Power and Grounding for Audio and Video Systems Part 2

Jim Brown
Andy Benton

Power Grounding

- ***Grounding*** **– An electrical connection to earth**
- ***System Grounding*** **– the bonding to earth of a conductor that normally carries current – the *neutral* or *grounded conductor***
- ***Equipment Grounding*** **– the bonding together of all exposed equipment that could be energized (due to an equipment fault)**
- ***Technical Grounding*** **– the scheme for bonding between the *equipment grounding* of technical equipment to minimize hum, buzz, and RFI**

Why an Earth Connection?

- **Low impedance discharge path for lightning**
  - **Energy in lightning extends well into MHz range, with a broad peak around 1 MHz**
- **Safety of personnel in outdoor systems**
- **A return path for a Faraday shield in power isolation transformers**

Earth Connections and Noise

- **The impedance of the connection to earth has very little to do with noise in audio systems!**
- **Ground rods are for lightning safety!**
- **Earth provides the fault path for the power company's service.**

Earth Bonding

- **Short (low inductance) is critical here too**
- **Made electrodes should be bonded together outside the building**

Some Lightning Realities

- **Very high voltages creates very large currents with very short rise time**
- **Large currents create large voltage drops**
  - **Heat can even vaporize a conductor**
  - **If impedance is high enough, voltage will arc over (insulators break down) and find an unintended path to earth**

For Lightning Protection

- Give it the shortest possible path to earth
- Avoid sharp bends (likely to arc across the bend or to another path)

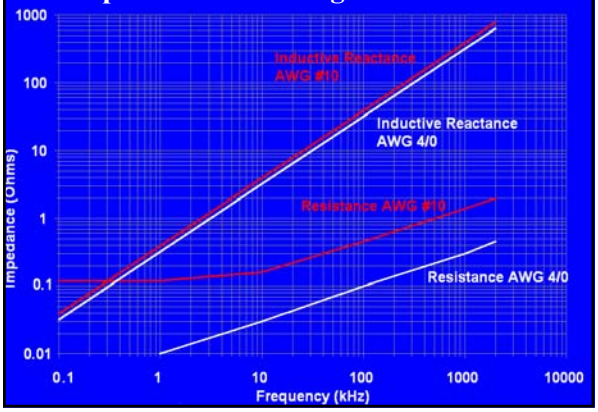
Does Impedance to Earth Matter?

- The impedance of the connection to earth affects
  - Lightning safety
  - Noise filtering by Faraday shields in a power isolation transformer

Making the Earth Connection

- Low Impedance Path
  - At nearly all frequencies, inductance dominates the impedance
  - Big copper simply allows greater dissipation of heat before it vaporizes

Impedance of a Straight 100 ft Wire



Making the Earth Connection

- Short is far more important than big!
- Wide flat conductors reduce inductance
- Add multiple connections in parallel by bonding to building structure
  - Building structure is bonded to earth at multiple points
  - Building structure provides multiple paths in parallel
  - Reduces impedance of the earth connection

Bonding Conductors in Conduit

- By virtue of its permeability, steel conduit significantly increases the inductance of a conductor within it
- The inductance will be reduced to that of the conduit alone if the grounding conductor is bonded to the conduit at both ends, and at all connecting points.
- The conduit is a second conductor in parallel, so reduces the impedance too.

Ground Electrode Systems

- Earth conductivity
- To lower the impedance
  - Increase earth conductivity
  - Increase surface area in contact
  - Add electrodes in parallel
  - Increase spacing between electrodes
    - Mutual inductance between parallel electrodes increases impedance
    - Try for spacing > length of rod

Increasing Soil Conductivity

- Keep the electrode system moist
  - Outside footprint of building
  - Outside footprint of pavement
- Chemicals are a bad idea
  - Must be regularly maintained to be effective over the long haul
- No limit on the number of ground electrodes, but they must all be bonded together

Lightning Protection Systems

- Cannot be relied on for grounding of power systems (per NEC)
- Must be bonded to power system ground

All Ground Electrodes Must be Bonded Together

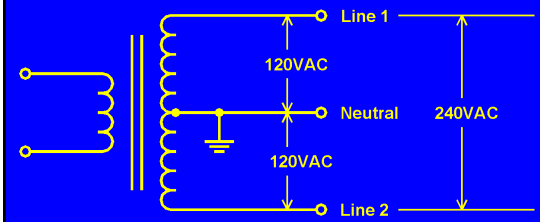
- Water pipes
- Building steel
- Gas pipe
- *Made* electrodes
  - Driven rods
  - Metal plates
  - Ground rings
  - Ufers
- Lightning system grounds

Ufers – Concrete Encased Electrodes

- Increases surface area in contact with earth
- Concrete can explode with a strike, so use of structural concrete can be a problem

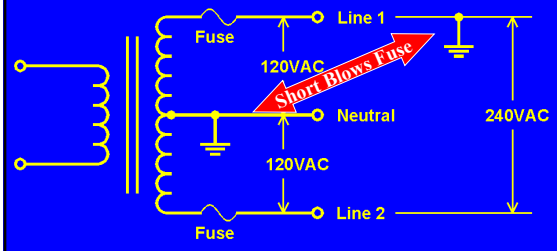
Developed by (Herbert G. Ufer) for US Army after WW II

System Bonding



- The purpose of bonding is protection of persons and property

System Bonding



- The purpose of bonding is protection of persons and property

System Bonding

- Each power system having a grounded conductor must be bonded once, and only once, at the point where the system is established
  - Note: some industrial systems are not required to be grounded
- The purpose of bonding is protection of persons and property

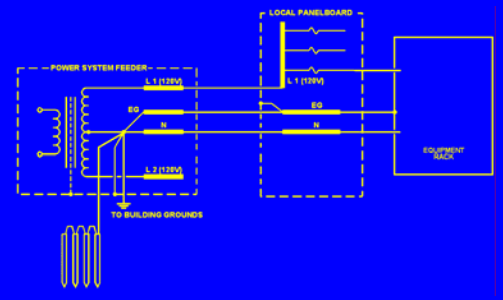
System Bonding

- A system is established
  - Where a service enters a building
  - By a distribution transformer within a building
  - By a motor generator
  - By a UPS, when it is running
- A building may have several *systems*
- In general, the bond must be very close to the point where the system is established.
  - A short bond having a low impedance path to earth tends to minimize noise on a power system
  - Building steel is generally a good bonding point because it typically provides many parallel paths to earth, thus reducing the total inductance

What Must Be Bonded

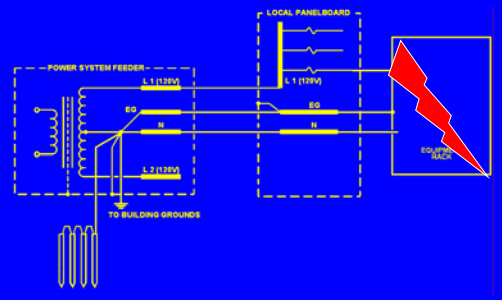
- In general, every piece of exposed metal that might be energized must be bonded
  - Energized means "come in contact with a power conductor"

How Equipment Grounding Protects Us



Equipment cases are bonded to the power source via the green wire

How Equipment Grounding Protects Us



When equipment fails making the case hot, the fuse blows quickly.

Why Technical Grounding?

Technical Grounding

- The primary purpose of *technical grounding* is to minimize the flow of power-related noise currents on the shields of signal wiring, while also providing the *equipment grounding* required for safety
- *Technical grounding* should also provide a suitable reference for cable and equipment shields at radio frequencies

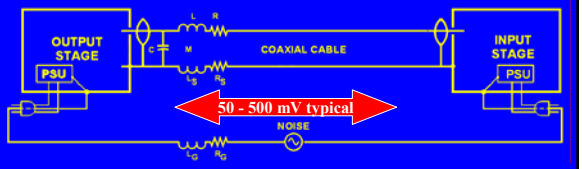
Primary Coupling Mechanisms

- IR drop on shields of unbalanced signal wiring
- Pin 1 problems
  - Improper shield termination within equipment
- Differential noise on signal pair
  - Inductive imbalance between shield and signal conductors -- Shield-current-induced noise (SCIN)
  - Capacitance imbalance of cable
  - Inadequate low-pass filtering lets it in the box
- Common mode noise
- Inadequate shielding of internal wiring

Unbalanced Signal Wiring

- All video
- RS-232 interfaces
- Cheap audio equipment
- Control wiring

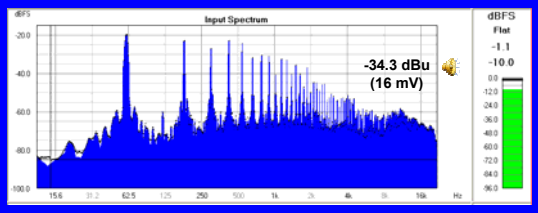
The Problem with Unbalanced Interfaces



Noise current flows on the shield, and the IR drop is added to the signal.

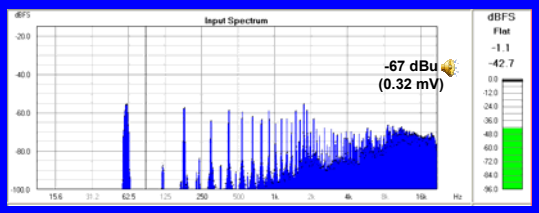
- Use a "beefy" cable shield
  - Minimizes the drop
- Reduce the noise voltage between the ends of the cable

Typical Noise Spectrum on "Ground"



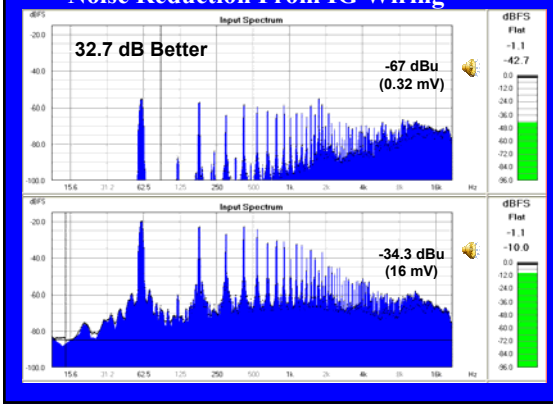
Measured between two outlets in my office, one a conventional outlet, and one an IG outlet

Typical Noise Spectrum on "Ground"

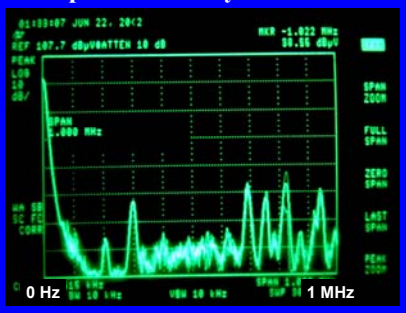


Measured between two IG outlets in my office

Noise Reduction From IG Wiring



RF Spectrum Analyzer 0 – 1 MHz



Measured between two different outlets in my office, one a conventional outlet, and one an IG outlet, into a 75 ohm load

For Unbalanced interconnections, shield resistance can be important!

- Shield current (noise) creates IR drop that is added to the signal
- $E_{NOISE} = 20 \log (I_{SHIELD} * R_{SHIELD})$
- Coaxial cables differ widely
  - Heavy copper braid (8241F) 2.6 Ω /1000 ft
  - Double copper braid (8281) 1.1 Ω /1000 ft
  - Foil/drain shield #22 gauge 16 Ω /1000 ft
- Audio dynamic range 100 dB
  - For 1 volt signal, 10 µV noise floor

A Calculated Example

- 25-foot cable, foil shield and #26 AWG drain with resistance of 1 S
- Leakage current between two pieces of equipment is measured at 1 mA
- From Ohm's law, noise voltage =1 mV
- Consumer reference level = 316 mV
- Signal to noise ratio = 316 mV ÷ 1 mV = 316:1 = 50 dB = pretty bad!
- Belden #8241F cable, shield resistance of 0.065 S, would reduce noise ≈ 24 dB!

Noise on "Ground" from Power

- Leakage currents to green wire
  - Power transformer stray capacitances
- Intentional currents to green wire
  - Line filter capacitors
- Power wiring faults
- Shunt mode surge suppressors
- Magnetic coupling from mains power
  - Harmonic current in neutral
  - Motors, transformers

Leakage Current to Green Wire

- Capacitance from phase ("hot") to equipment ground (green wire)
- $I = E/X_C = 120/X_C$
- $X_C = 1/(2\pi f C)$
- Maximum permitted leakage current is 5 mA with 110% of rated line voltage
- $X_C = E / I = 1.1 \times 120 / .005 = 26.4\ k\Omega$
- $C = 1/(2\pi f X_C) = 0.1\ \mu F$ is the largest capacitance that can exist from line to ground within equipment

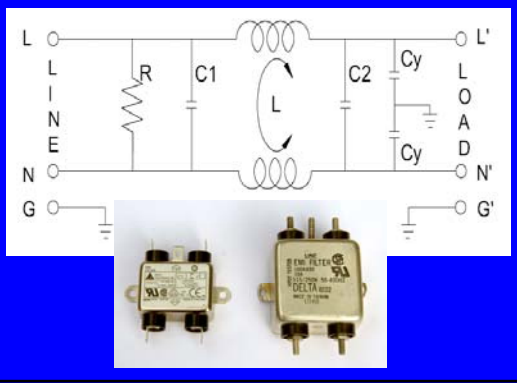
Leakage Current to Green Wire

- 0.1 µF is the largest capacitance that is permitted from line to ground within equipment
  - This includes stray capacitance within the power transformer
- We often have many pieces of equipment connected to the same branch circuit
  - All capacitances (and leakage currents) are in parallel, so they add
  - More noise

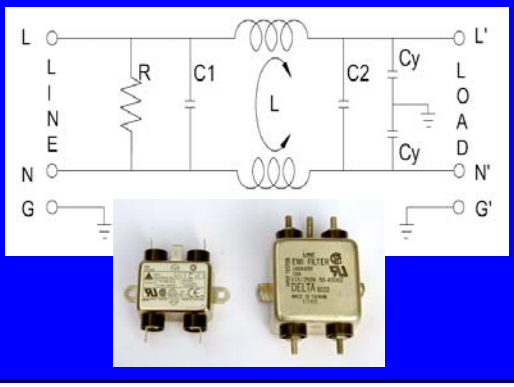
Triplen Harmonics and Leakage

- 3-phase equipment has stray capacitance to ground too
- Triplen harmonics contribute to leakage current, and ADD, just like in the neutral!
  - Third, sixth, ninth, etc
- Adds to noise current on cable shields
- Fundamental (50/60 Hz) and low harmonics (150/180 Hz, 450/540 Hz) are perceived as "hum"
- Higher harmonics are heard as "buzz"

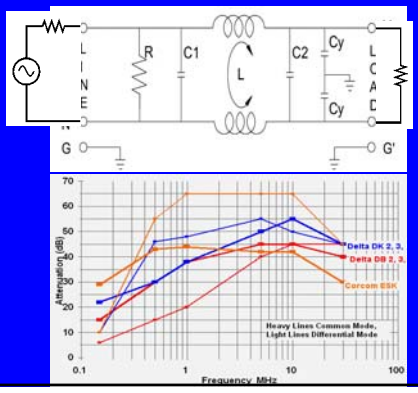
Line Filters Contribute Noise to Ground



Line Filters Attenuate RF Noise



Performance Depends on Impedances



Ground Fault Circuit Interrupter

- Senses imbalance between phase (hot) and neutral current
- Difference is flowing to ground
- Interrupts circuit if > 4-6 mA
- Required in locations where shock hazard more likely (outdoors, around plumbing)

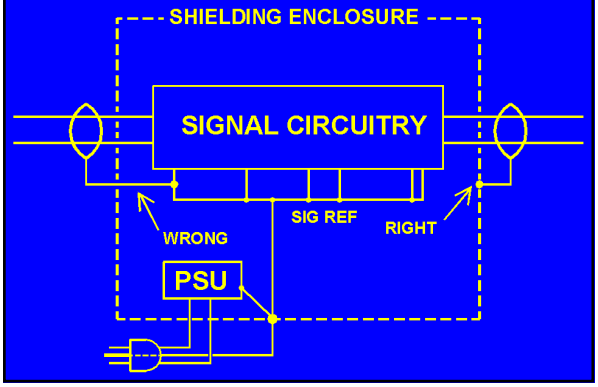
Pin 1 in Cable-Mounted Connectors

- Pin 1 is the shield contact of XL connectors (AES14-1992)
- No connection should be made to the shell of cable-mounted connectors

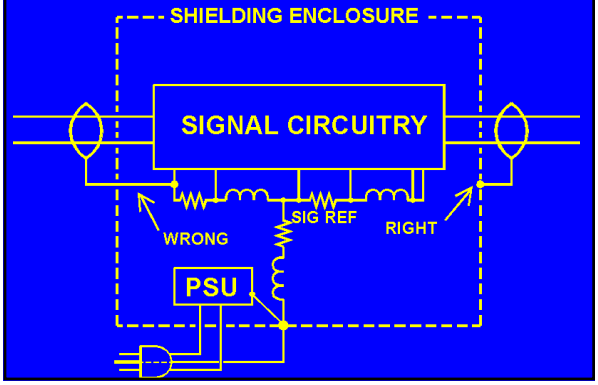
Pin 1 Within Equipment

- Pin 1 is the shield contact of XL connectors
- Cable shields must go to the shielding enclosure (and ONLY to the shielding enclosure) (AES48)
- If shields go inside the box (to the circuit board, for example), common impedances couple shield current at random points along the circuit board!
- Noise is added to the signal

Pin 1 in Balanced Interfaces



Pin 1 in Balanced Interfaces



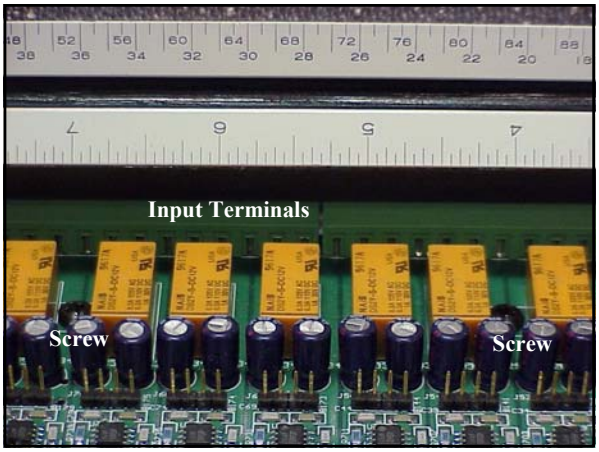
How Does It Happen?

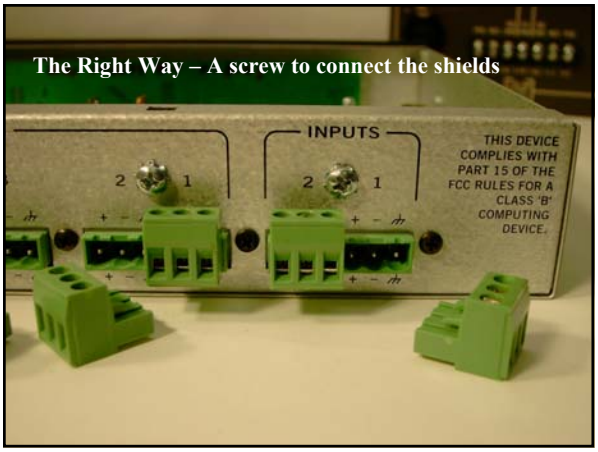
How Does It Happen?

- Pin 1 of XL's go to chassis via circuit board and ¼" connectors (it's cheaper)
- XLR shell not connected to anything!
- RCA connectors not connected to chassis

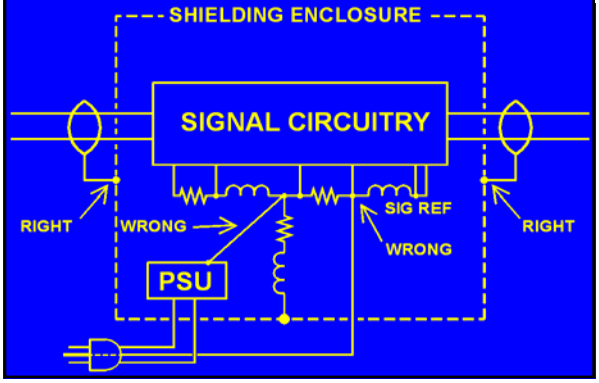
The G terminal goes to the enclosure, right?

Well, sort of, but it's a long and torturous journey!





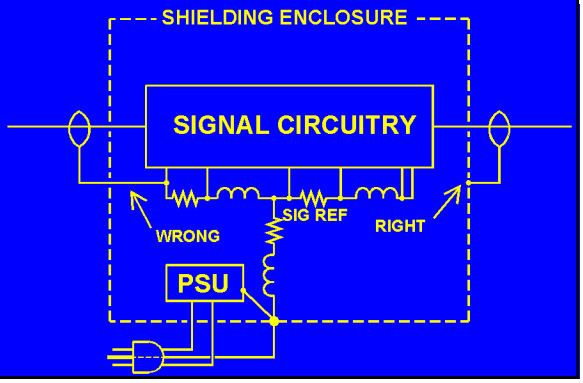
Power Supply Pin 1-Like Problem



Power Supply Pin 1-Like Problems

- It buzzes when I turn it on, and there are no signal wires plugged in
- Power line leakage current flows through circuit common
  - Stray capacitance in power transformer
  - Line filter capacitors
- Power supply filter capacitor returns via signal common bus

Pin 1 in Unbalanced Interfaces



Where are the Chassis Connections for this laptop's sound card?

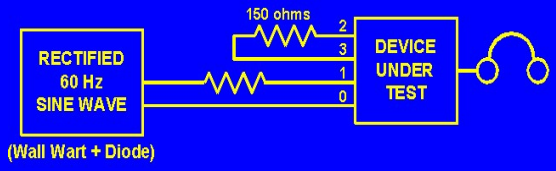
- Hint: It isn't an audio connector shell!
  - That metal is a shield, but not connected to connectors
  - And the cover is plastic too

Where are the Chassis Connections for this laptop's sound card?

Yes, it's the DB9 and DB25 shells!

Testing for Pin 1 Problems

John Wendt's "Hummer" Test for Pin 1 Problems



- Drive pin 1
- Listen to the output
- If you hear it, you have a problem

Cable construction is part of the problem!

- No cable is perfect
  - Inductive imbalance (SCIN)
  - Capacitive imbalance
  - Imperfect shielding (tiny openings in braid)
- Even small imperfections become more important at higher frequencies
  - No effect on audio
  - BIG effect on RFI

Foil/Drain Shield

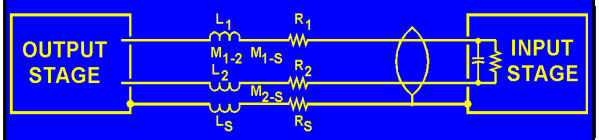
Braid/Drain Shield

Braid/Foil Shield

The drain wire is coupled more closely to the white conductor

So shield current induces more voltage on white than violet

Inductive Imbalance



- Below about 5 MHz, most shield current in a foil/drain shield flows in the drain wire
- As a result of cable construction, the drain wire couples more closely to one signal conductor than the other

Primary Coupling Mechanisms

- IR drop couples *shield current* in unbalanced interfaces
- Pin 1 problems couples *shield current* in balanced and unbalanced interfaces
- Cable imbalance couples *shield current* to a balanced signal pair
- ***Minimizing shield current is a key to preventing this noise!***

Technical Grounding

- The primary purpose of *technical grounding* is to minimize the flow of power-related noise currents on the shields of signal wiring, while also providing the *equipment grounding* required for safety
- *Technical grounding* should also provide a suitable reference for cable and equipment shields at radio frequencies

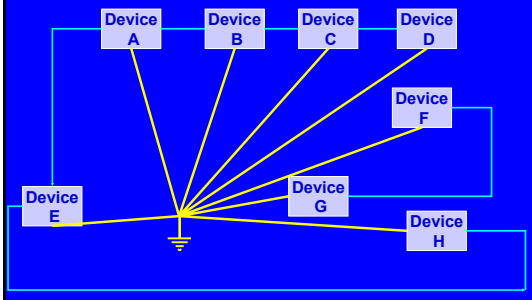
Technical Grounding

- *Isolated Star (Single point)* – The technical system is bonded to system ground only at a single point; equipment is isolated from random contact with ground, and bonded to the breaker panel via a dedicated conductor run with the power conductors
- *Mesh (Multipoint)* – a well controlled grid or mesh is established, all building elements and all technical equipment are bonded to it at every possible point
- *Random* – Use what the power system gives you

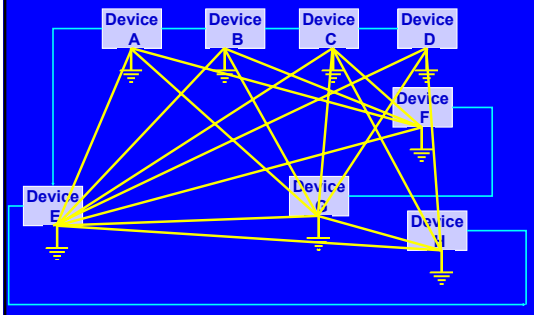
Technical Grounding

- ***Single point grounding*** usually provides the greatest noise immunity at low frequencies (below 3 MHz)
- ***Mesh (multipoint) grounding*** usually provides the greatest immunity at high frequencies
- ***Hybrid grounding*** provides both – cable shields have dc connection at one end, capacitive connection at other end
  - Shield current flows at RF, but not at AF
  - Common mode voltage minimized at inputs

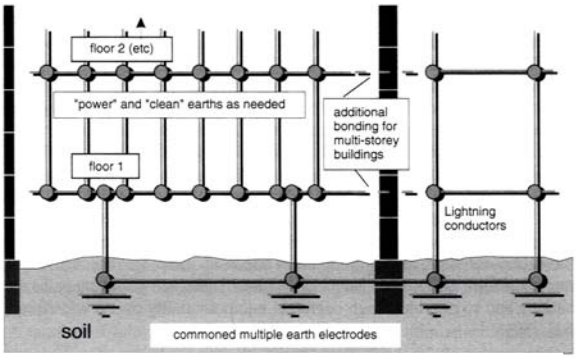
Single Point (Isolated Star) Grounding



Mesh Grounding

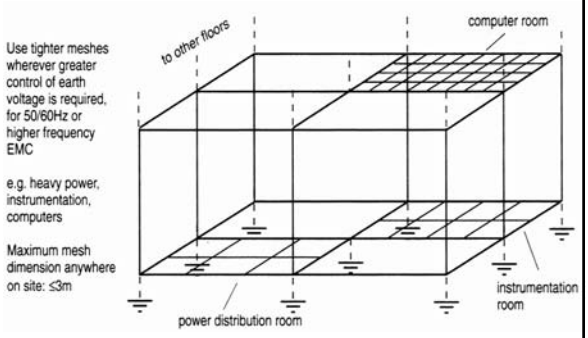


Conceptual Mesh Architecture



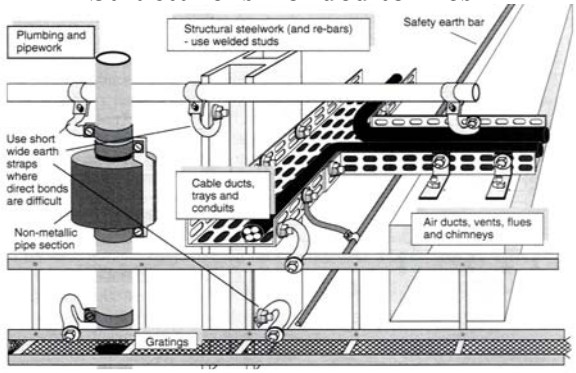
From Williams and Armstrong, "EMC for Systems and Installations" Newnes, 2000

Conceptual Mesh Architecture



From Williams and Armstrong, "EMC for Systems and Installations" Newnes, 2000

Structure is Bonded to Mesh



From Williams and Armstrong, "EMC for Systems and Installations" Newnes, 2000

Single Point Grounding

- Since the technical system has only one connection to other grounds, low frequency current on its ground conductors is limited to:
  - its own leakage currents
  - magnetic induction on loops that include its ground conductors

Single Point Grounding

- Generally far superior for audio systems
- Much less costly than a proper mesh, especially for a retrofit
- Keeps low frequency ground currents away from technical systems
- Principal costs are:
  - Isolated ground outlets
  - Isolated ground conductor to each outlet
  - Isolated mounting of equipment racks, video projectors, wireless mic antennas, etc.

Mesh Grounding

- Since the technical system has many connection to other grounds, low frequency currents on ground conductors divide between many parallel paths, so IR drops are much smaller
- All cables are run in close proximity to grounded structures along their entire length, so induced currents tend to be diverted to those grounded structures

Mesh Grounding

- A good choice for video studios
  - Many copper braid shields
    - Many parallel paths to divide current
    - Video cables have low shield resistance
  - Only one or two audio and video signals are "on the air" at one time, so little coherent addition
- Coherent addition can occur:
  - If there are pin 1 problems (audio or video)
  - If the studio does live production with many live mics and analog distribution at mic level

Mesh Grounding

- A good choice for facilities that handle only digital signals and data
  - No low frequency components of signal, so low frequency noise is easily rejected if system bandwidth is properly limited
- A poor choice for most audio systems and small video systems
  - Baseband noise appears on cable shields and cannot be removed by filtering

Mesh Grounding

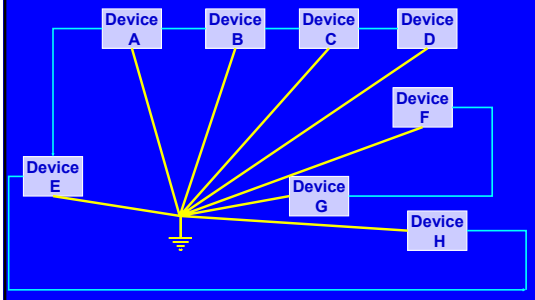
- Mesh grounding is expensive to do properly
  - All structure and conductive elements must be bonded to it
    - Retrofitting impractical
  - A very close-spaced mesh is required for good performance above HF
- While power-related ground currents divide between multiple paths, those currents can be very large, so ground potentials can still be problematic

Isolated Ground Systems

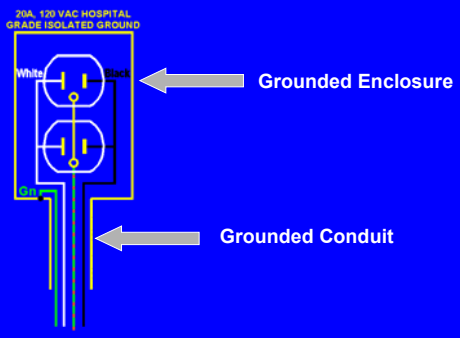
Isolated Ground Systems

- All system elements isolated from ground
  - Racks
  - Interconnecting cables
  - Antennas
  - Cameras
  - Projectors
  - Microphones
- All equipment enclosures bonded to a single grounded point (the "star point")

Single Point (Isolated Star) Grounding



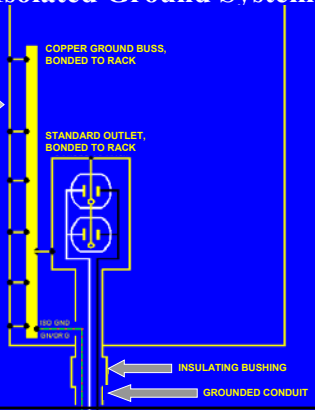
Power Wiring in Isolated Ground Systems



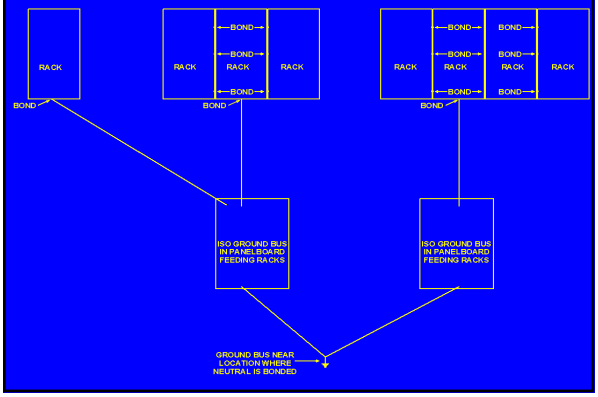
Power Wiring in Isolated Ground Systems

Equipment Rack, Isolated from Grounded Objects

(Concrete is conductive!)



Rack Grounding in Isolated Ground Systems



Signal Wiring

- Isolated Ground Systems
- Mesh Ground Systems

Balanced Line Level Wiring in Isolated Ground Systems

- Cable shields bonded only to equipment enclosure at either end
  - Always bond shield at sending end
  - At receiving end, bond may be omitted, or may be made through a capacitor (hybrid grounding)

Balanced Microphone Level Wiring in Isolated Ground Systems

- Cable shields bonded only to equipment enclosure at both ends
  - Shield continuity required for phantom power

Wiring Panels in Isolated Ground Systems

- Isolate cable shields from wiring panels
  - Wiring panels should be bonded to building structure via the conduit system
  - A connection to building structure would violate the isolation
  - Use plastic body connectors, insulating spacers
  - Use insulating feedthru connectors for RF, video
- Cable shields may be connected to building structure with a capacitor (hybrid grounding)
  - Almost never a good reason for doing this

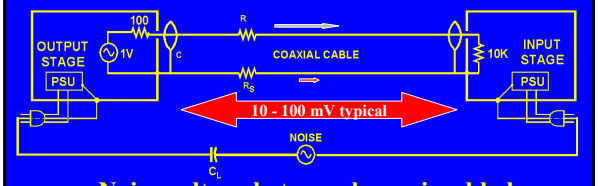
Equipment in Isolated Ground Systems

- Isolate equipment from building structure
  - Racks
  - Mixing Equipment
  - Projectors
  - Cameras
  - Antennas
- Use Isolated Ground Power for all equipment
  - Equipment properly grounded by IG wiring

Local Bonding

- Reduces Noise Between Equipment
  - Reduces Noise on Unbalanced Wiring
  - Less Current to Excite Pin 1 Problems
- Can improve all types of technical ground systems

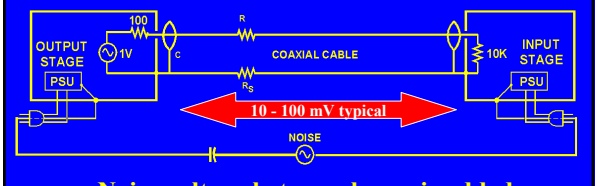
The Problem with Unbalanced Interfaces



Noise voltage between boxes is added to the signal.

- So we have 1v signal (on peaks) and 10mV – 100 mV of noise
- Average value of speech is 10 dB below peak
  So only 10dB - 30 dB S/N ratio!

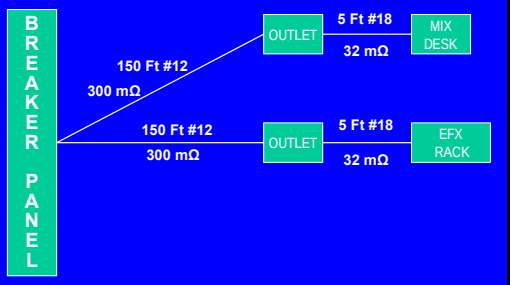
The Problem with Unbalanced Interfaces



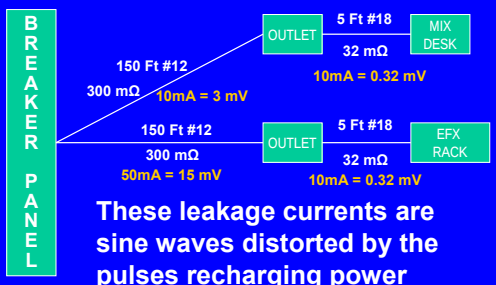
Noise voltage between boxes is added to the signal.

- Reduce the noise voltage between boxes!
- This noise voltage also excites pin 1 problems!

Power System Ground Wiring (The "Green Wire")

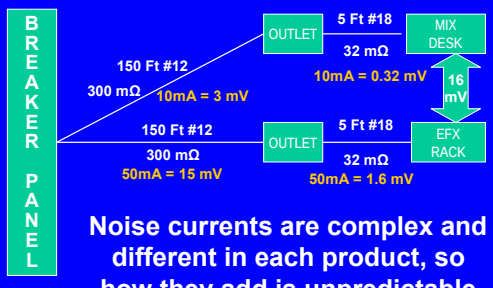


Power System Ground Wiring (The "Green Wire")



These leakage currents are sine waves distorted by the pulses recharging power supply filter capacitors!

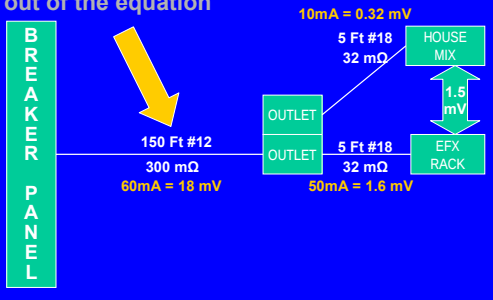
Power System Ground Wiring (The "Green Wire")



Noise currents are complex and different in each product, so how they <u>add</u> is unpredictable

Local Bonding Step #1

Take the largest component out of the equation



Local Bonding Step #1

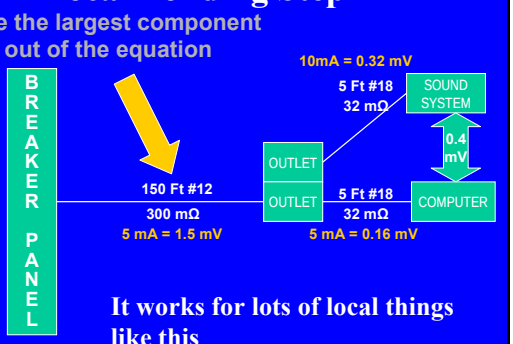
- This reduces the voltage between outlets to a few microvolts
- What's left are the IR drops on line cords within your racks and mix position
- Step #1 is typically good for 20 dB

Local Bonding Step #1

- Put all power outlets for the mix position in portable quad boxes that are bonded together
  - A 20A circuit can run almost any mix position
  - If you need more outlets, bolt multiple quad boxes together

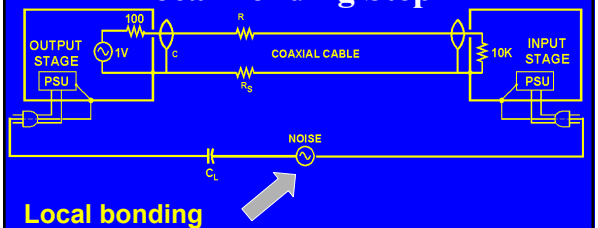
Local Bonding Step #1

Take the largest component out of the equation



It works for lots of local things like this

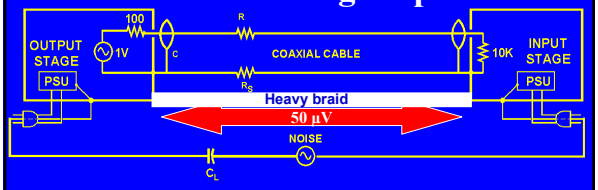
Local Bonding Step #1



Local bonding step #1 reduces this voltage, but not enough

So we need step #2

Local Bonding Step #2

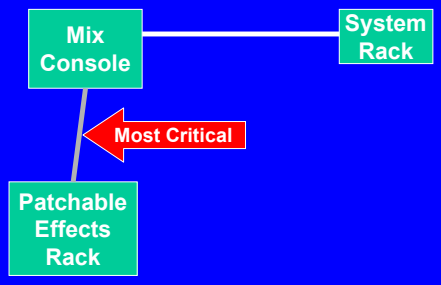


- Short out the remaining noise (or reduce IR drop) by adding a BIG conductor between the equipment enclosures
- 50µV would yield 76 dB S/R ratio
- 5µV would yield 96 dB S/R ratio

Local Bonding Step #2

- Bond all interconnected equipment together with heavy copper braid
- In our Mix Position example
  - Mix Desk to Signal Processing
  - Signal Processing to Signal Processing
  - Mix Desk to Equipment Patched to Inserts

Equipment Bonding – A House Mix Position



Guidelines For Local Bonding

- Add bonding in parallel with every unbalanced audio path
- Bonding should be #6 copper or larger
  - Buy braid from ham radio vendors
  - Copper braid stripped from transmitting coax (RG8, RG11, RG213, RG214) is #10 AWG
  - Multiple #10 THHN stranded conductors are OK, but stiffer
- Bond to chassis of equipment
  - Retaining screw of D-connector on laptops

Guidelines For Local Bonding

- Noise reduction = 20 log (R_2/R_1)
- -6 dB for cutting resistance in half!
  - Double the conductor size = -6 dB
  - Half the length = -6 dB
- Think BIG and SHORT!
- Take advantage of conductive racks

Bonding Equipment

- Take advantage of the racks
- Bond equipment to bare steel rack rails
- Steel is plenty good enough IF it is bonded together and IF equipment makes good contact with it
- Paint will defeat bonding!
  - At equipment mounting screws
  - Rack assembly screws
- If in doubt, add SHORT copper braid from chassis to chassis

When There's No Metal to Bond To

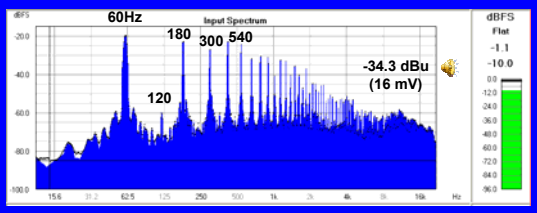
- Power that unit from a good DC power supply and bond the chassis of the supply
- Bond to a D-connector retaining screw

Local Bonding Only Works Locally

- Bonding must have very low resistance
  - That means very short bonding conductors!
  - +6dB noise for doubling of length
- 10 ft is a practical limit for #6 conductors
- Use proportionally larger conductors for longer runs
  - #3 for 20 ft
  - #0 for 40 ft
  - Or use multiple conductors in parallel

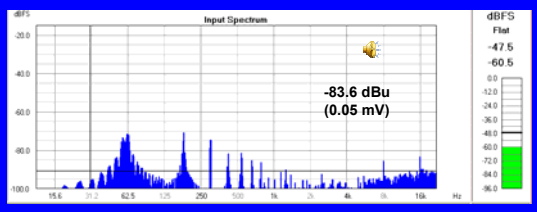
How Well Does This Work?

We Started With This



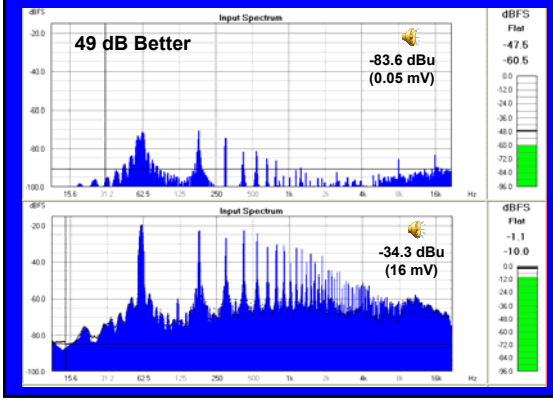
Measured between equipment with no bonding

Noise Spectrum on "Ground" After Bonding



Measured between equipment with only heavy braid bonding it together

Noise Reduction From Bonding



A Portable Isolated Ground System

- Put all power outlets for the mix position in portable quad boxes that are bonded together
  - A 20A circuit can run almost any mix position
  - Get that circuit from the amp rack!
  - If you need more outlets, bolt multiple quad boxes together
  - Do not bond these to ground locally
  - This ground for the mix position is the ground carried from the amp rack!

A Portable Isolated Ground System

- Put all power amps in racks that are bonded together
- Get all the power for your system from outlets connected to the same "green wire"
- Feed power from the amp racks to the house mix (and the monitor mix)
- Isolate the rack from ground (the building)
- Bond the rack(s) to ground using the power system green wire(s)

Shielding and Grounding

- Shielding and grounding are often confused
- This class is not really about shielding, but we'll talk about it a bit as a **BONUS!**

Fields and Shielding

- When there are no wires in common between the noise source and the victim system, noise coupling can occur by means of a *field*.
- Coupling by fields can be just as strong as (or stronger than) coupling by a direct connection

Fields

- Magnetic field
  - Surrounds a wire carrying current
- Electric field
  - Force (voltage) between two charged conductors
- Electromagnetic field (radio wave)
  - Combination of magnetic and electric fields at right angles to each other
- Virtually all power-related fields are magnetic

Magnetic Field

- Produced by current flowing in a wire
  - Could be part of a motor, a transformer, or just wiring that makes up a power system
  - Strength proportional to current
  - Strength proportional to loop area
- Change in field induces voltage in a wire passing through the field (inductive coupling)
  - Current will flow in that wire if there is a complete circuit
  - Strength proportional to loop area
  - Strength falls off with distance

Reducing Magnetic Field Interference

- Minimize the loop area (both source and victim)
- Increased distance between source and victim
- Use balanced wiring with twisted pairs
  - Source or victim or both (additive)
- Use coax with beefy copper shield if you must run unbalanced
- Shield with a magnetic material (steel, mumetal)
- **Cable shields provide no magnetic shielding**

Electric Field

- Produced by voltage between two conductors
  - Mostly confined to the space between them
- Induces voltage onto a conductor in or near that space (capacitive coupling)

Electromagnetic Field

- Produced by antennas carrying RF current
  - Travels through space
  - Follows inverse square law
- Coupled to our wiring by antenna action
  - That is, our wiring acts as a receiving antenna

Reducing Electric and Electromagnetic Field Interference

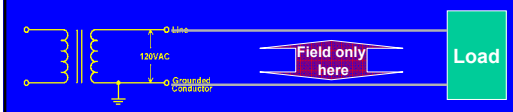
- Increase the distance between source and victim
- Use balanced wiring with twisted pairs
- Use coaxial cable with high % coverage shield
- Shield the equipment and the wiring
  - Cable shields DO work on Electric and Electromagnetic fields

Magnetic Field Noise Sources

- Conductors carrying large currents
  - Power system feeders
  - Lighting system wiring
- Transformers
- Motors
- Especially variable speed drive motors
  - HVAC systems
  - Elevators
  - Geothermal systems

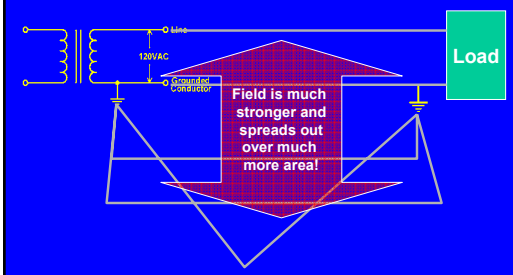
A Double-Bonded Neutral Creates An Interfering Magnetic Field

Fields with Single-Bonded Neutral



- Field mostly confined to the very small area between conductors – that is, within the conduit

Fields with Double-Bonded Neutral

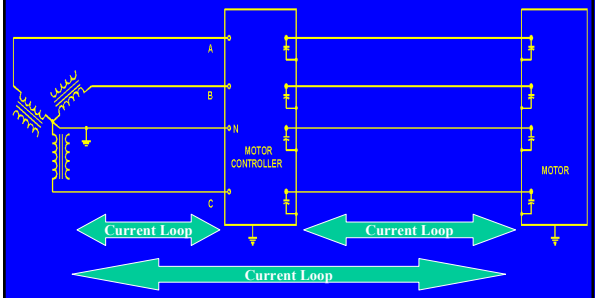


- Fields may engulf large areas of a building!

Magnetic Fields "On the Loose"

- Couple noise currents onto any conductors within the field
  - Audio cables
  - Video cables
  - Control cables
  - Computer interface cables
  - Single coil guitar pickups
  - Dynamic mics without hum-bucking coils

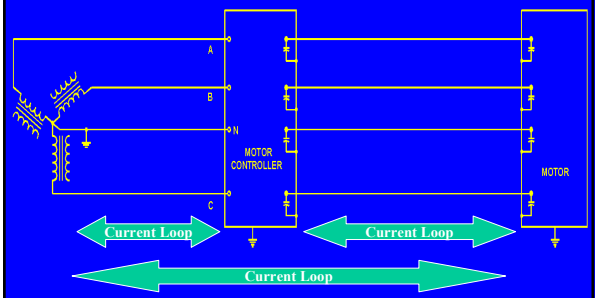
Variable-Speed Drive Motors



Variable Speed Drive Motors

- Operates by chopping DC into a variable width pulse
  - 10-20 kHz typical switching frequencies
  - Harmonics extend to hundreds of kHz
- Stray capacitance (and filter capacitors) between motor and earth causes very large currents to flow on earthed structure
  - Establishes a very large current loop
- Controllers often widely separated from motors to make installation easier

Variable-Speed Drive Motors



Variable Speed Drive Motor Solutions

- Minimize the size of the current loops
  - Locate transformer, controller, and motor in closest possible proximity to each other
  - Transformer should have delta primary, wye secondary, bonded very close to motor
    - Prevents feeders to transformer from being part of the current loop
  - Twist neutral and phase conductors

Reasons for Using Conduit

- Physical protection of wiring
  - Reduces long term maintenance costs
- Make installation (and upgrades) easier
- Shielding

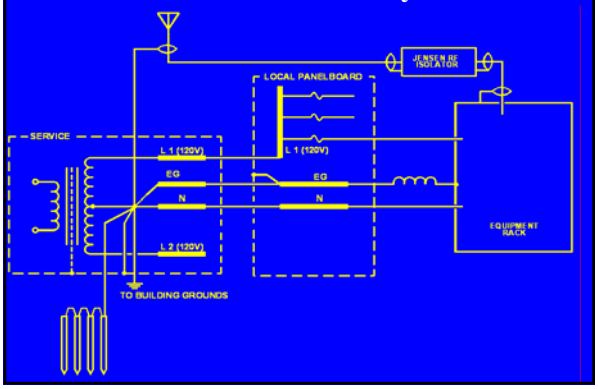
Conduit and Shielding

- Electric field
  - Continuous and conductive
- Magnetic field
  - Continuous and ferrous material (steel)
- Steel conduit is the only practical magnetic shielding for our wiring
- *Continuous* includes any junction boxes and couplings in the path

Antenna and Cable Systems

- Should enter the building near the power system earth bond and should be bonded to it by the shortest possible path
- Bond should be outside the building if possible
- Add isolator inside the building after the bond (to avoid audio ground loops)

Antenna and Cable Systems



Telephone Lines

- They are a common lightning target, so need a good arrester and short bond to the building bonding point
- Poor bonding is common
- Lightning doesn't know the installer was in a different trade union or covered by a different national safety code

Troubleshooting Tools

- Ammeters
  - Current Probes
- Volt-Ohmeter
  - Low Ohms Scale Important
- Magnetic Field Probe
- Radio Receiver
- Headphone Amplifier
- Battery Powered Scope

Snake Oil and other Bad Medicine

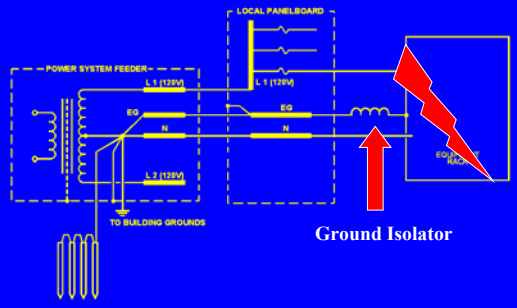
Ground Lifts – Bad Medicine

- Breaks equipment ground path
- Prevents breaker from blowing if chassis becomes "hot"
- **Can KILL someone**

Ground Lifts – Bad Medicine

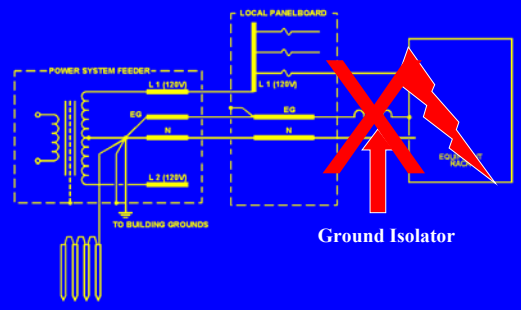
- Breaks equipment ground path
- Prevents breaker from blowing if chassis becomes "hot"
- **Can KILL someone**

Ground Isolators – Bad Medicine



Inductance delays breaker action, someone can die before it blows!

Ground Isolators – Bad Medicine



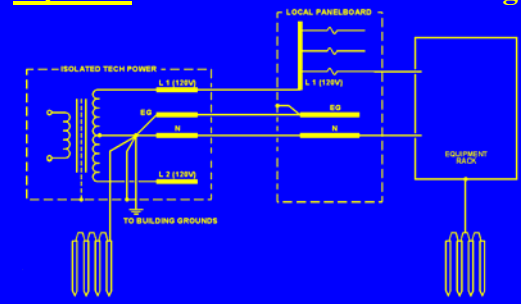
Ground Isolator

Inductance can delay breaker action, someone can die before it blows!

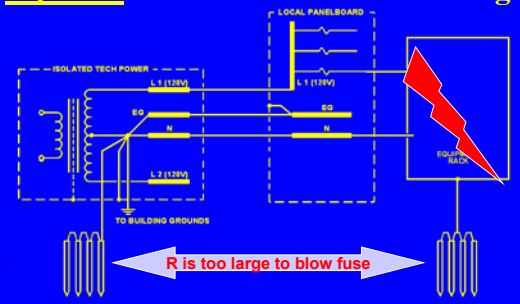
All Ground Electrodes Must be Bonded Together

- Isolated does not mean "separated"

Separate Ground is Unsafe and Illegal

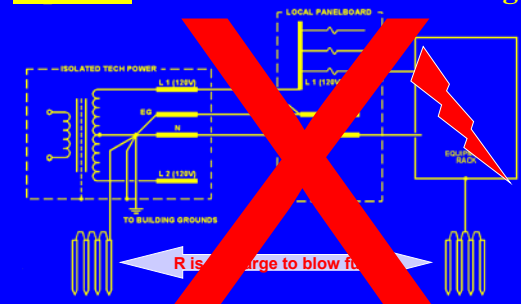


Separate Ground is Unsafe and Illegal



All ground electrodes must be bonded together

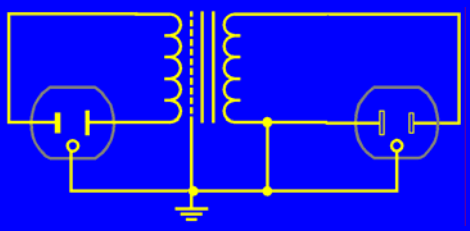
Separate Ground is Unsafe and Illegal



All ground electrodes must be bonded together

Power Isolation Transformer

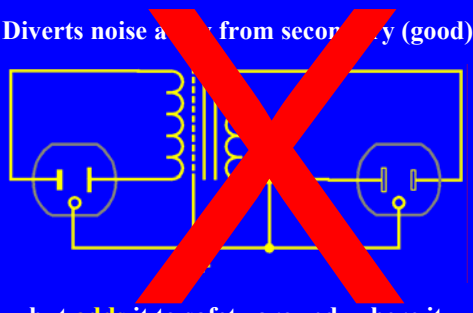
Diverts noise away from secondary (good)



but adds it to safety ground, where it increases leakage currents (bad)

Power Isolation Transformer

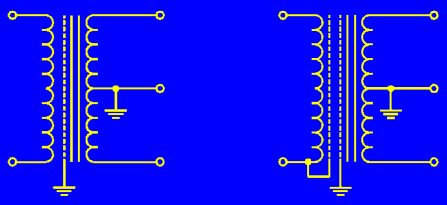
Diverts noise a[illegible] from secon[illegible]y (good)



but **adds** it to safety ground, where it increases leakage currents (bad)

Power Isolation Transformer

Use a good one <u>only</u> to establish the technical power system, but not downstream



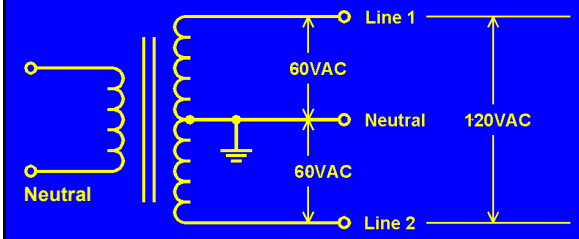
Single Faraday Shield Two Faraday Shields

Ralph Morrison, *"Grounding and Shielding Techniques"*

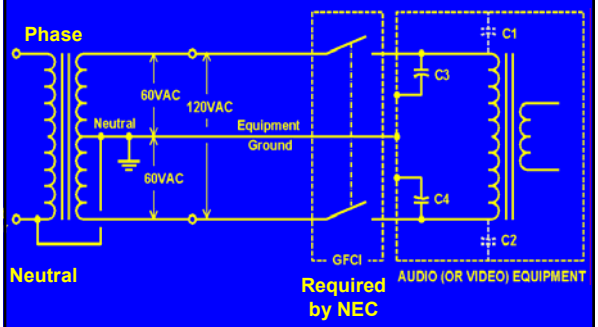
"Balanced" Power

- *Symmetrical* power <u>seems</u> like a good idea
  - 120-volts between two 60-volt legs
  - In ideal world, it would completely <u>cancel</u> leakage currents into safety ground system
- But not in the <u>real</u> world
- Predicted benefits based on false assumptions

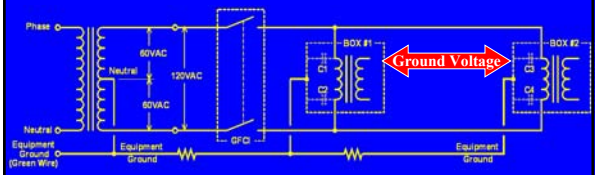
"Balanced Power"



Balanced Power per NEC



"Balanced Power"

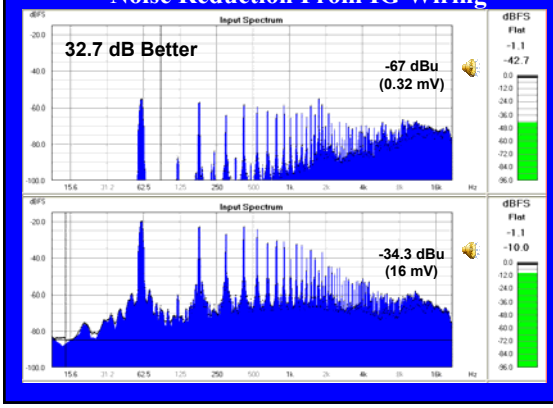


- Ground voltage (and leakage current) are zero <u>only</u> if C1 = C2, C3 = C4, etc.
  - Real world imbalances typically 3:1
  - Real improvement 20log (60/120) = 6 dB + 3 dB for mild cancellation (9-10 dB total)

"Balanced Power"

- Actual noise reduction generally under 10 dB and rarely exceeds 15 dB
  - May be cost-effective in certain video applications (video is far less demanding than audio)
- Isolated ground systems can provide more than 30 dB noise reduction
  - And IG systems are a lot less expensive
- Local bonding can provide an additional 20-40 dB noise reduction

Noise Reduction From IG Wiring



Balanced Power – A Field View

- With ordinary un-balanced power, fields from "hot" and neutral currents cancel at any reasonable distance from the wiring.
  - Balanced power does not improve on that.
- With ordinary un-balanced power, an unbalanced field exists between phase (hot) and neutral, but this field also falls off quickly with distance
  - Balanced power balances that field. BUT:
  - Power system noise is coupled by magnetic fields, not electric fields!

Snake Oil – Exotic Power Cords

- Branch circuit wiring typically 75 ft of #14
  - 1.13 volt drop with 3A load
  - 3.78 volt drop with 10A load
- Common IEC power cord is 6 ft of #18
  - 0.23 volt drop with 3A load
  - 0.77 volt drop with 10A load
- Total voltage drop
  - 1.46 volts (118.54 V at outlet) with 3A load
  - 4.55 volts (115.45 V at outlet) with 10A load

Snake Oil – Exotic Power Cords

- Branch circuit wiring typically 75 ft of #14
  - 1.13 volt drop with 3A load
  - 3.78 volt drop with 10A load
- Unobtainium power cord 6 ft of #12
  - 0.057 volt drop with 3A load
  - 0.19 volt drop with 10A load
- Total voltage drop
  - 1.19 volts (118.81 V at outlet) with 3A load
  - 3.97 volts (115.03 V at outlet) with 10A load

Plain Ordinary Copper

- Change branch circuit wiring to #12
  - .715 volt drop with 3A load
  - 2.38 volt drop with 10A load
- Common IEC power cord 6 ft of #18
  - 0.23 volt drop with 3A load
  - 0.77 volt drop with 10A load
- Total voltage drop
  - .945 volts (119.05 V at outlet) with 3A load
  - 3.15 volts (116.85 V at outlet) with 10A load

About Surge Suppression

- Mindless use of MOV suppressors can actually increase equipment damage risk
- MOV's are shunt-mode devices that divert surges onto the equipment ground system
- Surges generate brief but extreme voltage differences in the safety ground system
- Equipment interfaces are often damaged

How MOV's Cause Failures

- An MOV between phase and equipment ground raises the equipment ground to a very high voltage at the point where is is connected
- Another MOV between phase and equipment ground at a different outlet raises the equipment ground at that outlet to a different very high voltage
- If equipment plugged in at these locations is interconnected by low voltage wiring, it will see the difference of the two high voltages.

MOV's Often Fail Destructively

- MOV's are sacrificial – they fail after they have conducted a certain number of joules!
  - They often short, and blow a fuse
  - They often open, and give no indication of failure
  - They may partially degrade, losing their ability to conduct the surge
  - On a sufficiently high voltage surge, they can explode
  - And they can catch fire!
- But they are cheap, so they're everywhere!

A Good Use for MOV Suppressors

- Use professional-grade unit at the service entrance to protect an entire building
- MOV's divert surge to the main building common ground bonding point
- The ground reference for the entire building goes up with a surge
- Minimizes likelihood of equipment damage because gradients between grounds exist only due to the lightning field, not due to pollution of equipment ground

What the UL Label Means

- Nearly all UL testing is for safety
  - Fire, flame spread, noxious fumes
  - Electrical shock hazards
- Surge suppressors are usually listed under UL 1449 and tested only for safety (that is, to verify that they won't start a fire)
- The effectiveness of surge suppressors is verified by adjunct testing under UL 1449
  - Very few products are adjunct tested
  - Few would pass

Real Surge Protection

- To protect from lightning induced surges, install devices at main power service entry
- To protect sub-circuits or equipment, use series-mode suppressors
  - Presents a *high impedance* to the surge
  - Does not dump current into safety ground

Series-Mode Suppression

- Stores the surge in reactive components, then discharges it slowly back onto the line
- Not cheap ~ $250 - $500/branch circuit

NEMA Boxes

Rack Mount

"Brick"

Power and Grounding for Audio and Video Systems Part 2

Jim Brown
http://audiosystemsgroup.com
Andy Benton
http://www.surgex.com