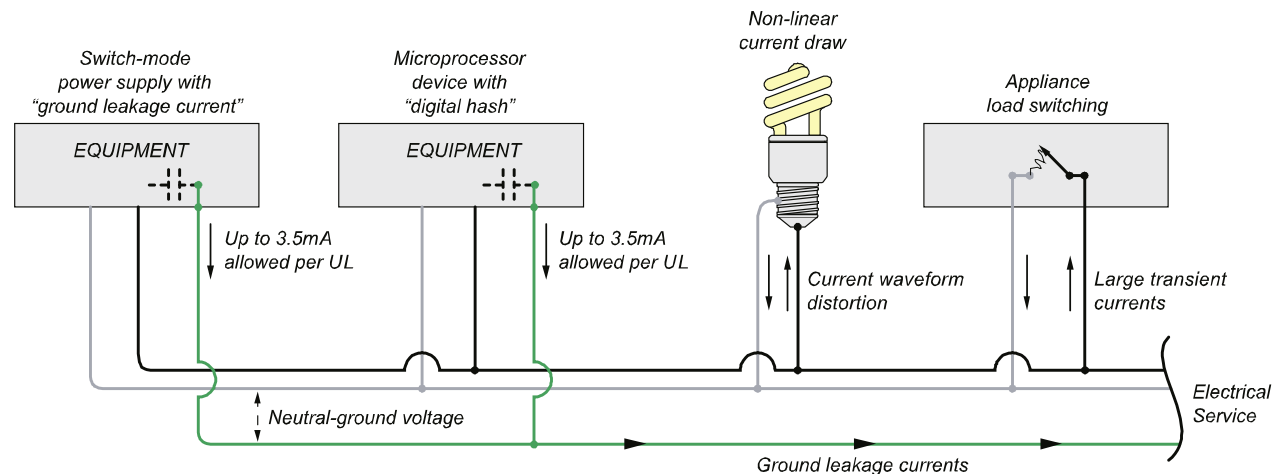
Blackouts: While accounting for fewer power quality issues than the other problems listed, power loss is the most evident and requires UPS safeguarding in specific places to prevent the control systems, projectors, digital mixers and computers from improper shutdown.

System Interconnect Disturbances: Although not directly on the AC power connections, noise can enter the system via a secondary path like cable TV, telephone lines, security systems, network cabling, I/O connections and control wire shields bonded at different potentials (see “Intersystem Bonding” section of this paper).

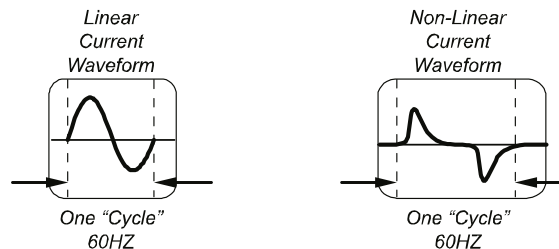
Electrical Noise

Ground voltage differences, or 'ground noise,' between various locations in premises safety-ground wiring are the main driving force behind ground loops that cause hum, buzz, and video hum bar problems. 'Noise' in the context of AC power generally refers to energy at frequencies from 60 Hz up to a few MHz. For example, whenever a power circuit containing a reactive load is turned on or, especially, off by mechanical contacts (a switch or relay), a high-frequency (i.e., fast risetime) voltage or current "spike" (also known as a "transient") is generated.

Many electrical devices create 60 Hz harmonics and high-frequency noise currents that can couple onto the safety-ground conductor. Such devices include computers, printers, electronic lighting ballasts, compact fluorescent lights (CFLs), lighting dimmers and anything with a "switch-mode" power supply (also known as 'solid state' or 'electronic') - see figure below. As these currents flow in the safety-ground conductors, they add voltage differences to the safety ground system.



Many lighting dimmer controls use an SCR or TRIAC switch, which "chops" the sine wave. The reduced duty cycle of the resulting wave achieves the desired effect of dimming. However, the extremely fast current rise time creates a large repetitive voltage spike twice per cycle. Rapid changes in current will always produce electrical noise. AV equipment itself can produce electrical noise and poorly designed equipment containing a microprocessor can couple "digital hash" into the safety ground system through its power supply or ground prong.



Power Conditioning

“Power Conditioning” is a very misused term, with no industry standards to allow adequate comparison. Numerous products are marketed to “cure” AV system noise, lock-ups, reboots and various power quality issues. Many of these are sold partly by fear, partly by swindling and mostly on misleading “education” that lacks any basis in accepted engineering principles, meaningful data or realistic demonstrations.

Some people may install power conditioners because they are led to believe that “conditioned power” will improve the way the system sounds or looks. However, except in rare and extreme situations, these attributes are determined primarily by the quality and topography of the safety ground system and the integrity of the signal path of interconnected equipment, not by the quality of the AC utility power.

Two examples of such extreme situations where power conditioning may make a difference include:

- when power is fed from a utility source that is **shared by** a nearby user of industrial machinery that injects high levels of RF noise, such as some welding equipment
- when using electronic equipment with cheaply made and poorly designed power supplies, instead of higher quality equipment that provides adequate noise rejection.

Most power conditioners are essentially low pass filters that are designed to attenuate high frequencies. However, for AV systems, problematic noise frequencies are under 25 kHz and are essentially unaffected by power conditioners, whose filtering action is typically effective only at frequencies over about 50 kHz.

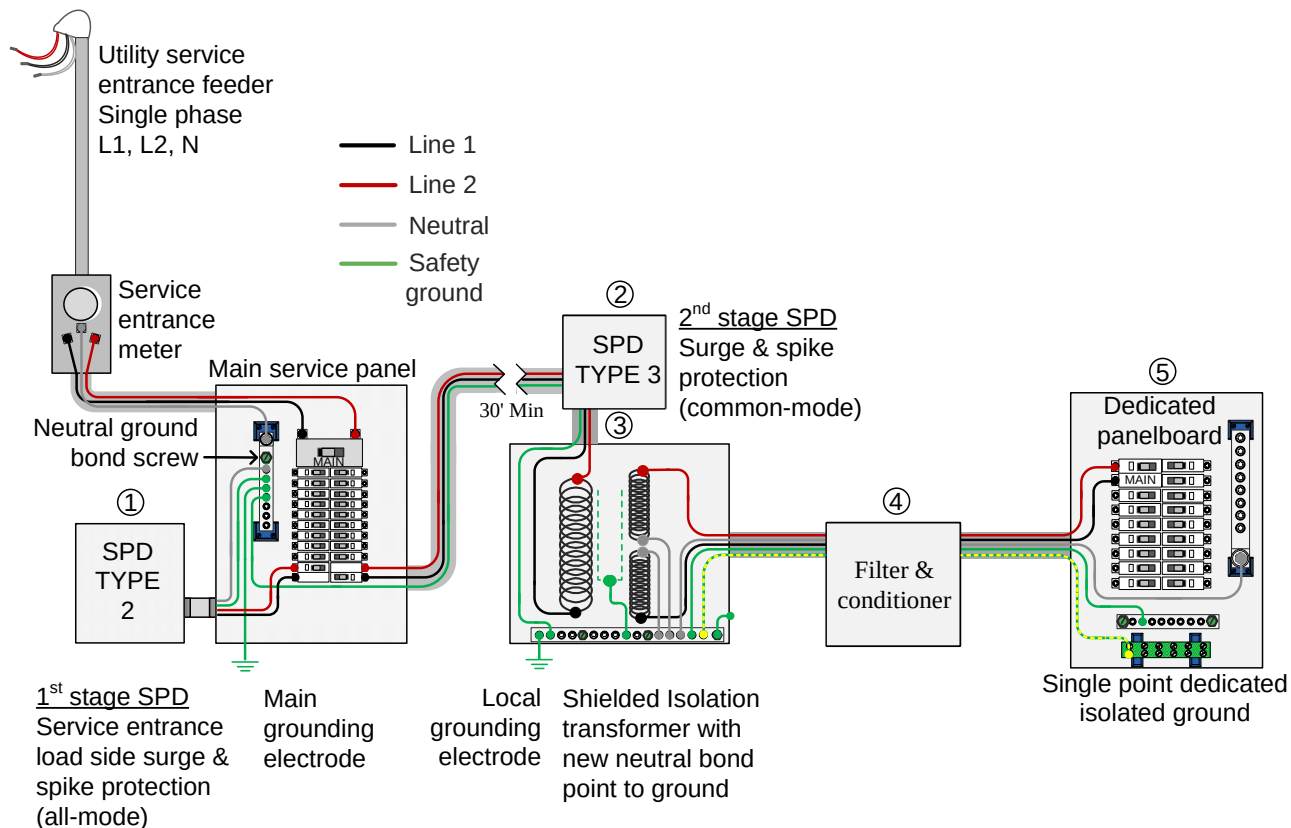
The following common problems result in many undesirable situations, including hum, buzz and noise in AV systems, none of which are solved by power conditioners:

Power Conditioners do not solve any of these common problems	What actually does solve them
Effects of ground loops (hums, buzzes & video hum bars)	Single-point reference ground (can be derived by an isolation transformer), balanced interfaces, heavy braid shields on unbalanced signal interfaces (keep shorter than 3 ft.), twisted power conductors
Power line common-mode noise	Shielded isolation transformer
AC magnetic field induction (hum & video roll bars)	Coaxial cables or twisted conductors within signal and power cables; separation of signal and power wiring bundles
Cross phase coupling (doubles hums & buzzes)	Same phase power
Shield current induced noise	Heavy braid shields (instead of signal cables with drain wire)
Pops, clicks and noise from arcing contacts	AV equipment powered from dedicated branch circuits, local arc suppression devices at the appliance or switching device
Control system lock-ups	UPS, surge & spike protection, single-point reference ground, avoiding AC electromagnetic induction into control wires, opto-isolators for long RS-232 links
Hissing at loud volumes during quiet passages	Tiered gain structure; higher quality equipment

The System Approach to Power Quality

A system approach needs to be taken to address power quality issues rather than addressing each individually. An example of a system approach is shown below.

- (1) Voltage spikes and impulses from outside the facility are addressed with a service entry type 2 surge protective device.
- (2) Voltage spikes and impulses from inside the facility are addressed with a type 3 surge protective device.
- (3) Common-mode voltage is suppressed by a shielded isolation transformer, additive cross-phase noise is eliminated with a 120/120 “same phase” secondary (see section on Isolation Transformer Neutral-Ground Bonding Methods).
- (4) High frequency electrical noise is attenuated with a noise filter/conditioner.
- (5) Single point dedicated isolated safety ground bar reduces ground loops.



Ground Voltage Induction (GVI)

Equipment chassis / safety ground voltage differences between interconnected Audio-Video equipment causes current to flow through signal cable shields when connected at both ends. This can add noise voltage to the signal path through a variety of coupling mechanisms. Balanced interfaces can cancel out much of this noise voltage, but any common-mode voltage canceled by an active balanced interface reduces its signal headroom and the cancellation can be incomplete if the common-mode rejection ratio (CMRR) of the input device is inadequate. Furthermore, if enough current flows in a balanced signal cable with a drain wire, Shield Current Induced Noise (SCIN) can generate noise voltage differentially in the signal pair. Unbalanced interfaces (analog video, “RCA” audio) are especially susceptible to ground voltage differences.

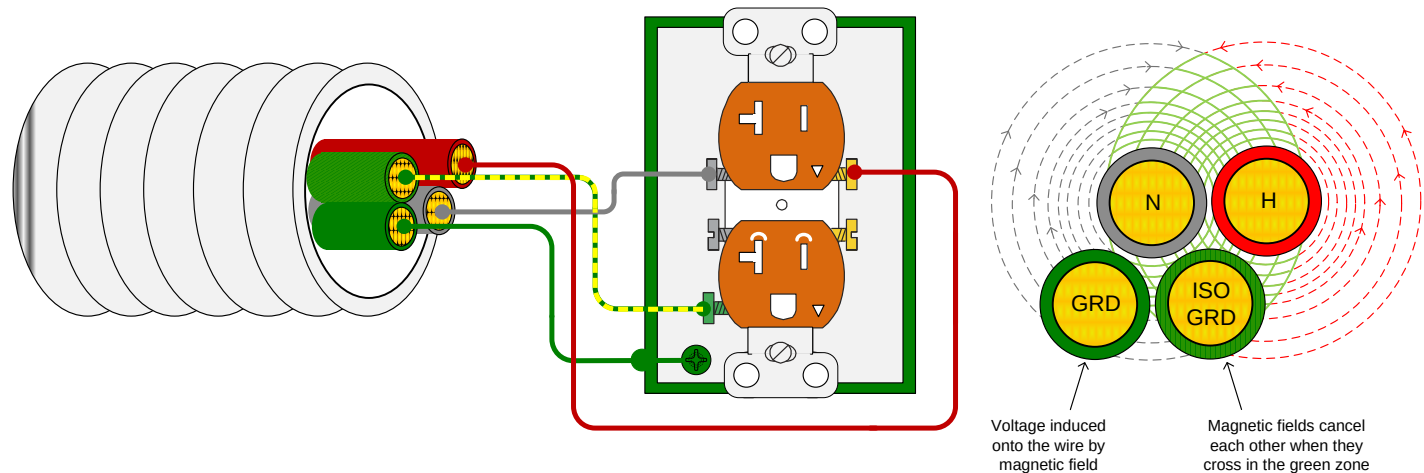
There are many causes of ground voltage differences between equipment chassis, and much has been written about the benefits of using a single-point ground (SPG) or isolated grounds to minimize this. However, significant voltage differences can exist between equipment grounds even when utilizing these wiring schemes, depending upon the harmonic content and current draw of the load and length and physical arrangement of the conductors. Even a length as short as 50 ft with a 40 watt compact fluorescent load has been proven to be problematic.

Almost always mistaken as a “ground loop” because the resultant hum and/or buzz are the same, **Ground Voltage Induction (GVI)** is increasingly recognized as a common source of system noise.

Voltage will be magnetically induced in an insulated ground wire if it is positioned unevenly between current-carrying phase conductors (see diagram below). In the phase conductors, the greater the current, the longer the length, the faster the current rise time and the higher the frequency, the greater the induced ground voltage will be.

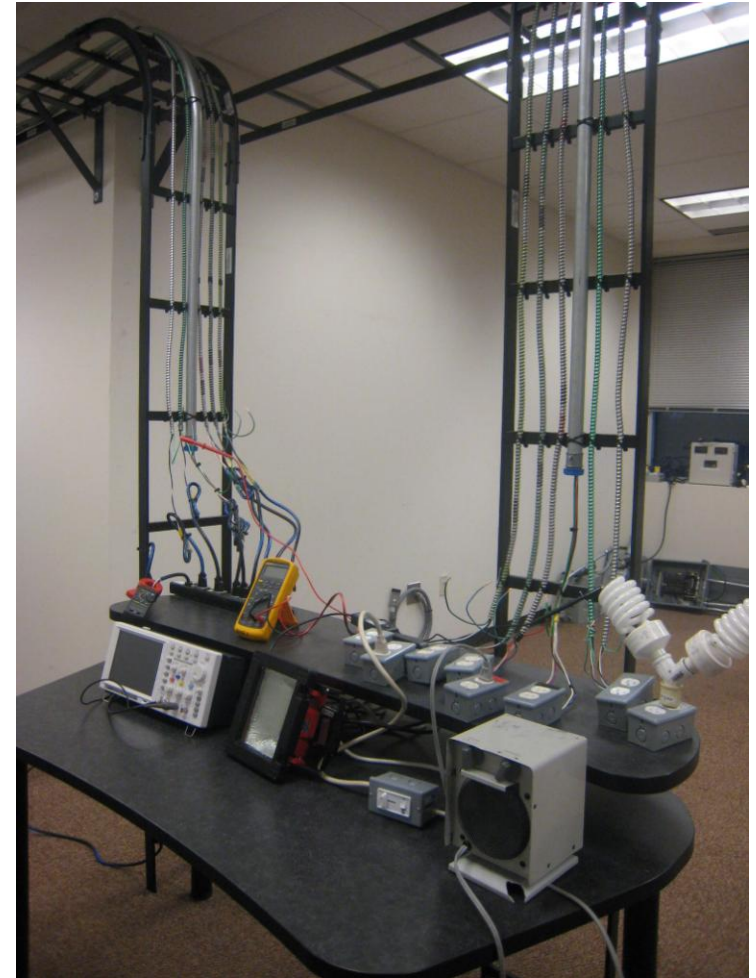
Modern non-linear loads (such as light dimmers and compact fluorescent bulbs) have a fast current rise time which greatly increases the induction. This is why 15 years ago isolated grounding schemes worked better than they do today, especially over longer runs.

In conduit, wires lay in a haphazard manner.



Ground Voltage Induction (GVI) (cont'd)

Controlled experiments (pictured here) have been conducted with varying current flow, wiring methods and proximity from line conductors to “victim” safety ground wires using both linear and non-linear (harmonic) loads. They clearly show that significant voltage differences at opposite ends of a safety ground wire can be present, even with dedicated isolated ground circuits. Non-linear loads have the greatest impact on ground voltage induction. A non-linear load is defined as a device that draws a pulse of current, the duration of which is less than that of the voltage waveform. These non-linear loads contain a semi-conductor switch that causes current to be drawn for a period less than the full cycle. Some examples of non-linear loads include switch-mode power supplies, audio power amplifiers, lighting dimmers and non-dimmable compact fluorescent bulbs. The rapid rise time of the current draw from these types of loads, will induce more voltage on ground wires than equivalent linear (resistive) loads such as incandescent lights, as shown in the diagram on the following page. Non-linear loads incorporating ‘power-factor correction’ (PFC) can significantly reduce GVI since PFC tends to smooth the load current waveform, slowing its rise time.



Ground Voltage Induction (GVI) (cont'd)

As evidenced by the chart below, aluminum jacket “AC” (Armor clad) type cable with an insulated ground conductor (AC-HCF Aluminum jacket) is currently the best choice for isolated ground AV circuits. In this cable, there are two insulated grounding conductors; one of which is equidistant with respect to both phase conductors along the entire length of the cable. This symmetry cancels almost all the magnetic field in this one grounding conductor.

“MC” type cable (2-wire plus insulated ground) is currently the best choice for non-isolated ground circuits. See AC Power Wiring Types section for a full description of the differences between MC type cable and AC type cable.

Some non-metallic sheathed cable (commonly known as Romex) is designed with its ground wire in-between the phase conductors and is sometimes less susceptible to induction, but the amount of GVI will vary greatly due to the inconsistent spacing of the ground wire caused by the paper filler.

The most effective way to reduce GVI is to twist the phase conductors together and pull through a conduit with a straight ground wire. This may be time consuming and impractical, but for critical situations where millivolts matter, this may be the best solution.

Cable Type (100 feet, 12 gauge)	Load Type	RMS Load Current	Ground Voltage Induced (mV)	Ground Current Induced (mA)**
MC-STAT* Steel Jacket	Non-linear (compact fluorescent)	7.6A	41	135
	Resistive (incandescent)	7.8A	5	28
	Non-linear (dimmed incandescent)	1.8A	77	51
MC-STAT* Aluminum Jacket	Non-linear (compact fluorescent)	7.6A	19	80
	Resistive (incandescent)	7.8A	5	22
	Non-linear (dimmed incandescent)	1.8A	54	33
AC-HCF Steel Jacket	Non-linear (compact fluorescent)	7.6A	4	13
	Resistive (incandescent)	7.8A	1	5
	Non-linear (dimmed incandescent)	1.8A	8	8
AC-HCF Aluminum Jacket (best for IG runs)	Non-linear (compact fluorescent)	7.6A	1	6
	Resistive (incandescent)	7.8A	1	2
	Non-linear (dimmed incandescent)	1.8A	4	4
MC Aluminum Jacket (best for non-IG runs)	Non-linear (compact fluorescent)	7.6A	<1	2
	Resistive (incandescent)	7.8A	<1	<1
	Non-linear (dimmed incandescent)	1.8A	2	1

* trademark AFC Cable Corporation

** measured with AEMC 565 True RMS leakage current meter

Isolated (Technical) Ground vs. Safety & Building Ground

Grounding in general:

In most electrical systems the term “grounding,” as it is commonly interpreted, has little to do with the connection to soil (earth), although it is required that the grounding system be in contact with earth, at the source of supply. The primary reason for the connection to earth is to divert current that is caused by a lightning strike. While this is very important, in practical applications, the term “grounding” refers to a path of “fault current” (sometimes called ‘short-circuit current’) back to its source. 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. Thus the integrity of the ground wire is crucial to safety. The neutral-ground bond in the originating panel or transformer completes the path to the current’s source. 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.

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.”

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.

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. 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 little impact on the signal. In special cases, such as two interconnected buildings, significant current may flow in grounding conductors between them (via wire, metallic conduit and plumbing pipes).

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? Depending on the frequency range and dynamic range requirements of the system, two effective equipment grounding schemes are an Isolated Ground System and a Mesh Ground System (discussed later in this paper).

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

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 the separately derived system transformer as described previously in the section on Isolation Transformers and as per NEC 250.30 (A)(1). This grounding conductor must be insulated. It may be spliced when passing through sub-panels or junction boxes, but must not be connected to them.

The use of an isolated equipment grounding conductor does not relieve the requirement for grounding conduits, raceways and junction boxes.

One problem with an isolated ground circuit is that its integrity is easily compromised. Any inadvertent connection between the isolated ground system and any other 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. These inadvertent connections to ground can be via signal cables as well as grounding conductors.

To check the integrity of an isolated ground system, do the following with all equipment installed, connected and plugged in, with assistance from a qualified electrical professional:

1. Switch off the main breaker in the technical power panel
2. Remove the jumper between the isolated ground bus and the neutral bus and/or neutral-ground bond point
3. Check for continuity between the isolated ground bus and the safety (building) ground using a DC battery and bulb tester, or a mechanical ohmmeter. A DVM (digital volt meter) will not be adequate for this test, as it is subject to gross errors caused by small residual voltages and RF. The reading should be open because step #2 should have removed the only connection between the two ground systems.
4. If any improper grounds were found, they must be removed. Inadvertent connections to building ground from the isolated ground system can come from mounting conduit to floating equipment racks, hardware connecting projectors or powered speakers to building steel, signal cables routed to remote areas not powered from the isolated ground system, signal cables being grounded at wall plates, etc.
5. Reconnect the isolated ground bus before turning the power back on

Other problems with isolated ground systems may 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. Isolated ground systems with long power conductor runs can be vulnerable to ground voltage induction (see GVI section of this paper). Isolated ground systems can be vulnerable to large induced voltages from nearby lightning strikes in some cases. It may help to consider isolated ground wires as prongs on a fork spreading out.

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.

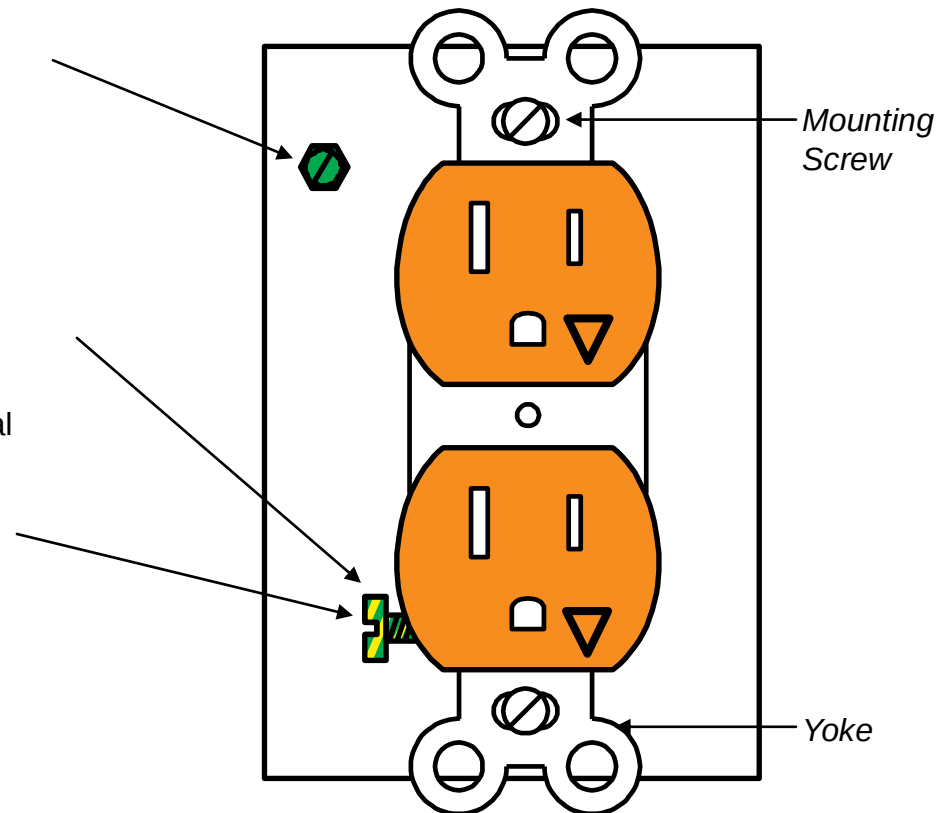
The electrical box must still be bonded to the building ground. If a supplemental (auxiliary) equipment grounding conductor is installed for box grounding, it must be installed in the conduit with the circuit conductors. It may be bare or insulated. The grounding of all metallic components is also referred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

The isolated (insulated) 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 connect to 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.

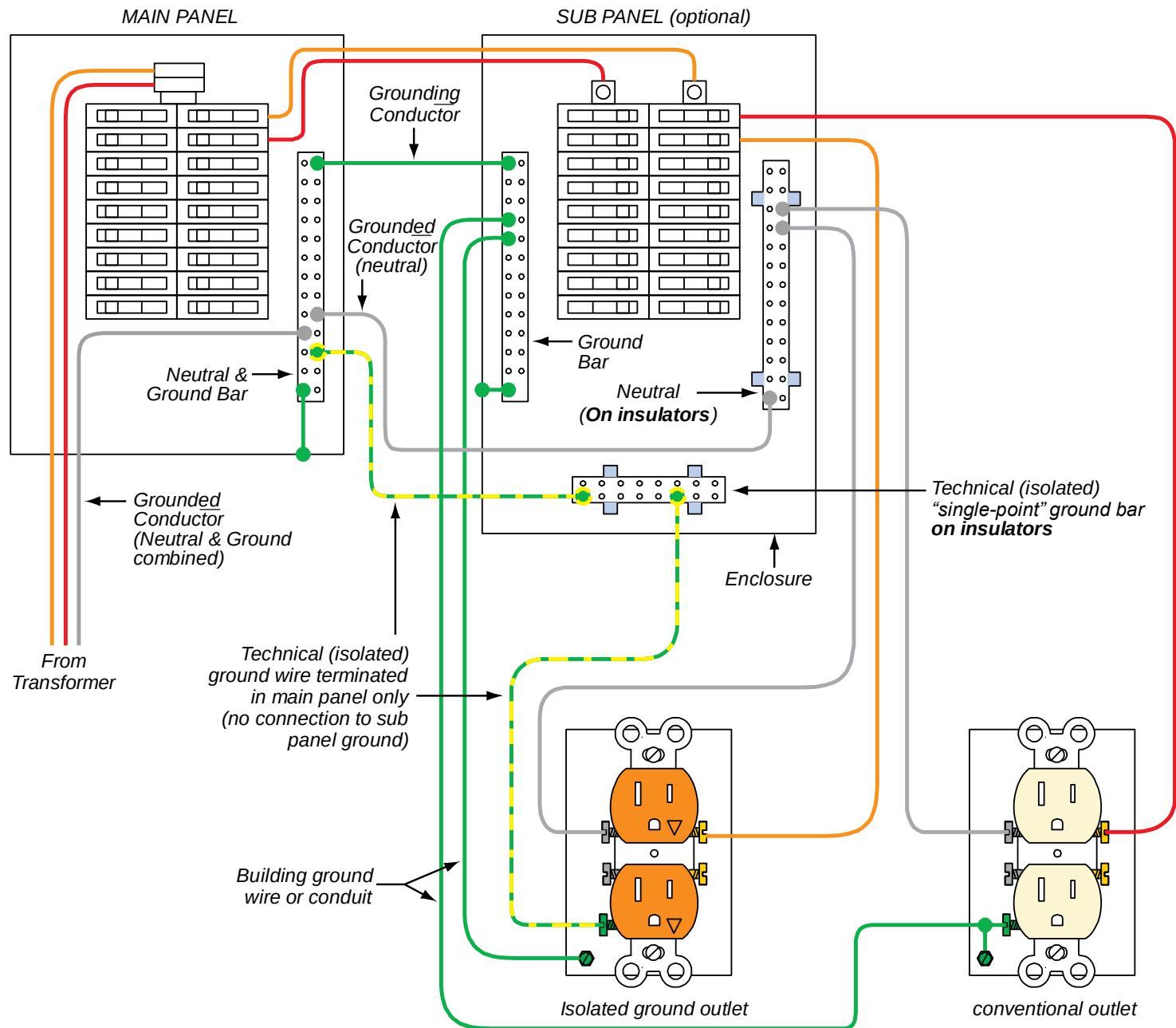
DO NOT BOND THE OUTLET GROUND SCREW TO THE ELECTRICAL BOX WHEN USING ISOLATED GROUND RECEPTACLES

The mounting yoke is not bonded to the outlet 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 (safety 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.

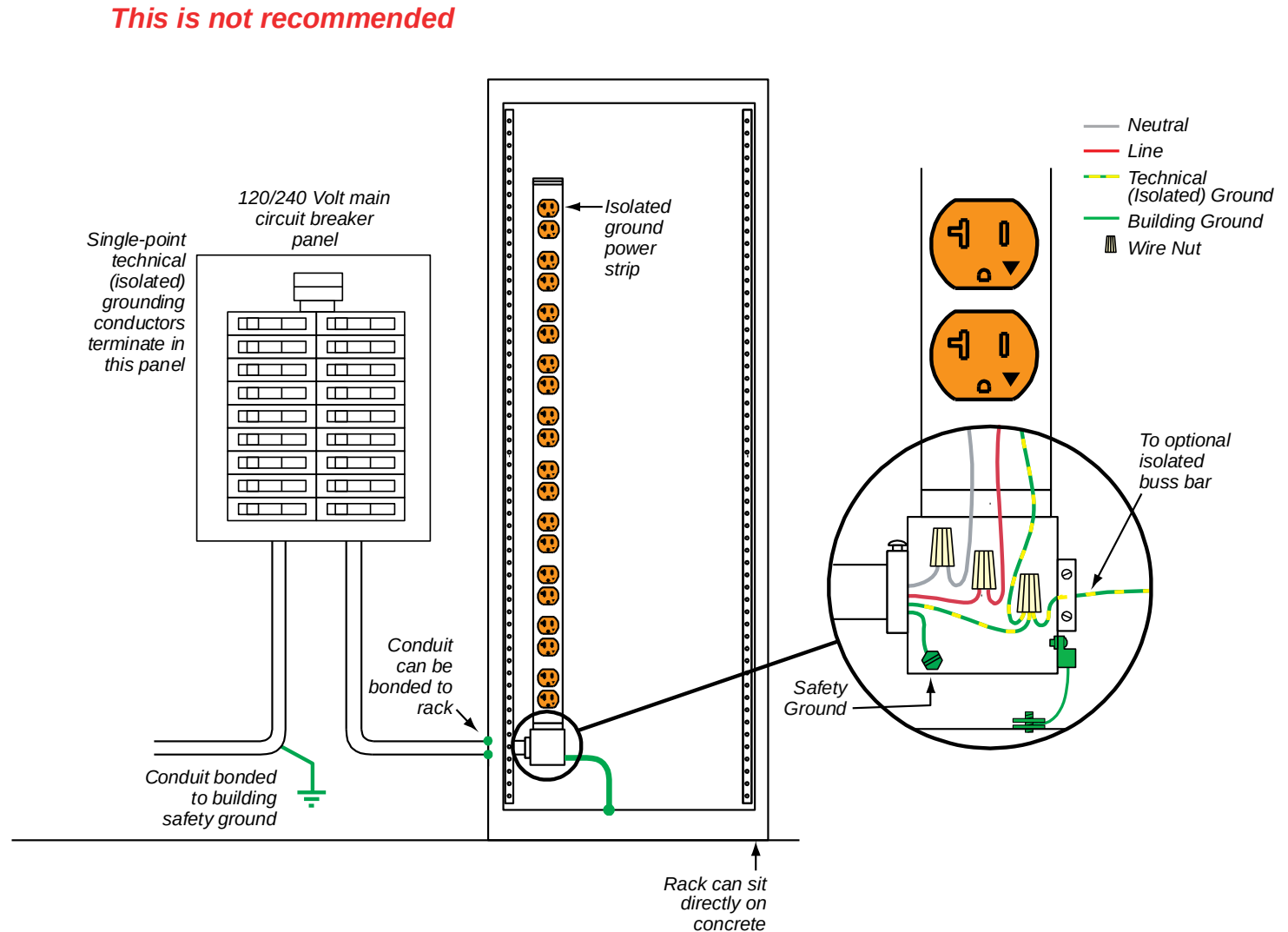


Isolated Ground Power Strip in a Non-Isolated Rack

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

An “isolated ground” system installed in the manner shown here (conduit bonded to rack, rack sitting directly on concrete floor) does not guarantee a noise-free system, and is defeated by the smallest breach of isolation via a stray ground, including plugging three-prong equipment in and screwing to the rackrails (see figure on next page). When an isolated grounding system is breached, current will flow in the shields of the signal interconnect cables, potentially inducing noise onto the signal conductors.

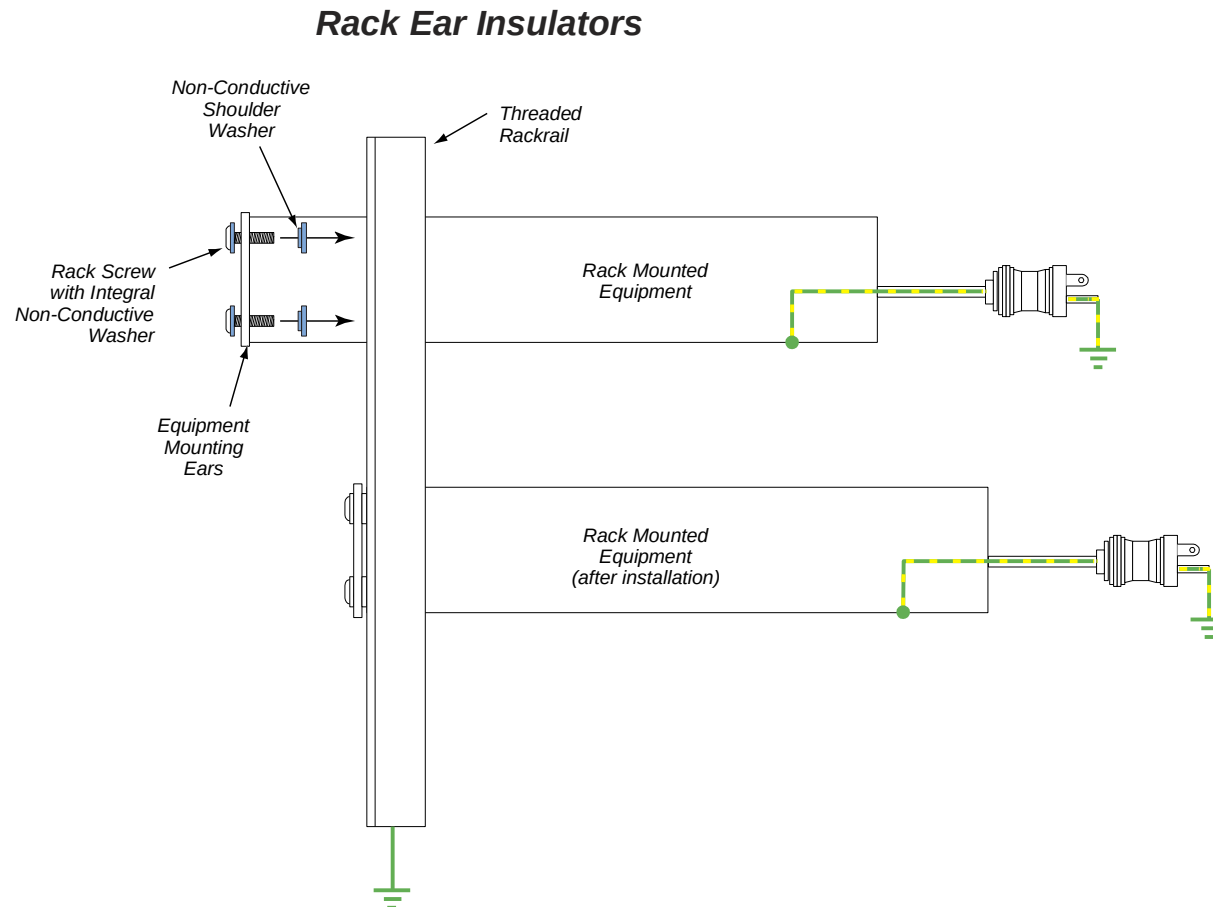
Rackmounted equipment and connector panels, including cable shields, must be isolated from the rack for proper operation as an “isolated ground” system.



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

A problem will exist due to the fact that all equipment with a three-prong (grounded) plug per UL requirements 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.**



Isolated Rack with Standard Power Strip (not isolated ground receptacles)

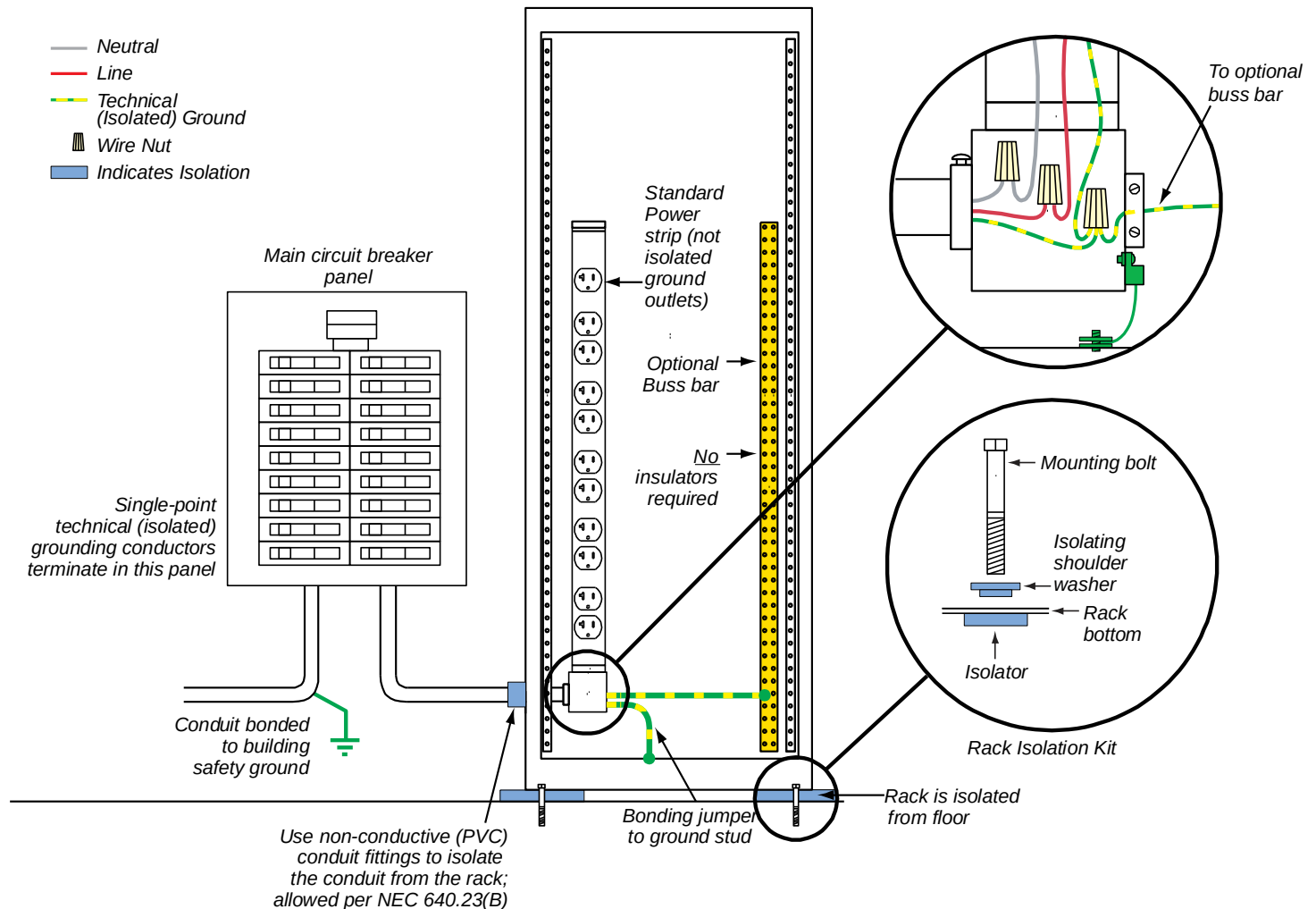
Isolate the entire equipment rack by connecting the power and signal conduits to the rack using non-metallic fittings. An insulated grounding conductor must be installed in the power conduit to comply with NEC requirements (Article 640.22) and must also be bonded to the rack's ground stud.

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.

*This is highly effective and is recommended**

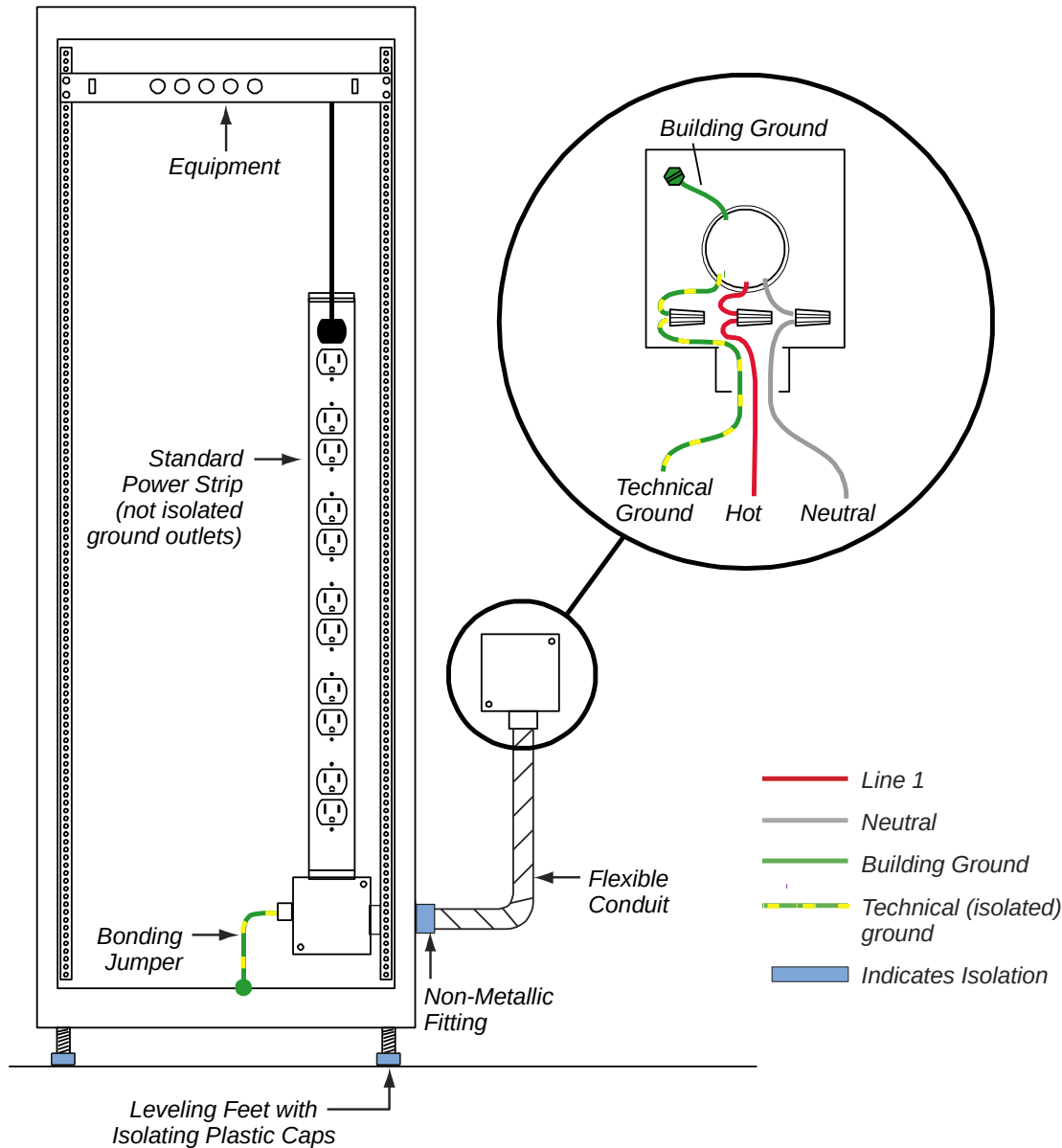
Rackmounted equipment does not have to be isolated from the rack. However, “non-technical” metallic connections (stray grounds) must be isolated from the rack.

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



Flexible Connections to Isolated Equipment Racks

Example #1



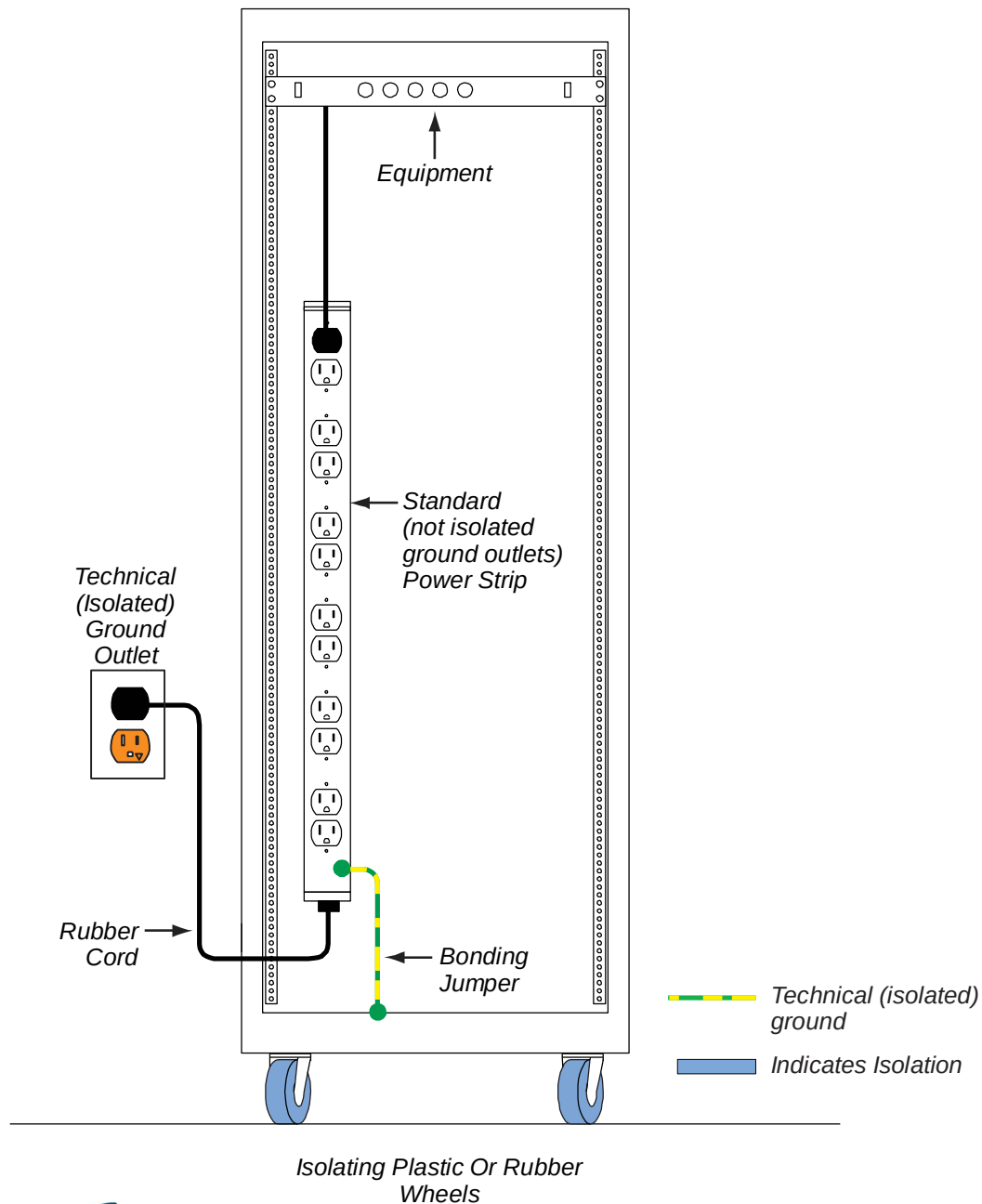
In the following examples, the racks are grounded via a technical (isolated) ground, and isolated from the building safety ground. Additionally, these racks are isolated from the floor by use of insulated leveling feet (example 1), and rubber or plastic wheels (example 2, next page).

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.

Main Considerations When Implementing Surge and Spike Protection

Direct lightning strikes – Lightning strikes always want to get to earth. Of critical importance is to ensure that the path to earth is not through the facility's safety ground wiring system. Direct lightning strikes are not covered in the scope of this paper as there are many techniques to address this for different geographical areas.

Nearby lightning strikes – Lightning strikes are surrounded by very powerful magnetic fields that can induce brief high-voltage spikes into utility power lines. The most effective way to protect against these spikes in 240V/120V single phase systems is to install a type 2 service entry surge protection device (SPD) at the main service panel. SPD was formerly known as TVSS, changed per 2008 NEC, and UL 1449 3rd edition. To perform effectively, this service entry SPD must have "3 mode" (sometimes known as "all-mode") protection, which diverts surges between the phase conductors themselves, and between phase conductors and earth ground (L1-G, L2-G and L1-L2). Surge protection that incorporates all three modes (L1-G, L2-G and L1-L2) should **only** be installed at the service entry, with Telco and cable TV grounds all bonded per 2008 NEC: 800.100 (see Intersystem Bonding section of this paper).

Best practices dictate that all equipment is ultimately bonded (earthed) at the same potential, ideally at the main service entrance. This ensures that any abrupt rise in ground voltage (due to a nearby lightning strike) raises the voltage of all equipment grounding conductors simultaneously and equally. This reduces the possibility of any large ground voltage differences between interconnected equipment, and thus reduces the chance of damage to the equipment, which may otherwise cause fire and damage. "3-mode" or "all-mode" protection should not be used anywhere after the main panel, including at equipment racks and local convenience receptacles. Nonetheless, many commercially available surge and spike protection devices do contain line-to-ground (L-G) and/or neutral-to-ground (N-G) MOV diverters. In certain situations, using a 3-mode surge protector downstream of the main service panel can actually increase the possibility of equipment damage. This is especially true when two separate branch circuits are feeding interconnected equipment, and only one of them is protected with a 3-mode SPD. This style of protection (3-mode SPD) can also increase system noise due to the fact that the MOVs used in these designs capacitively couple higher frequency line noise to the ground circuit.

Surges and spikes - "Switching" surges or spikes are some of the most common threats to good power quality and most often occur when a load (resistive, reactive, or both) is turned on or off. When switching a reactive load, an abrupt voltage or current surge can occur, the magnitude of which will increase as switching time decreases. When compact fluorescent lights (capacitive reactance) are switched on an abrupt change in current draw occurs, which creates a spike. When inductive components are switched off, they release magnetically-stored energy that can cause arcing across the contacts of the switch and produce voltage spikes on the line conductors. To protect AV equipment from switching surges, ensure AV equipment is powered from dedicated branch circuits, and install local arc suppression devices at the offending appliance or switching device. Other voltage spikes and impulses, aside from lightning, mostly arise from electrical devices inside the facility switching on and off, such as motors, pumps, air conditioning units and other machinery. The switching action causes abrupt transient currents throughout the electrical wiring system. Additionally, because of shared utility service wires with other buildings, voltage spikes and impulses can be introduced from outside. Microprocessors and digital electronics have evolved to utilize faster data rates and smaller signal voltages, which make the equipment potentially more sensitive to transients - poor equipment design plays a role, too. Symptoms range from disruption to degradation. Transients as short as 0.1 microseconds can degrade some electronic circuits permanently. It is recommended these sensitive devices be protected by installing "1 mode" (Line to Neutral) surge and spike protection at the point of use.

Surge and Spike Protection Technologies

Although there are many different types of surge and spike protection technologies, the three most common are series mode surge suppression, shunt mode surge suppression and shielded isolation transformers. All these technologies offer varying benefits depending on deployment and system design.

Series Mode - The most important benefit of series mode suppressors is that they block or reduce the size of the transient surge current, by slowing the transient and storing the energy in an inductor. This also filters out high frequency differential-mode noise. The most commonly perceived benefit however is that their components do not degrade. This is true only when series mode devices are operating within their current draw design limits. For this reason, series mode suppressors cannot be effectively used at the service entry for lightning protection nor to suppress surges on large amperage circuits at panel boards due to the excessively large and costly inductor that would be required.

Shunt Mode - The most common form of shunt mode surge suppression utilizes MOVs (Metal Oxide Varistors) which, under normal operating voltages, act as an open circuit and allow no current (other than high frequency leakage current) to flow through them. However, should the voltage level rise above the clamping voltage of the MOVs (i.e. a surge condition), then the MOVs will start to conduct, shunting the potentially damaging surge away from connected equipment. MOVs respond quickly to surge and spike conditions. MOVs can be permanently degraded if subjected to repeated surges above their rated capacity. The NEC (2008, Article 285) has recently categorized shunt mode SPDs into four types:

Type 1 – Permanently connected SPDs intended for installation between the secondary of the service transformer and the line side of the service equipment overcurrent device, as well as the load side, including watt-hour meter socket enclosures and intended to be installed without an external overcurrent protective device.

Type 2 – Permanently connected SPDs intended for installation on the load side of the service equipment overcurrent device; including SPDs located at the branch panel.

Type 3 – Point of utilization SPDs, installed at a minimum conductor length of 10 meters (30 feet) from the electrical service panel to the point of utilization, for example cord connected, direct plug-in, receptacle type and SPDs installed at the utilization equipment being protected. The distance (10 meters) is exclusive of conductors provided with or used to attach SPDs.

Type 4 – Component SPDs, including discrete components as well as component assemblies.

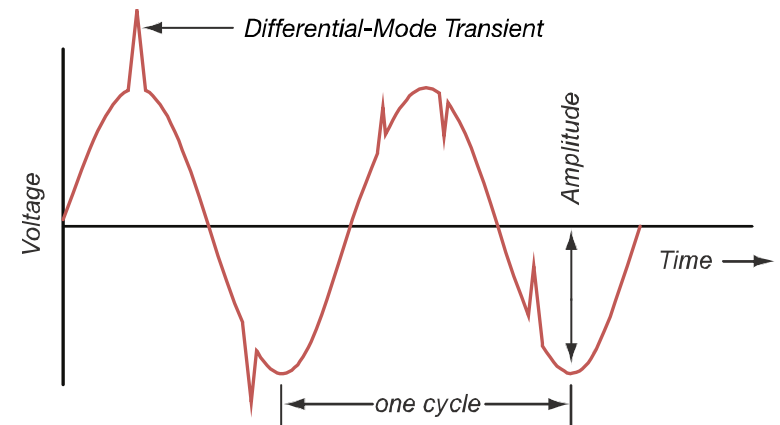
Surge and Spike Protection Technologies (cont'd)

Shielded Isolation Transformers - Voltage spikes (sometimes called transients) 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 or common-mode.

Differential-mode transients, which can arise within or outside the premises (such as lightning strikes to the power line) occur between current-carrying load conductors. See figure to the right for example of differential-mode transients.

Common-mode noise arising within a facility can be caused by many devices, including motors, lighting dimmers, etc. and is undesirable voltage (noise) which appears equally and in phase from each conductor relative to ground potential.

Power transformers without an electrostatic (Faraday) shield, may allow common-mode transients to couple from the primary to secondary through the transformer's inter-winding capacitance (see Isolation Transformer section of this paper). For the best performance, specify transformers that have one or two electrostatic (Faraday) shields, which divert common-mode transient current to ground, effectively preventing it from appearing on the secondary. Additionally, the leakage inductance of the transformer and its optimized performance at 60Hz suppress rapid differential-mode voltage transients. In extreme over-current cases, the transformer core's ability to magnetically couple voltage is reduced, further attenuating the spike.

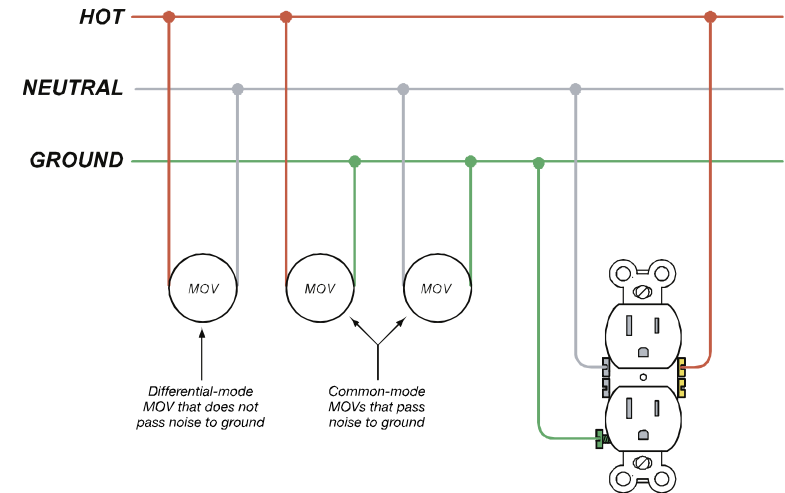


Surge Suppressors and Noise on Safety Ground Wires

Example of a Branch Circuit Surge Suppressor Design (“3-Mode” or “All-Mode”) that **Can Pass Noise** to Ground

This design provides both common-mode and differential-mode surge protection, and should only be used at the main panel. A disadvantage with using 3-mode surge protection on branch circuits is that the internal capacitance of the MOVs couples higher frequency line noise directly to the safety ground wiring.

Additionally, in certain situations the use of a 3-mode surge protection device downstream of the main service panel can actually increase the possibility of equipment damage; during a large surge or spike, very large voltage differences may be created across the safety ground wiring. These voltage differences can appear across the signal wires interconnecting equipment, and can damage input and output circuitry. This is especially true when two separate branch circuits are feeding interconnected equipment, but only one of them is protected with a 3-mode SPD.



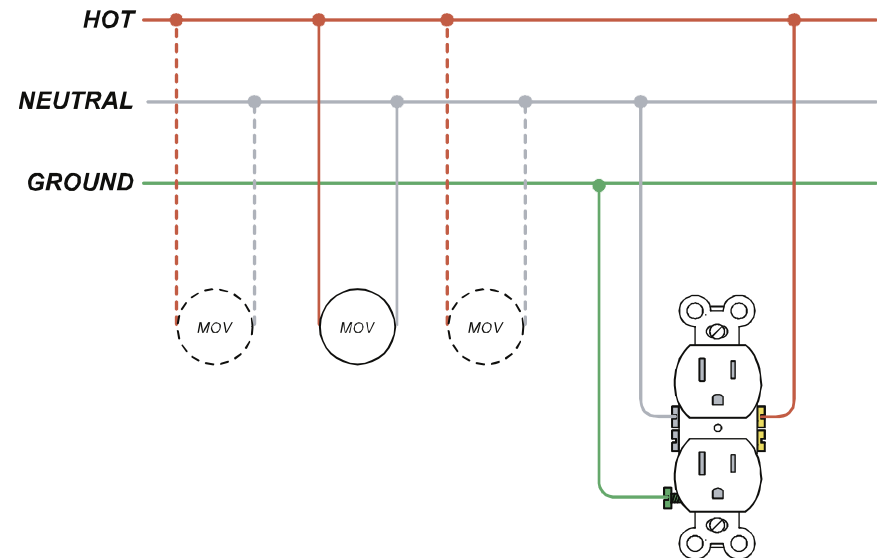
Example of a Branch Circuit Surge Suppressor Design (“1-Mode” or “Single-Mode”) that **Does Not Pass Noise** to Ground

Since no MOVs are connected to ground, there is no possibility of high frequency noise coupling to ground through it.

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

For increased surge capacity, many MOVs can be placed in parallel. However, while providing additional benefit, the increase in surge protection capacity is not directly proportional to the number of MOVs added because MOVs are not precisely matched.

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.

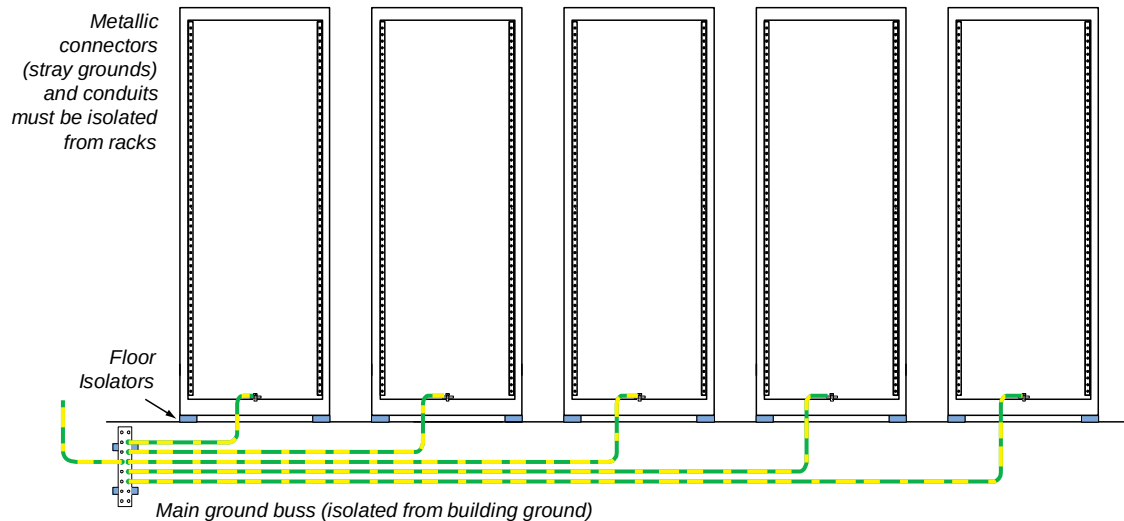


With all methods of surge and spike protection, it is recommended that installers specify SPDs that include remote status notification to alert a control system or facility manager that service may be required.

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

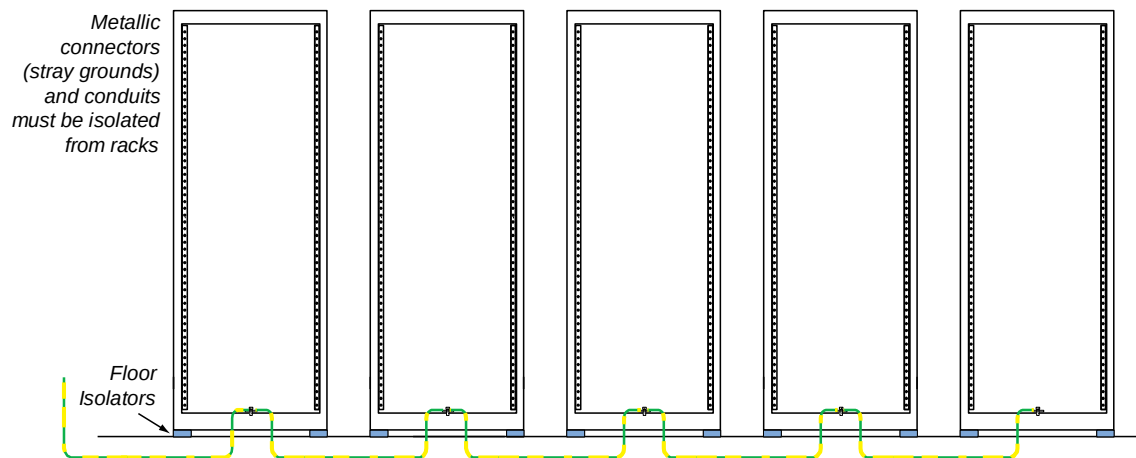
Two common methods of bonding racks together with equipment grounding conductors are known as “star” grounding and “daisy chain” grounding.

“Star” Grounding (isolated or technical ground)



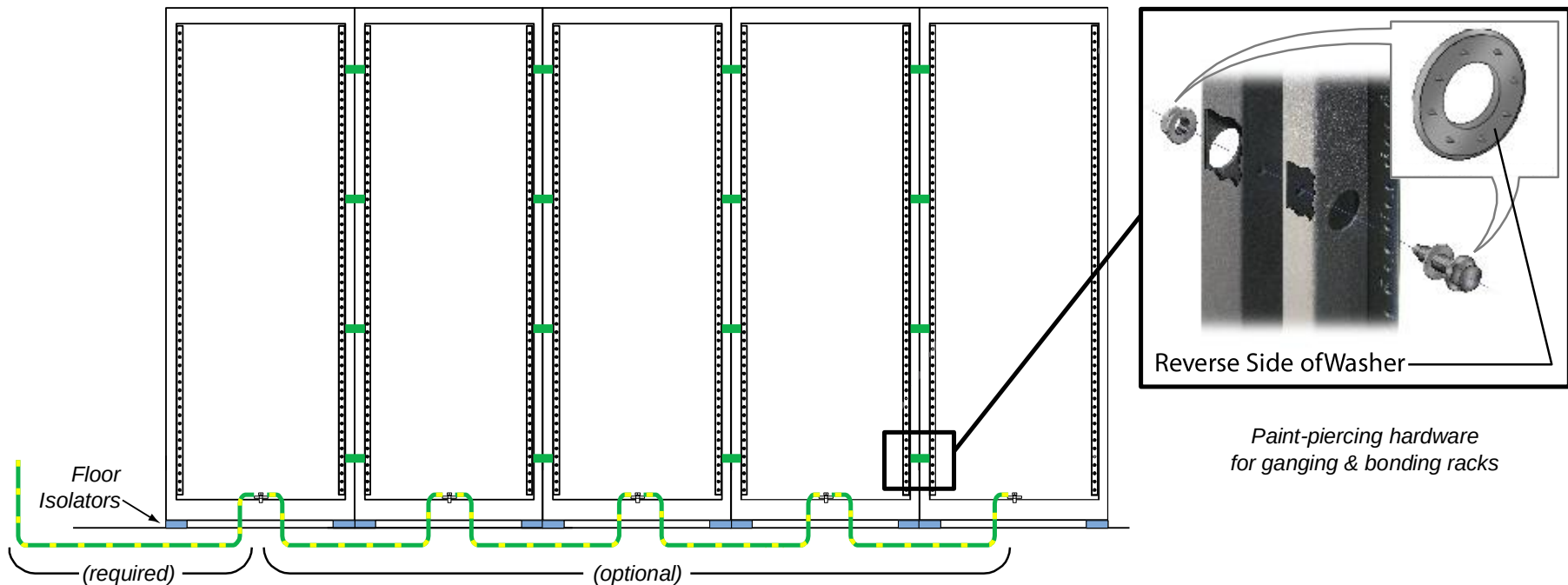
When properly configured, an isolated ground (also known as a technical ground or single-point ground) system is arranged electrically in a “star” pattern. Each rack is bonded to a common single point ground with separate equipment grounding conductors, reducing voltage drop. If paint-piercing hardware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

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. For practical floor grids, performance deteriorates at frequencies over about 10MHz. For this reason, such schemes are rare in modern computer and equipment rooms.

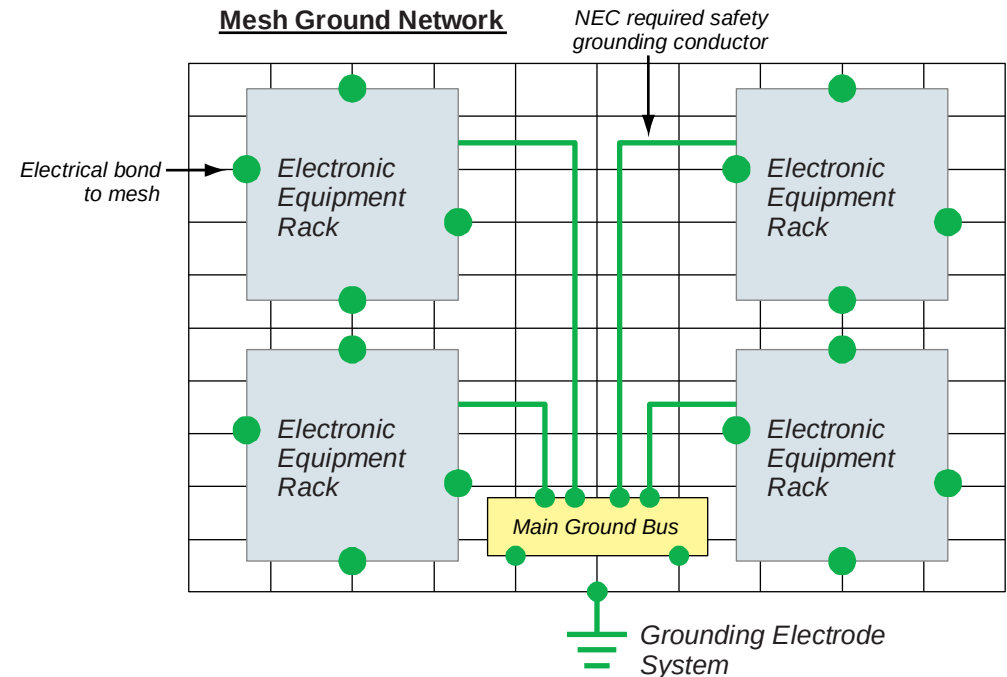
Mesh Grounding

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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Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the member states relating to electromagnetic compatibility and repealing Directive 89/336/EEC

BICSI Telecommunications Distribution Methods Manual, 10th 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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