Power, Grounding, Bonding, and Audio for Ham Radio

Safety, Hum, Buzz, and RFI

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Don’t Bother Taking Notes

- These slides are on my webpage k9yc.com/publish.htm

Grounding Vs. Bonding

- Grounding Is An Earth Connection
  - Lightning and Power Safety
- Bonding is connecting everything together in a controlled manner
  - Lightning and Power Safety
  - Minimizes Hum, Buzz, RFI
- Both must be done right to have a safe and problem-free system

Why An Earth Connection?

- **Lightning Safety**
  - **That's all!**
- **Does not help with RFI**
- **Does not make a transmitting antenna work better**
- **Is required for many low-noise receiving antennas**
- **Is not a "sump" into which bad stuff is poured**

Lightning is NOT a DC Event

- Lightning is an impulse, with most of its energy concentrated in a very broad spectrum roughly centered around 1 MHz
  - Mostly from 100 kHz – 10 MHz
- Above 1 kHz, impedance is dominated by inductance, not resistance

Bonding & Grounding

- In combination, they provide:
  - Lightning Safety
  - Life Safety – Electrical shock
  - Fire Safety
  - Minimize hum, buzz, and RFI

What is The Goal Of Bonding?

- To minimize the potential difference between all equipment in the event of a lightning strike
- The entire building should rise to as nearly as possible the same potential in a strike
- A difference in potential between connected equipment is what causes it to fry!

What is Bonding?

- A Robust, Low Impedance connection between grounds, and between equipment enclosures
  - Low impedance => short, fat
  - Fat => low resistance
  - Short +> low inductance
- No system will be perfect
  - Short and fat makes it better

What Must We Bond?

EVERYTHING!

What Must We Bond?

- Power Service Entry
- Telephone Entry
- Cable TV Entry
- Antenna Entry
- All ground electrodes
- Towers near the building
- Building structural steel
- Grounded metallic plumbing
- Everything in our stations

Everything Must Be Bonded Together

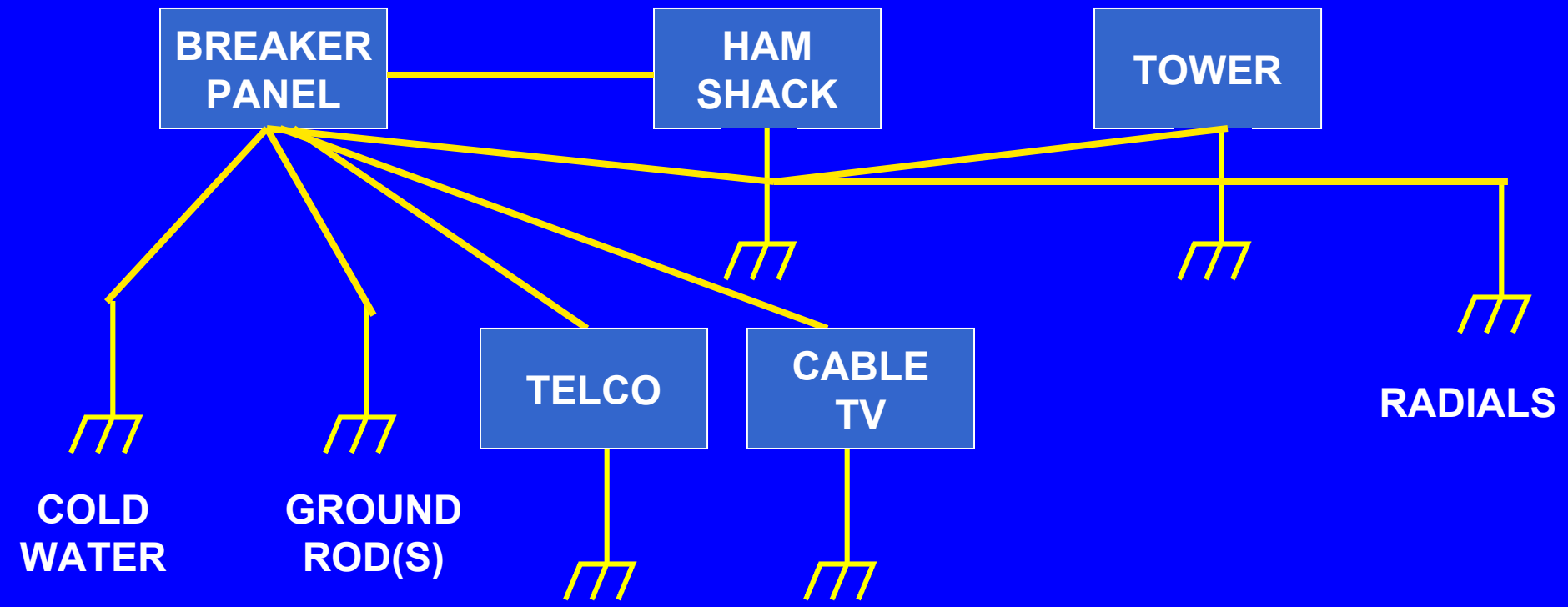
- Separate grounds are illegal and unsafe!

Station Grounding

ALL GROUNDS MUST BE BONDED TOGETHER FOR SAFETY

AND BY LAW!

Bonding All Building Grounds

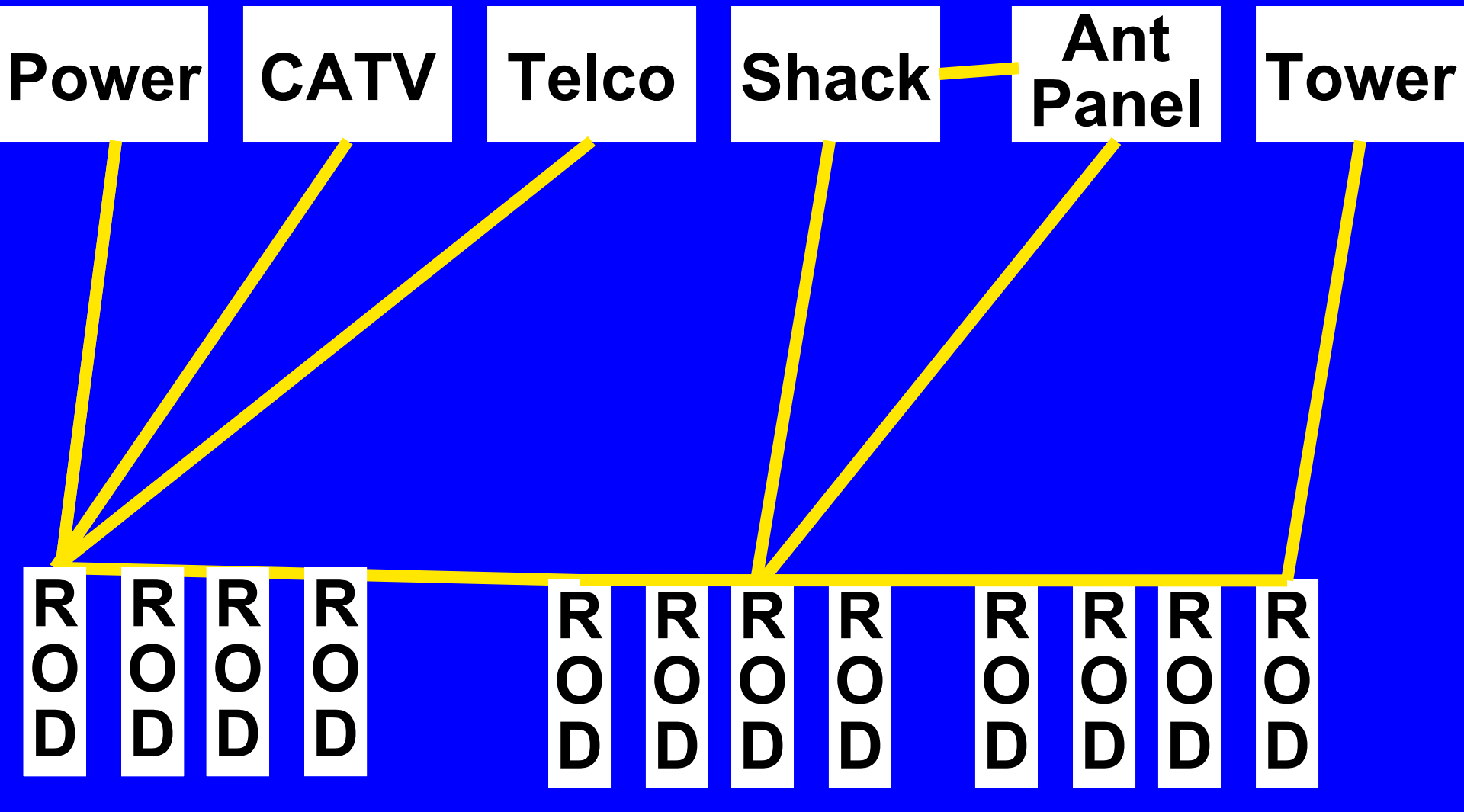


Bonding is for SAFETY

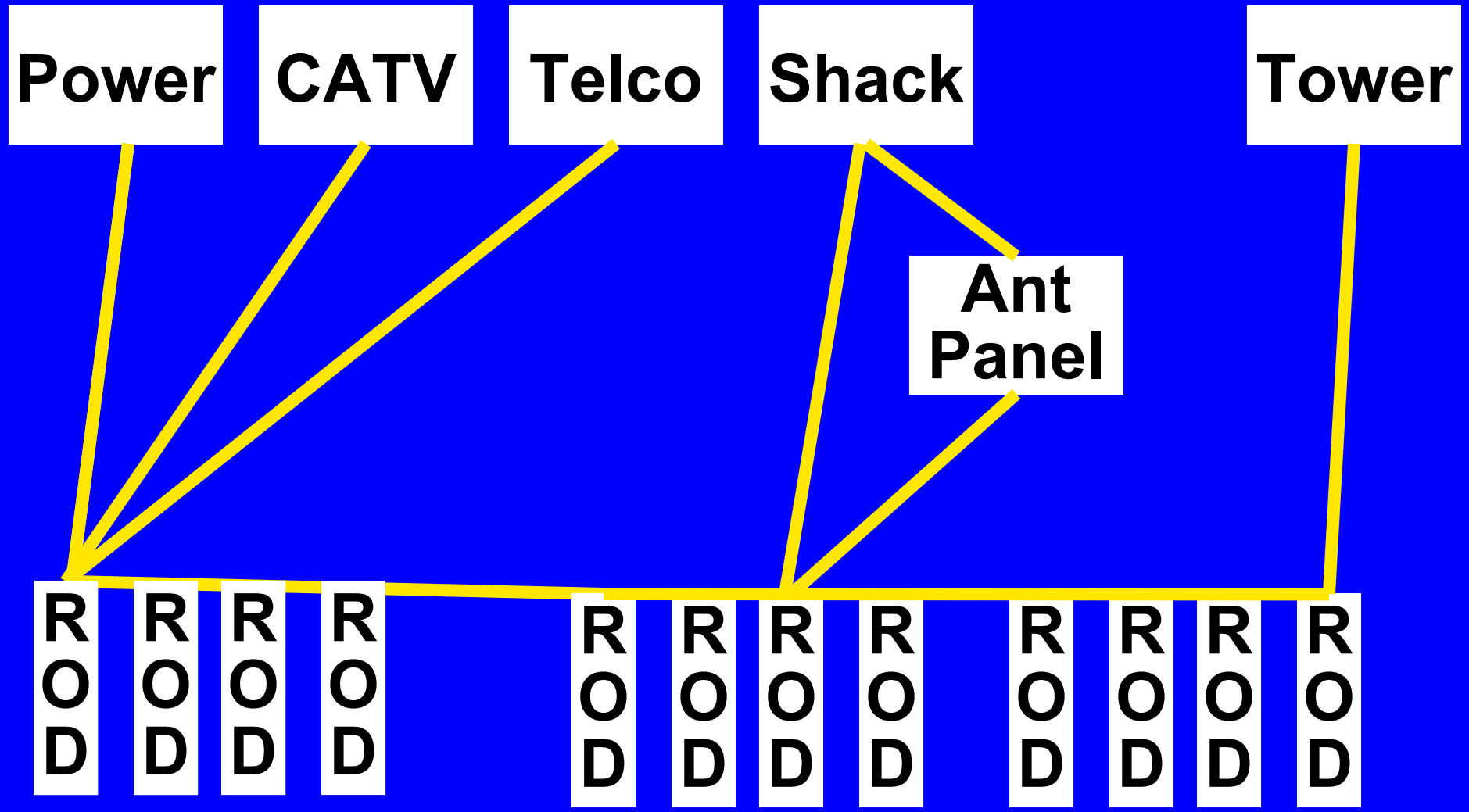
- **Lightning protection**
- **Blows a breaker if a power system short**

Connections should be big copper and short

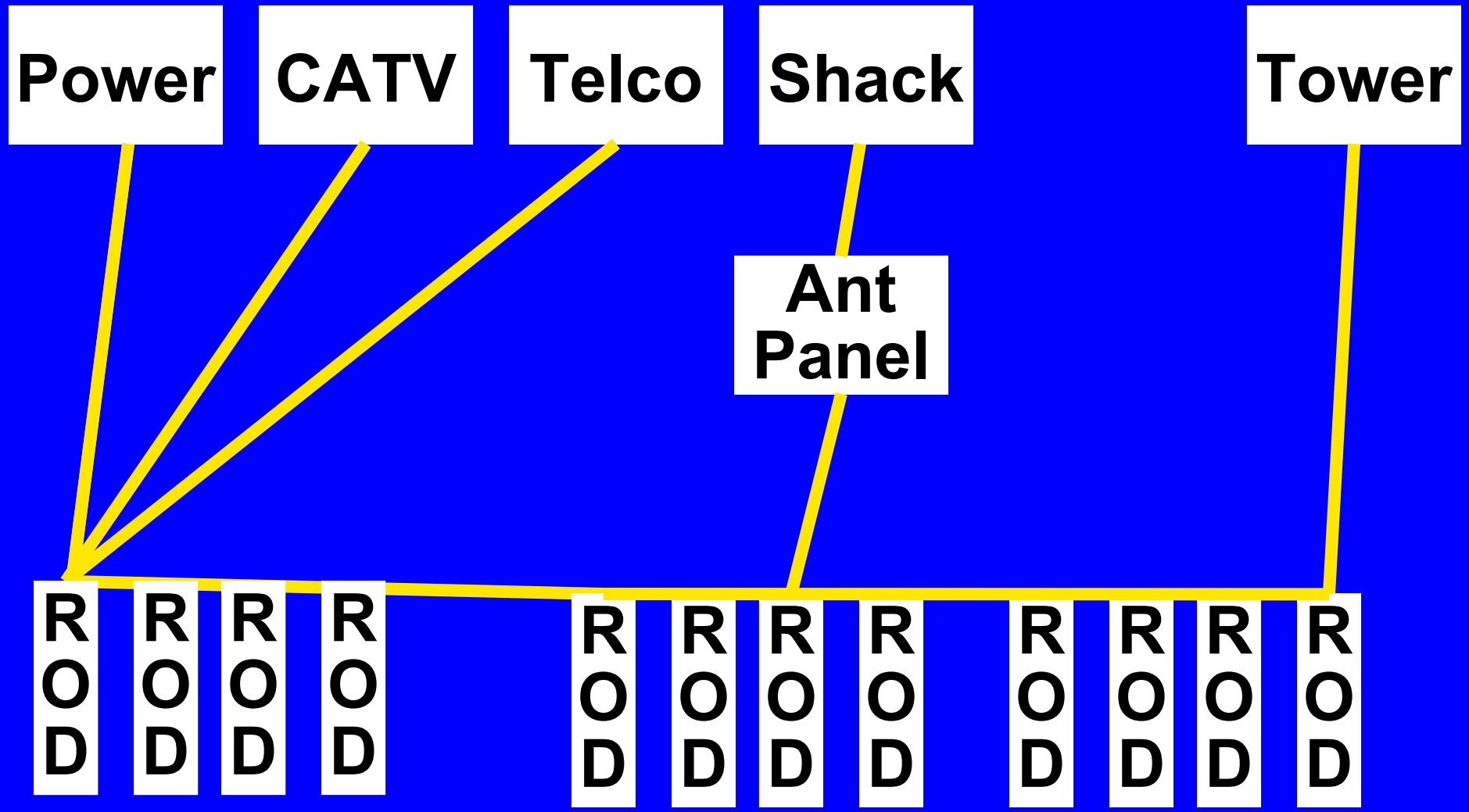
With widely separated use and entry points, consider a perimeter or part-perimeter ground with more rods



Bonding All Building Grounds



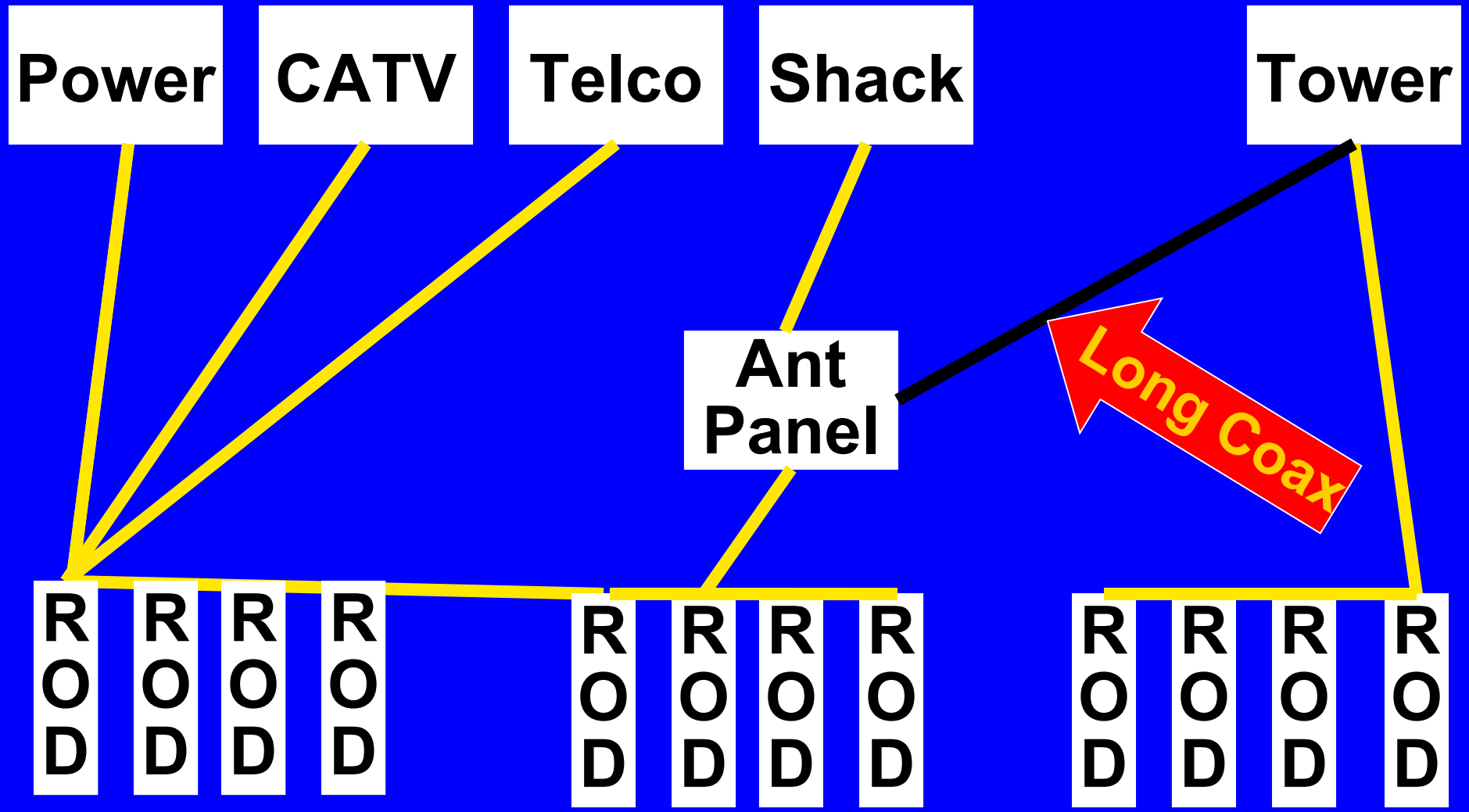
Bonding All Building Grounds



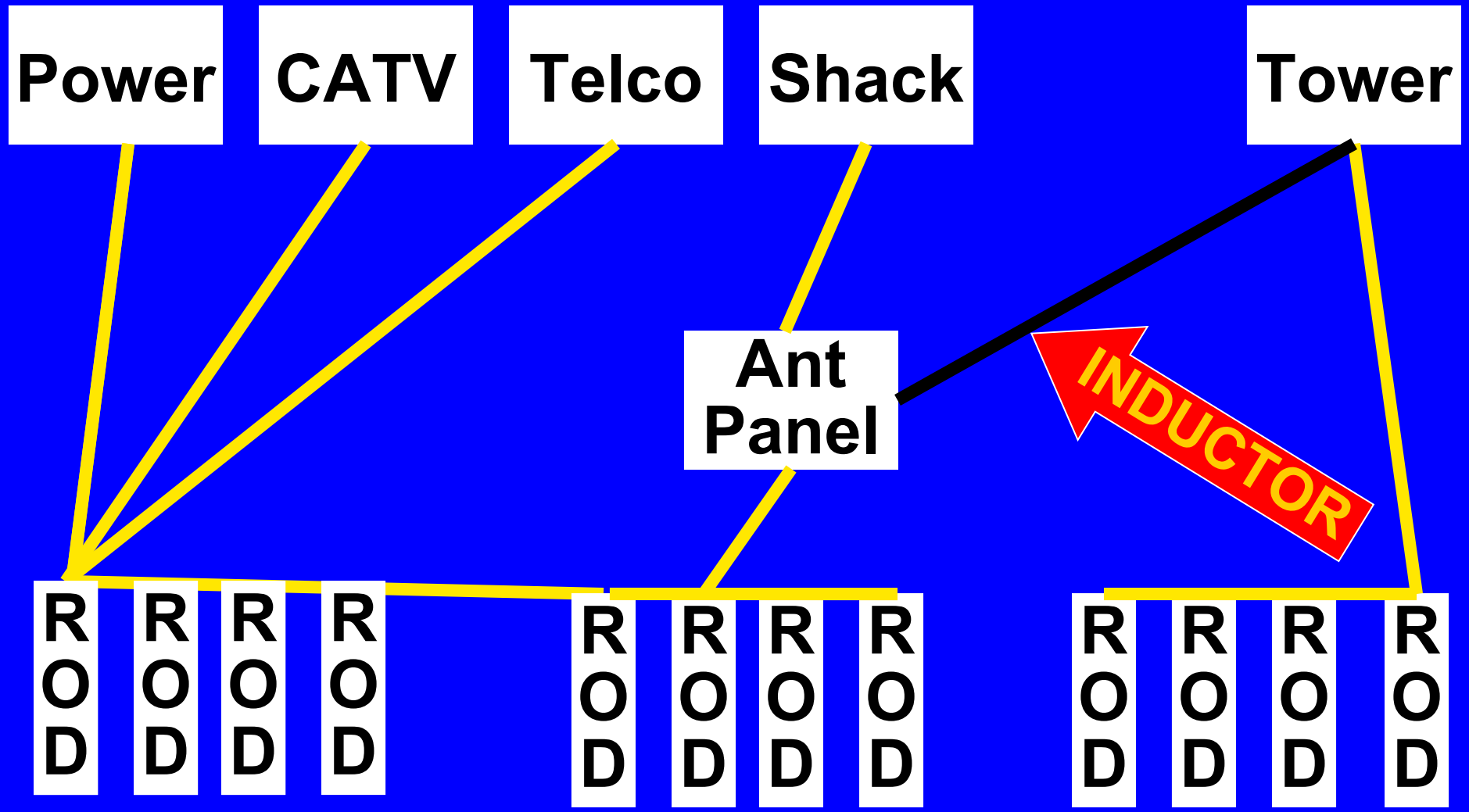
Bonding Tower To House

- If close to the house, tower must be bonded to house ground
- If distant from house, tower should not be bonded to house ground
  - Coax shield will provide inductive connection, so most lightning current will go to tower grounds
  - "Distant" >100 ft cable run from tower base to house (some say 60 ft)

If Tower is Widely Separated



If Tower is Widely Separated



Exception: If 120V or 240V At Tower

- Green wire MUST be run with phase (hot) and neutral conductors from breaker panel to equipment and/or outlet
- Green wire MUST be bonded to tower
- This bonds tower to breaker panel that supplies mains power

Tower Grounding

- Bury copper strap in concrete
- Bond copper strap to rebar cage
- Bond copper strap to tower legs
- Connection to concrete forms a Ufer ground
  - Named for inventor, Herbert Ufer
  - Bonding in concrete must be done properly

Tower Grounding

- Bond each tower leg to at least two buried rods arrayed radially
  - Spacing needed because there is inductance coupling between rods
  - Rods at least 8 ft long (longer is good)
  - Spacing between rods at least equal to their length (greater is better)
  - Same spacing rules for first rod from tower base if Ufer

Feedlines On Towers

- Bond shields to the tower at top and bottom
  - Keeps lines at the same potential as the tower
  - Prevents arc-over between line and tower from lightning
  - Arc-over fries the coax / hard line at points where it occurs
- Run feedline and other cables inside the tower

Bonding Conductors

- Bigger is better
  - At least #6 around tower, to all rods, between rods, rods to building
  - #10 / #12 between equipment in the shack
  - Steel conduit is great if properly installed
  - If steel, bonding conductors must be bonded to it at each end
- Shorter is better
  - Minimizes both R and L

Bonding Conductors

- Tinned copper braid OK indoors
  - Should be in heat shrink
- Do NOT use braid outdoors or in moist interiors
  - Corrodes quickly with moisture
- Henry Ott has shown that the reduced impedance of braid/strap compared to wire is overblown, thanks to skin effect

Bonding Hardware

- Be careful with dissimilar metals
- DX Engineering sells a fixture for bonding copper to steel tower
- This one, made by Harger, is much better

Harger Bonding Clamp

Harger Bonding Clamp

Bonding In The Shack

Why Bond Equipment?

- Lightning and Power Safety
- Lightning protection for equipment
- Kill hum, buzz, and RFI

Shielded Wiring In Our Shacks

- USB, HDMI, RCA, Shielded Ethernet, Video
- Sending CW – computer/keyer to radio
- Control signals to/from radio, amp
  - Rig control and data for logging software
  - Frequency and mode readout, band changes

Shielded Wiring in our Shacks

- Audio between radio and computer
  - Playback voice messages to radio
  - Transmit and decode RTTY, other digital modes
- Mic to radio
- Mic to computer
  - Record messages for contests

Unshielded Wiring In Our Shacks

- Unshielded Ethernet
- RS232

Unbalanced Interconnections

- Many of our interconnections are unbalanced
  - Shield is signal return
  - Shields can also carry power system leakage currents that are added to the signal in unbalanced systems
  - Shields act as receiving antennas for our transmitted RF
  - “Pin One Problems” couple RF inside the box, where it is detected

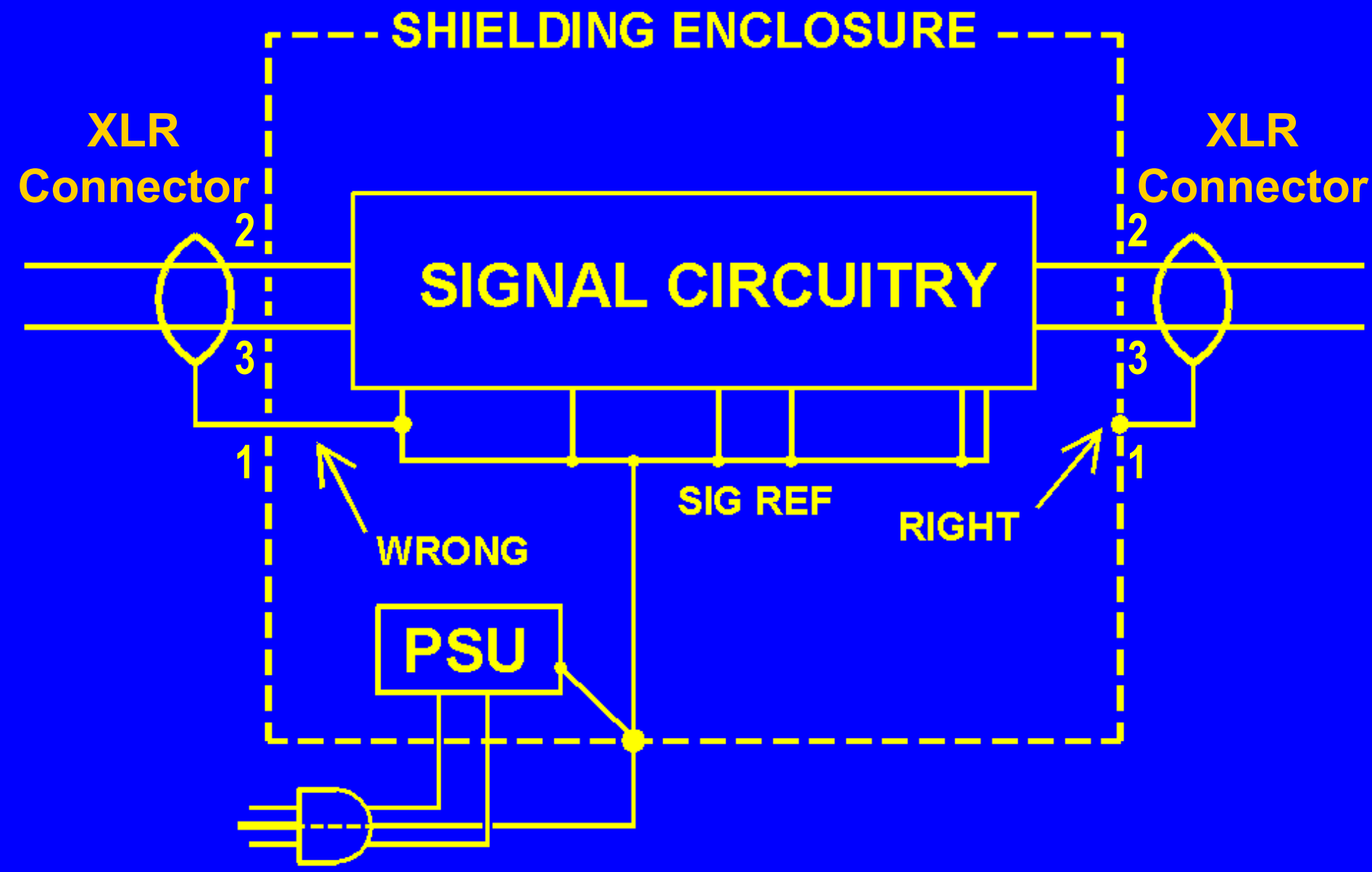
What's A "Pin One Problem?"

- Failure to bond a cable shield to shielding enclosure at point of entry
- Shield goes through hole in enclosure to circuit board
- Shields act as receiving antennas for our transmitted RF
- Shields can also carry power system leakage currents that are added to the signal in unbalanced systems
- Pin One Problems couple RF inside the box, where it is detected

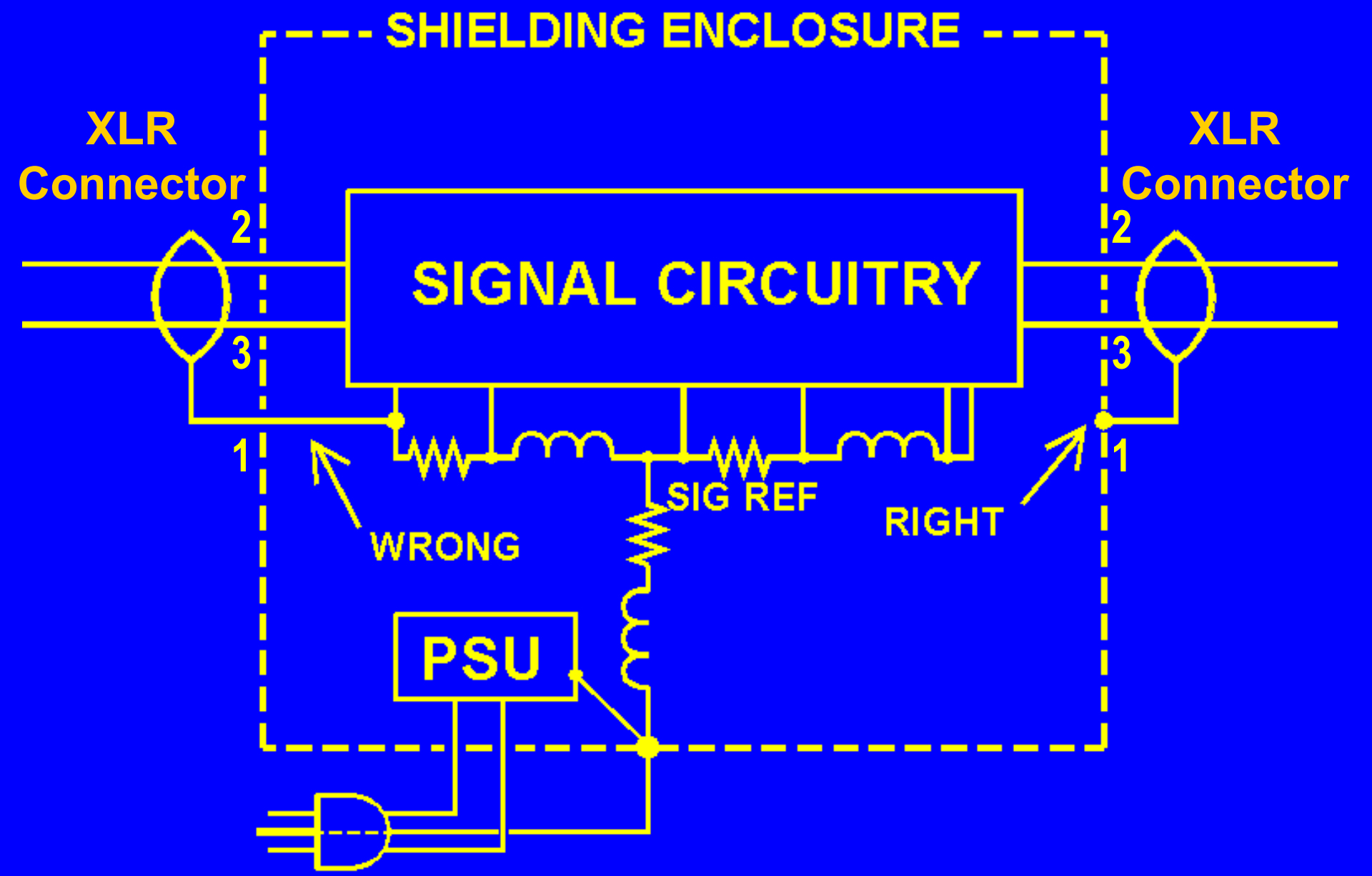
Why is called a “Pin One Problem?”

- It was discovered by a ham working in pro audio (Neil Muncy, W3WJE, SK)
- 3-pin XLR connectors are used for mics, other interconnects
- Cables are shielded twisted pairs
- Pins 2 and 3 carry the signal
- Pin 1 is the cable shield

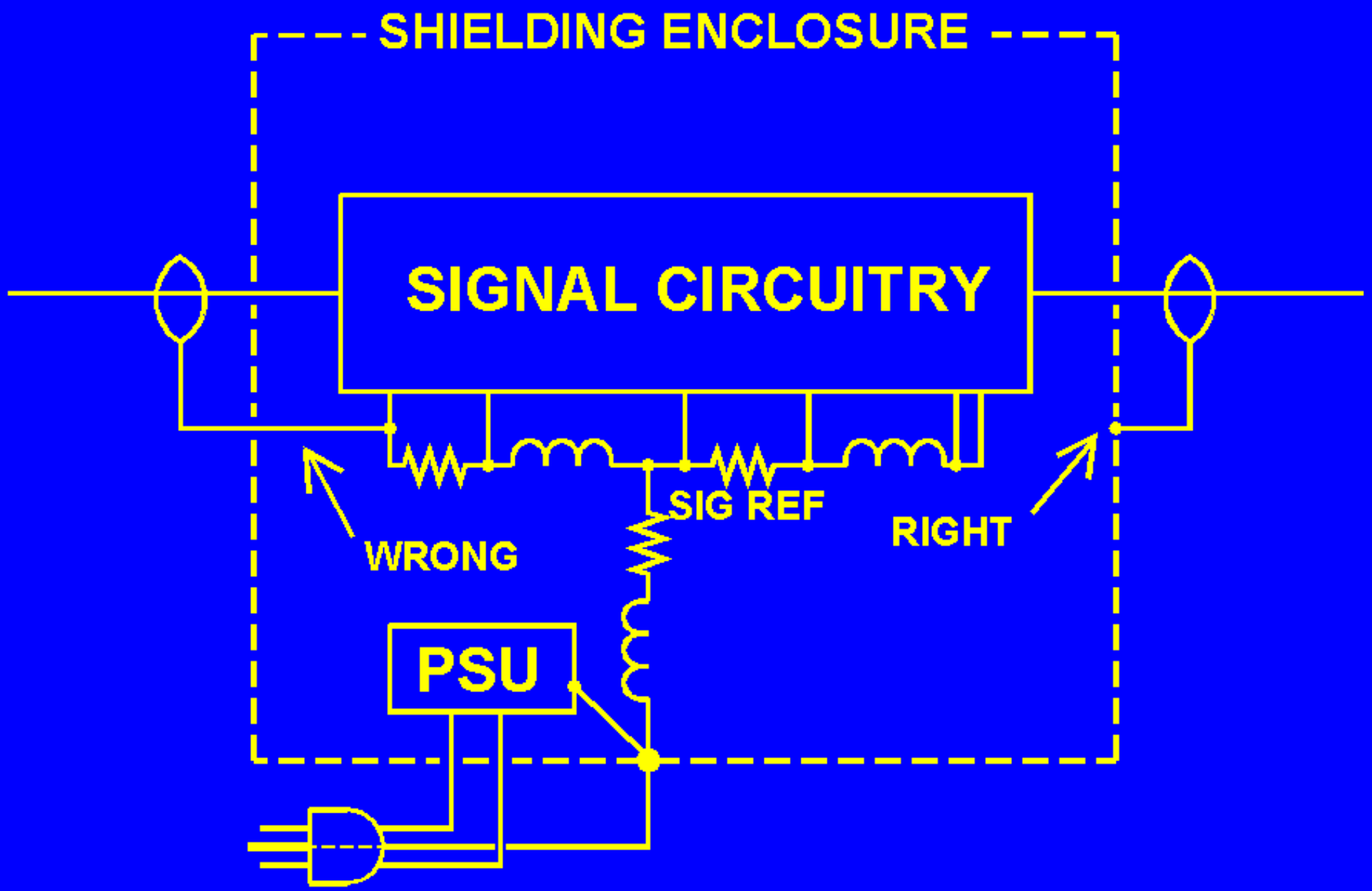
Pin 1 Problem in Balanced Circuits



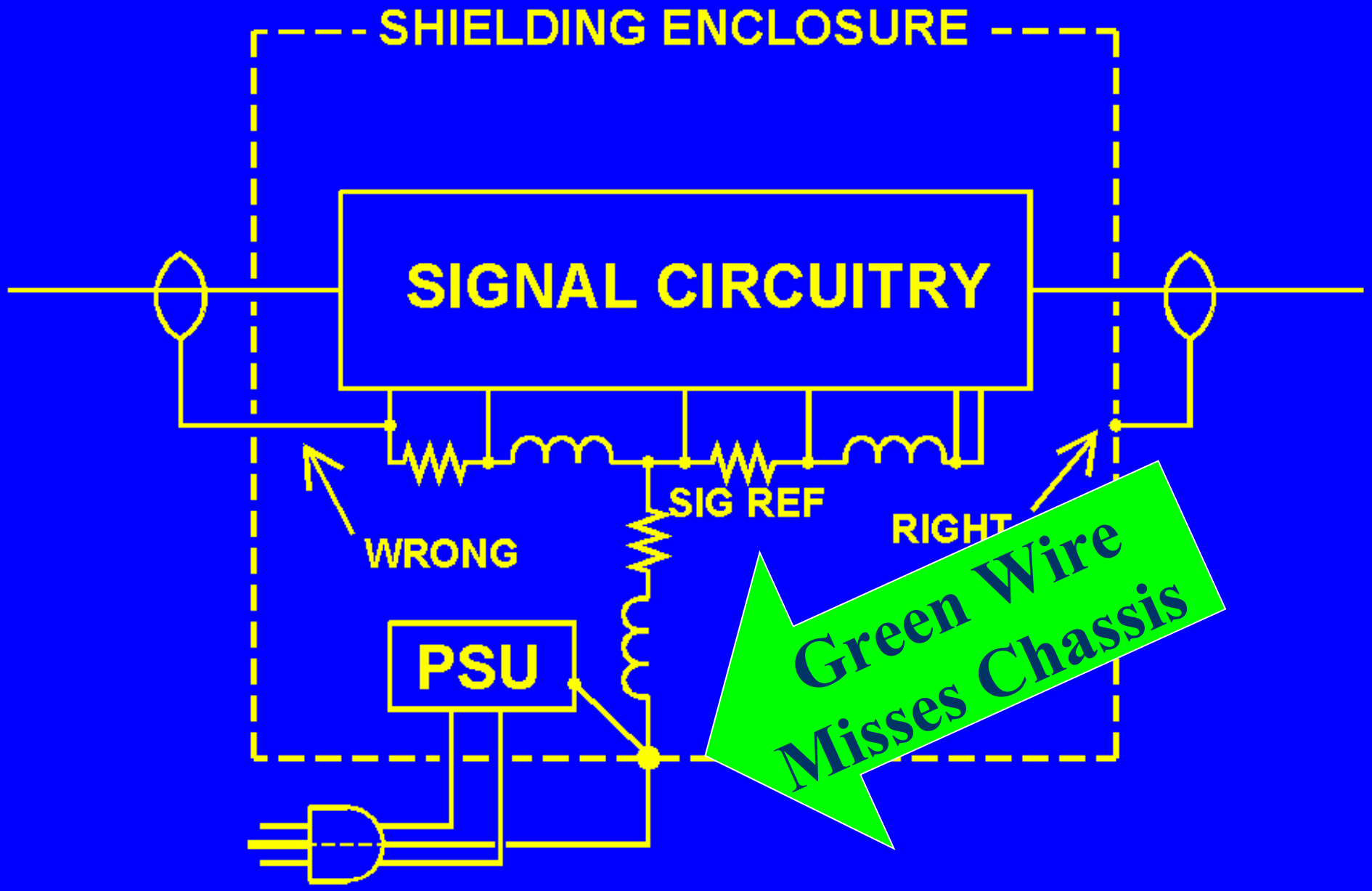
Pin 1 Problem in Balanced Circuits



“Pin 1” in Unbalanced Circuits



"*Green Wire*" Pin One Problem



Most RFI is caused by Pin 1 Problems!

That Includes “RF in the Shack,” AKA “RF Feedback!”

Nearly All Equipment Is Built With Pin 1 Problems

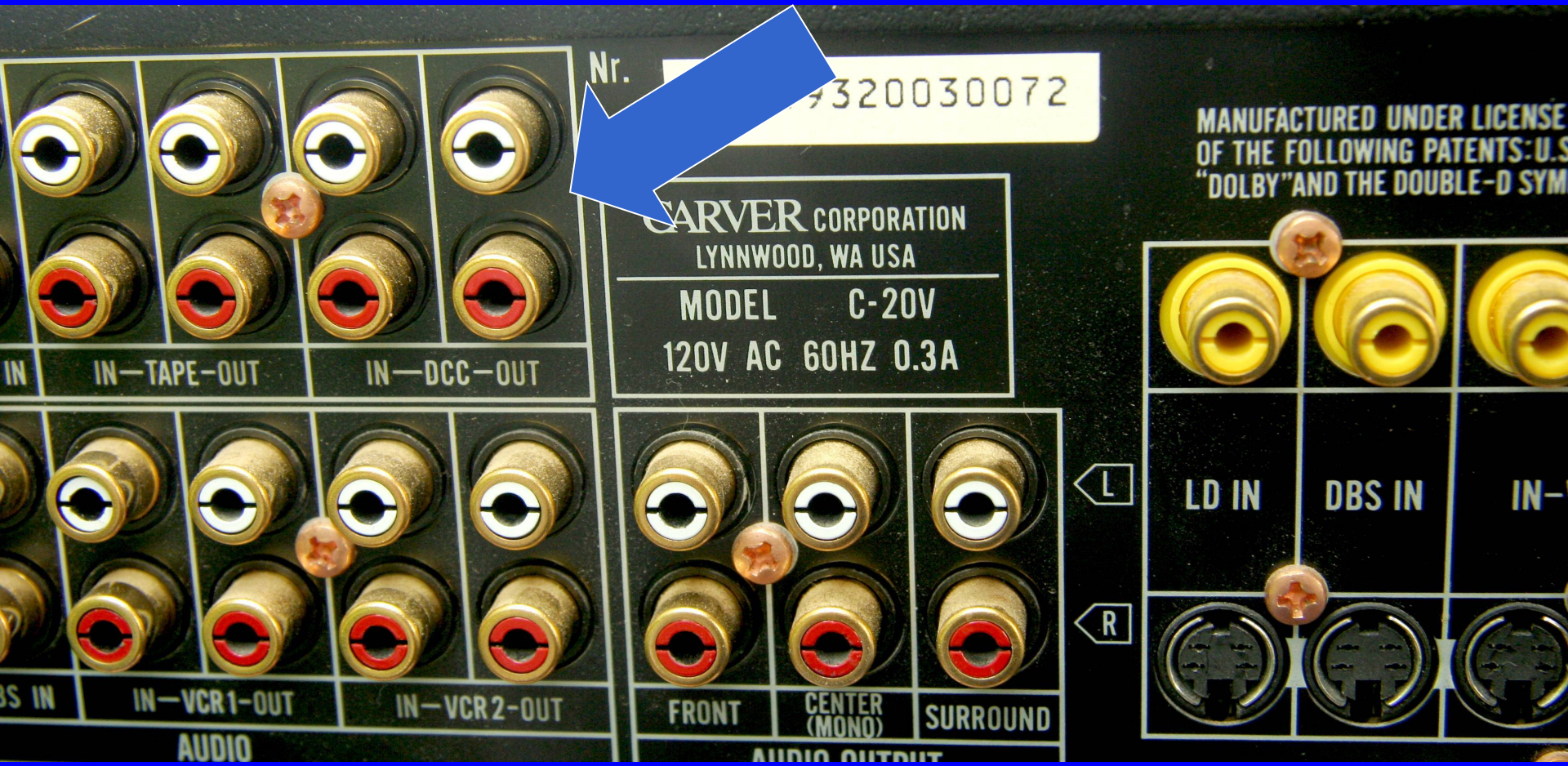
- Audio and Video Gear
  - Home Audio Systems
  - TV Sets, Video Monitors, Recorders, Cable Boxes
- Computers and Accessories
- Ham Rigs and Accessories
- Telephone Equipment
- CATV Equipment

How Do Pin 1 Problems Happen?

- Connectors mounted to PC board
- Shell not bonded to chassis
  - Should be, but is not – that costs more!
- All inputs and outputs are usually wrong
  - Audio and video
  - Serial and USB interfaces
  - Control wiring

How Do Pin 1 Problems Happen?

Insulating rings around connectors prevents chassis contact!



Nice Radio, Had Pin 1 Problems

So do the K3, K3S, KX3

Pin One Problems in Elecraft KX3

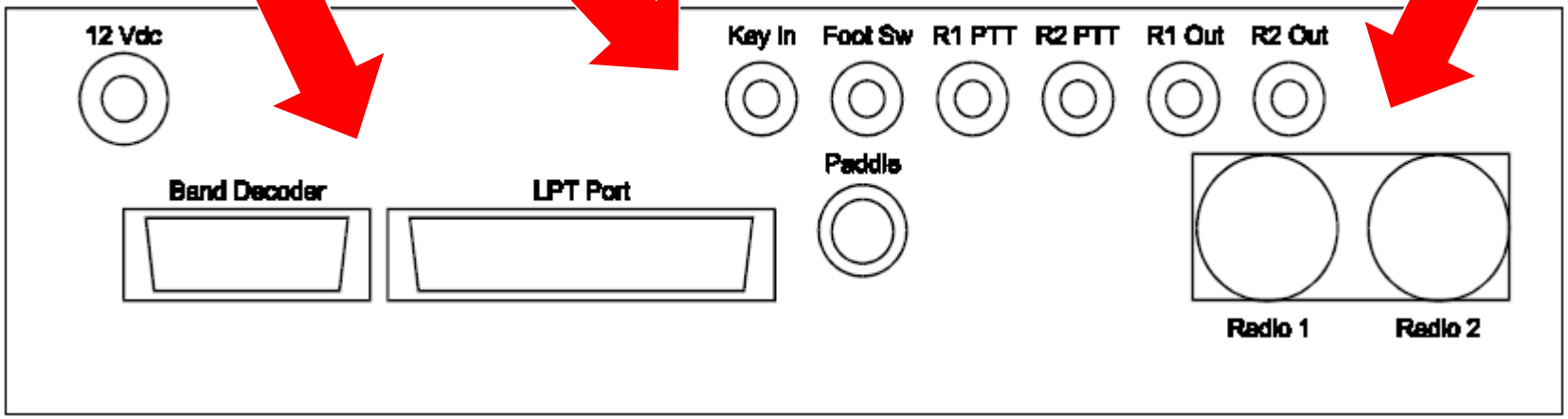
- Only the mic and BNC connectors are bonded to the chassis

A Pin 1 Problem in FT-1000MP

RF Feedback on 75 and 15 Meters

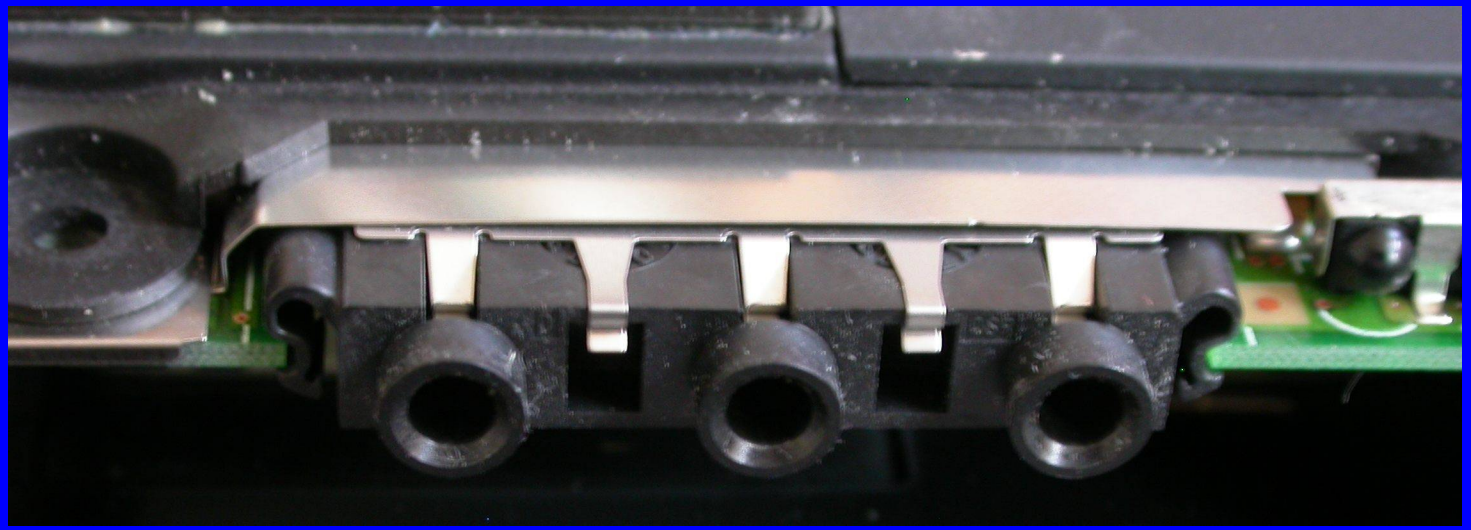
Multiple Pin 1 problems cause hum, buzz, and probably RF feedback

Rear Panel C ections



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

- Hint: It isn't an audio connector shell!
  - They <u>should</u> be, but they are <u>not</u>!



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

Yes, it was the DB9, DB15, and DB25 shells!

In today's computers, it's USB, HDMI, and VGA shells

Dayton 2014 Booth Survey

- Rigs With Apparent Pin One Problems
  - Yaesu (all I could look at)
  - Kenwood (all I could look at)
  - ICOM (all I could look at)
  - Ten Tec (all I could look at)
  - Elecraft (K3, KX3)
  - Many (most?) other booths
  - Flex (most models)
  - ANAN Radios

Visalia 2019

- Same result – every rig had an obvious Pin One Problem at every audio and control connector

Green Wire "Pin One-Like" Problems

- Common in all sorts of equipment
  - Green wire insulated from enclosure by paint
  - Common in Astron Power Supplies
  - More about Astron later
- RF trash escapes from gear on power cord, is conducted and radiated

Killing Pin One Hum, Buzz, RFI

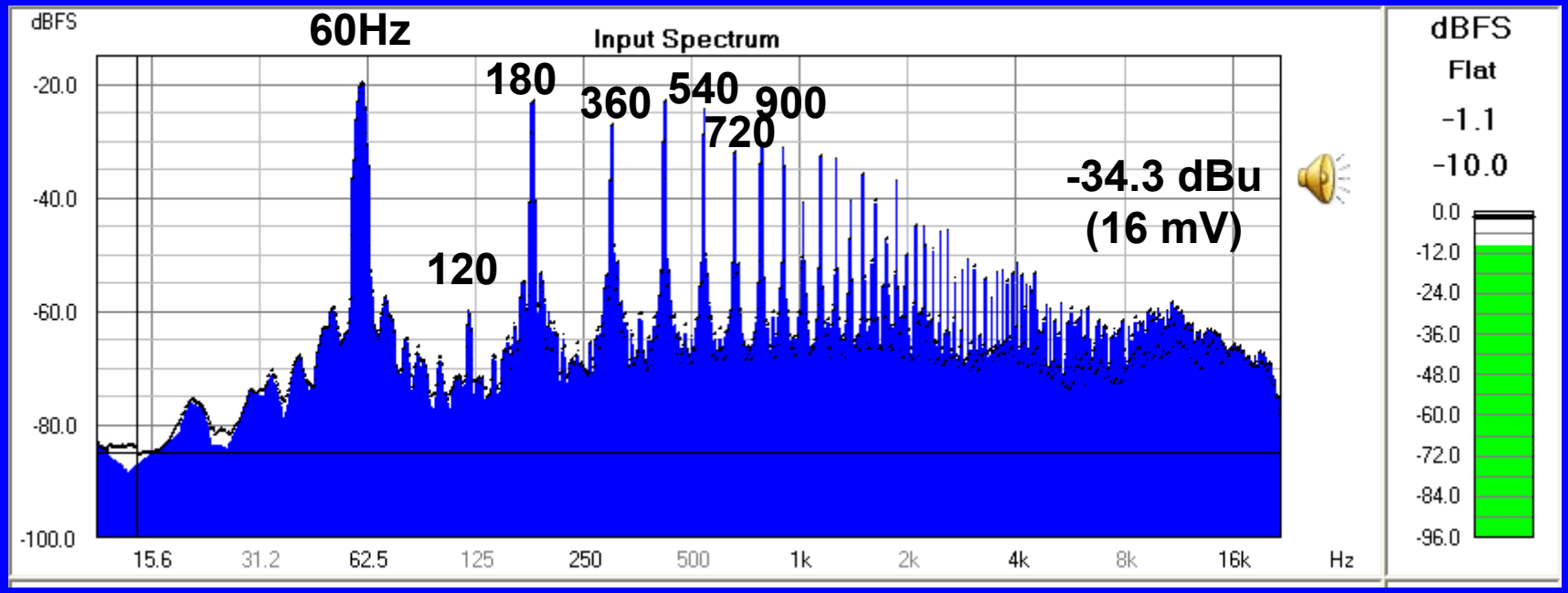
- Nearly impossible to fix the equipment because of how its built
- Even if you could, the change could open a can of worms

Audio Hum and Buzz

Audio Transformers

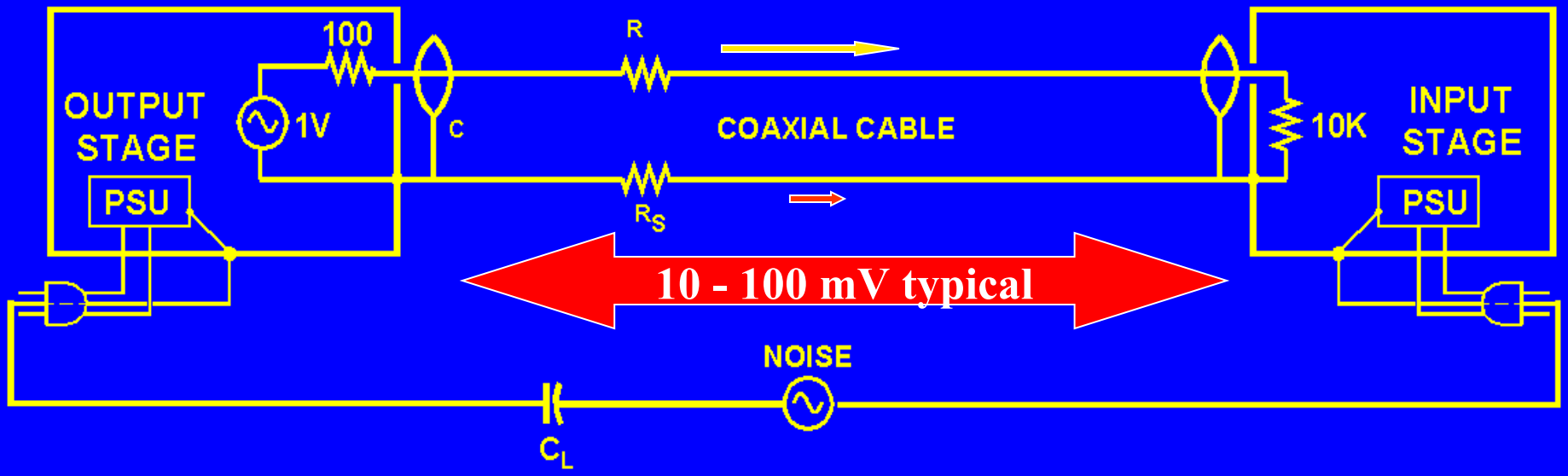
- Because we didn't understand the cause of the hum/buzz, we've used the wrong solution – audio transformers
- The bonding we must do for lightning and electrical safety also kills hum and buzz, and makes a big dent in RFI

Typical Noise Spectrum on “Ground”



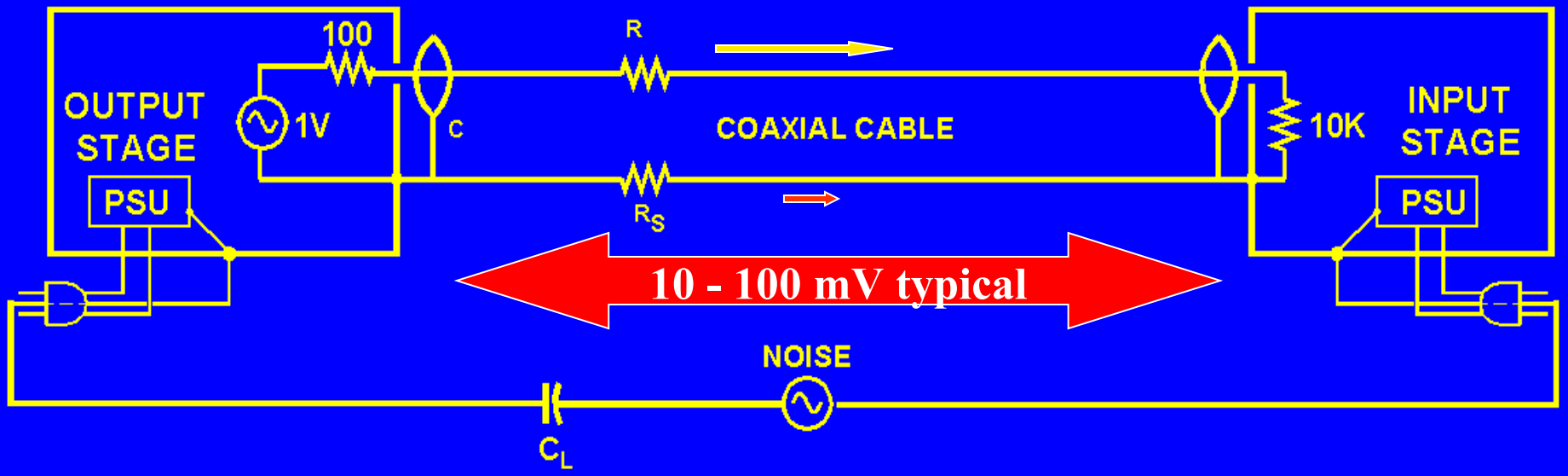
Measured between Green Wires of outlets on opposite walls of my ham shack, into a high impedance

The Problem with Unbalanced Circuits



Here, two connected boxes are plugged into different power outlets. Connection between their green wires goes all the way back to the breaker panel!

The Problem with Unbalanced Circuits



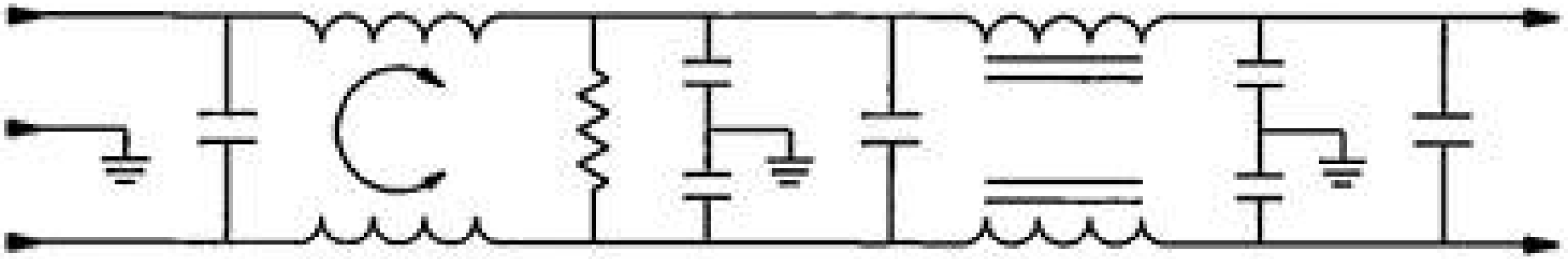
Noise current flows on the shield, and the IR drop is added to the signal.

Any voltage between the two chassis is added to the signal.

Leakage (Noise) Currents On Green Wire – Where Do They Come From?

- Capacitance from phase (hot) and neutral to equipment ground
  - Bypass capacitors in line filters
  - Capacitance between windings and frame of power transformers
- Unequal inductive coupling from phase and neutral conductors to green wire
  - Depends on how conductors are twisted
  - Random spacing of conductors in conduit

Typical Line Filter



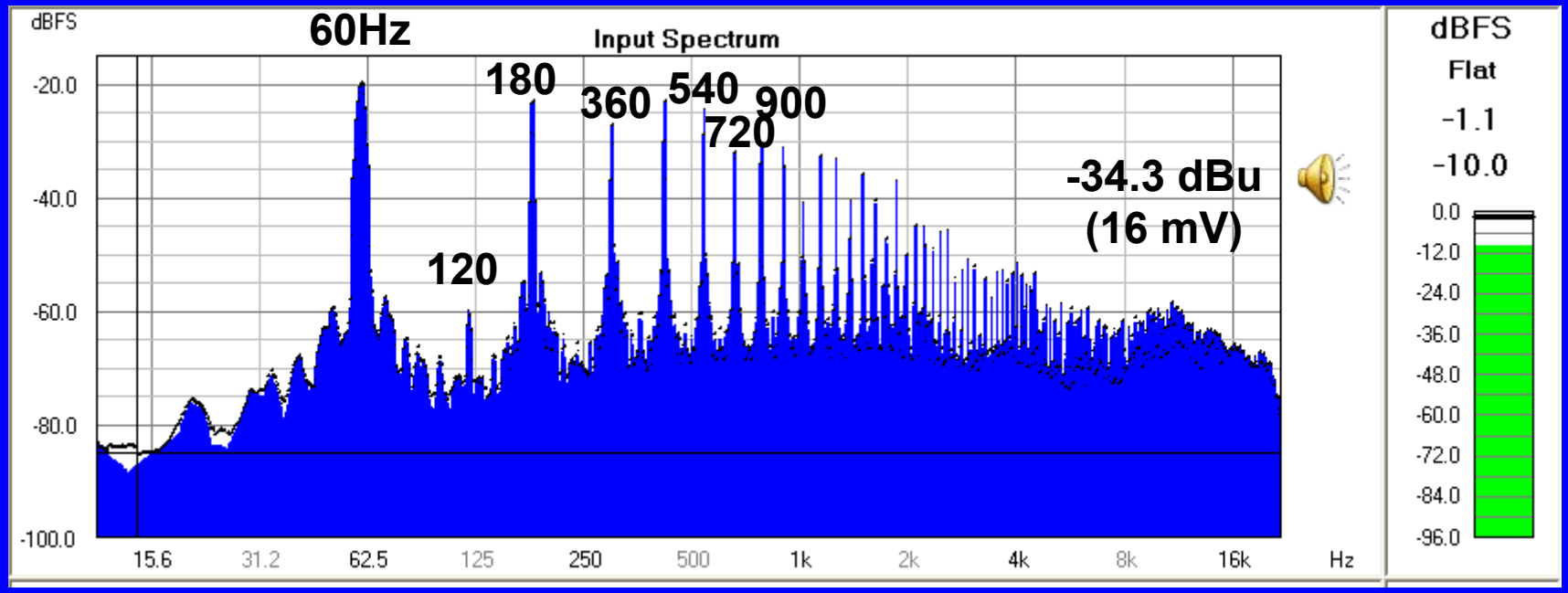
Bypass caps

Bypass caps

Other Sources of Noise on Green Wire

- Magnetic induction
  - Leakage flux from power transformers
  - Wiring errors in buildings and homes
    - Double bonded neutrals
  - Leakage fields from motors and controllers
- Controllers for variable speed motors
- Noise currents from 3-phase neighbors

Typical Noise Spectrum on “Ground”



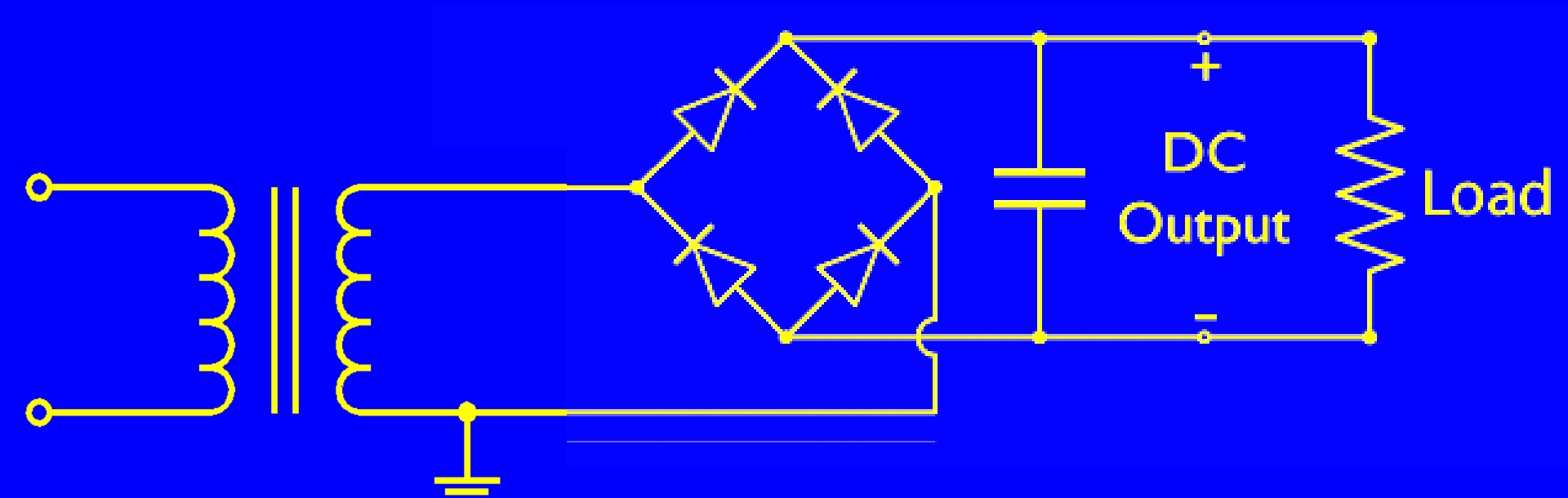
Measured between Green Wires of outlets on opposite walls of my ham shack, into a high impedance

That's Not 60 Hz Hum, it's Buzz!

- Where did all those harmonics come from?

The Harmonic Problem

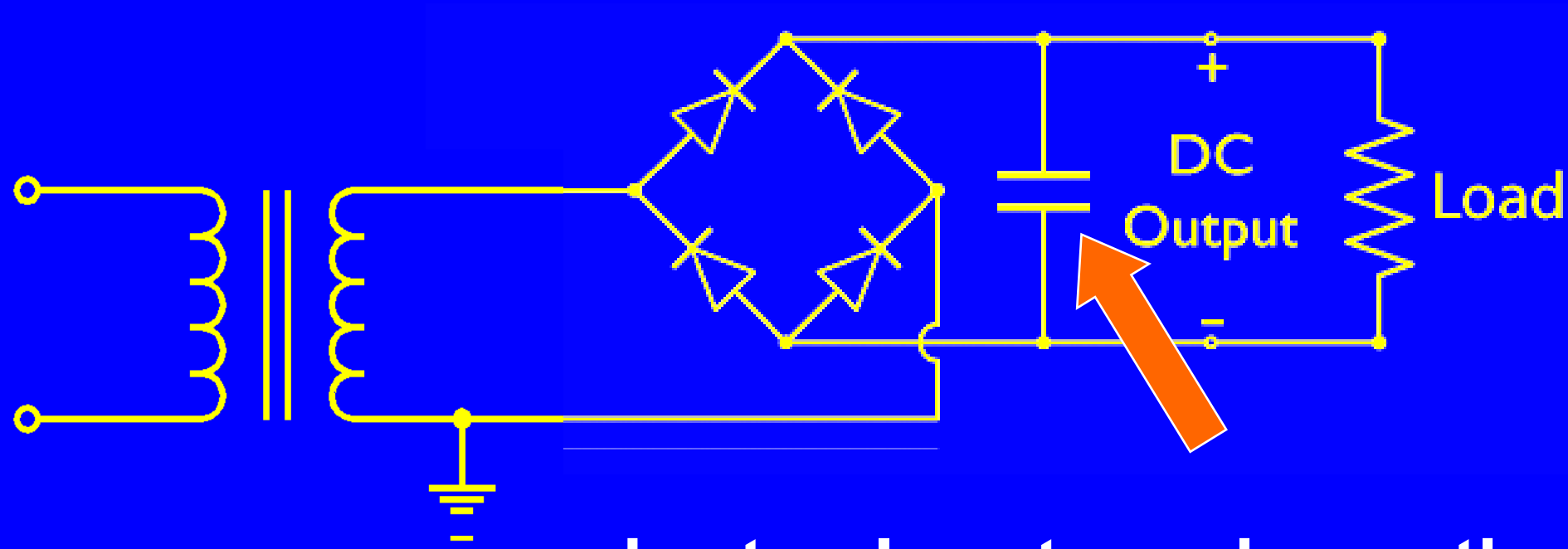
Recognize this power supply?



it is in <u>every</u> piece of electronic gear – computers, audio, video, printers, copiers, appliances, (even switching power supplies)

The Harmonic Problem

Recognize this power supply?



Current flows in short pulses to recharge the filter cap on each half cycle

Current is not even close to a sine wave

The Harmonic Problem

- Nearly all electronic loads have power supplies with capacitor-input filters

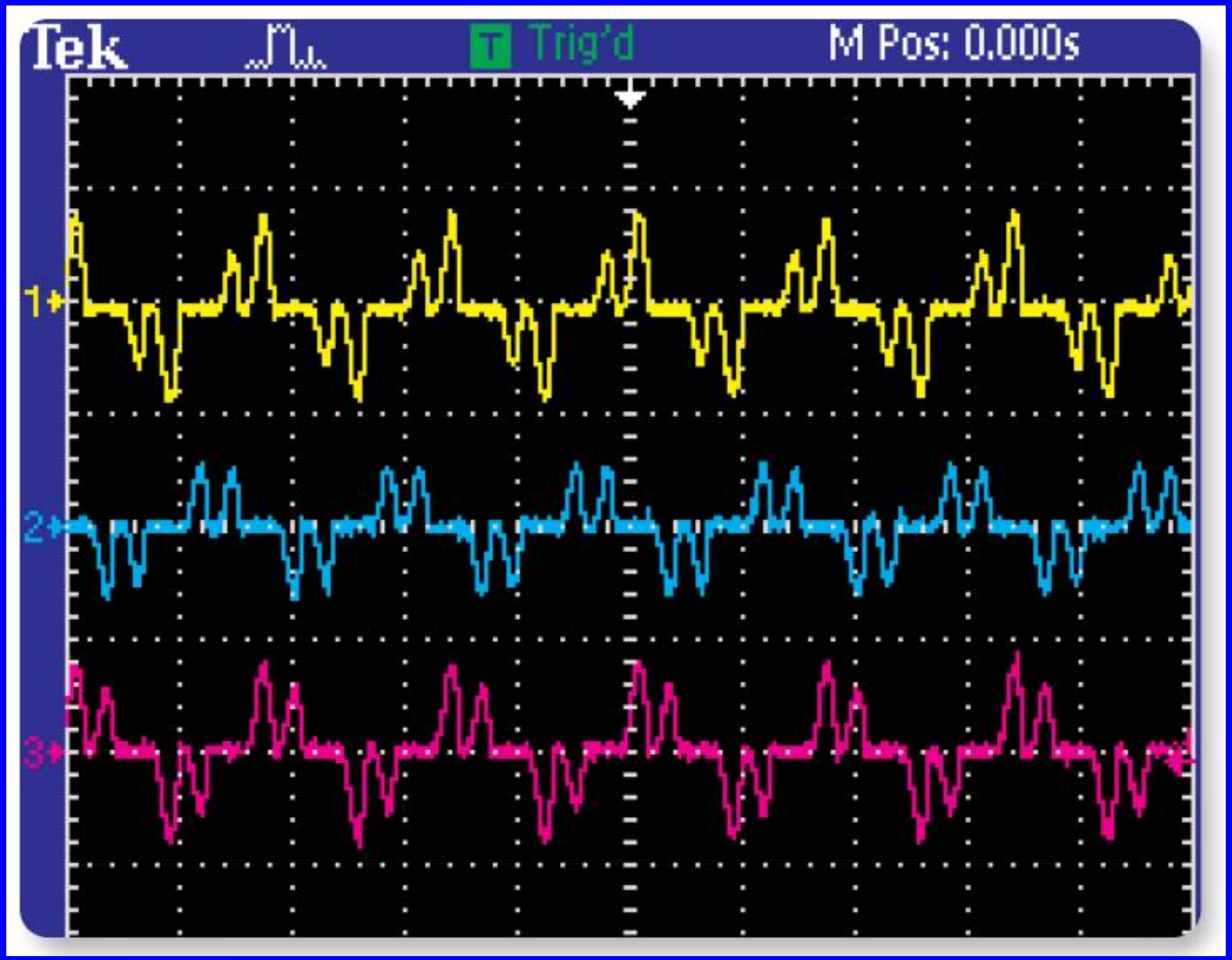
so:

- Load current is drawn in short pulses at peaks of the input sine wave

thus:

- Phase, neutral, and leakage currents are highly distorted
- Distortion => harmonics

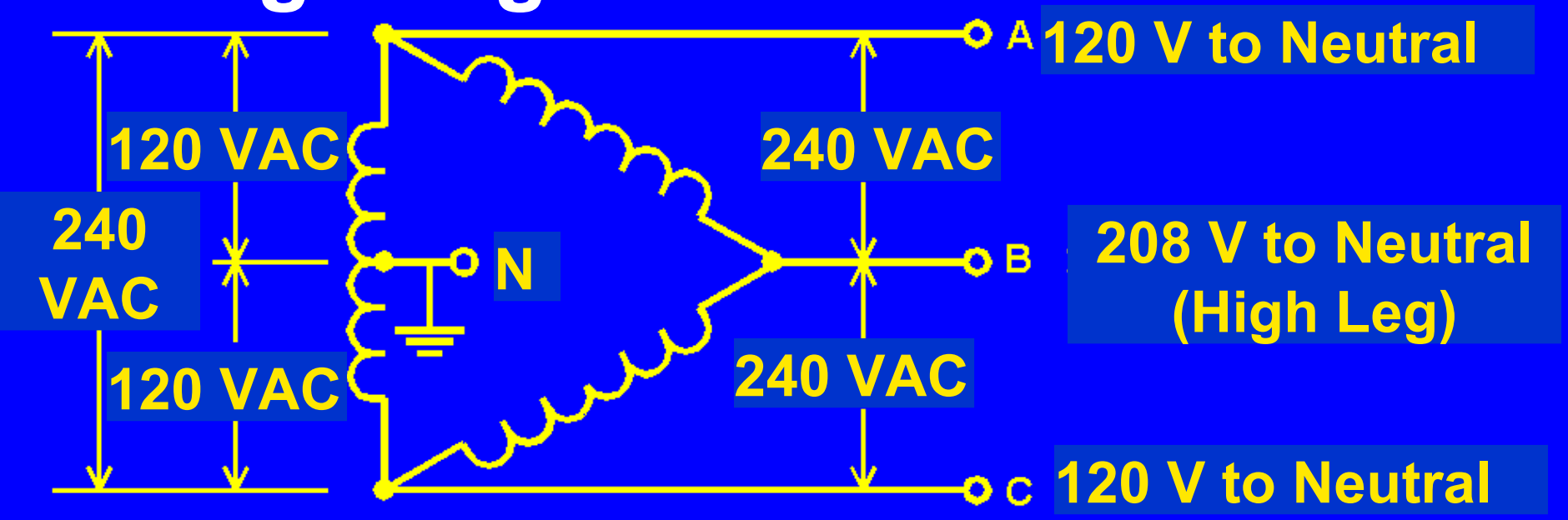
Load Currents in a 3-Phase System



But I Don't Have 3-Phase at Home!

- No, but a factory or business down the street does, so many of use get our 120V-0-120V service from a "High Leg Delta" service in the alley!
- High Leg Delta feeds my home in the Santa Cruz Mountains
- Much of that factory's neutral current gets to ground through our neutral!

“High Leg” Delta 3-Phase Power

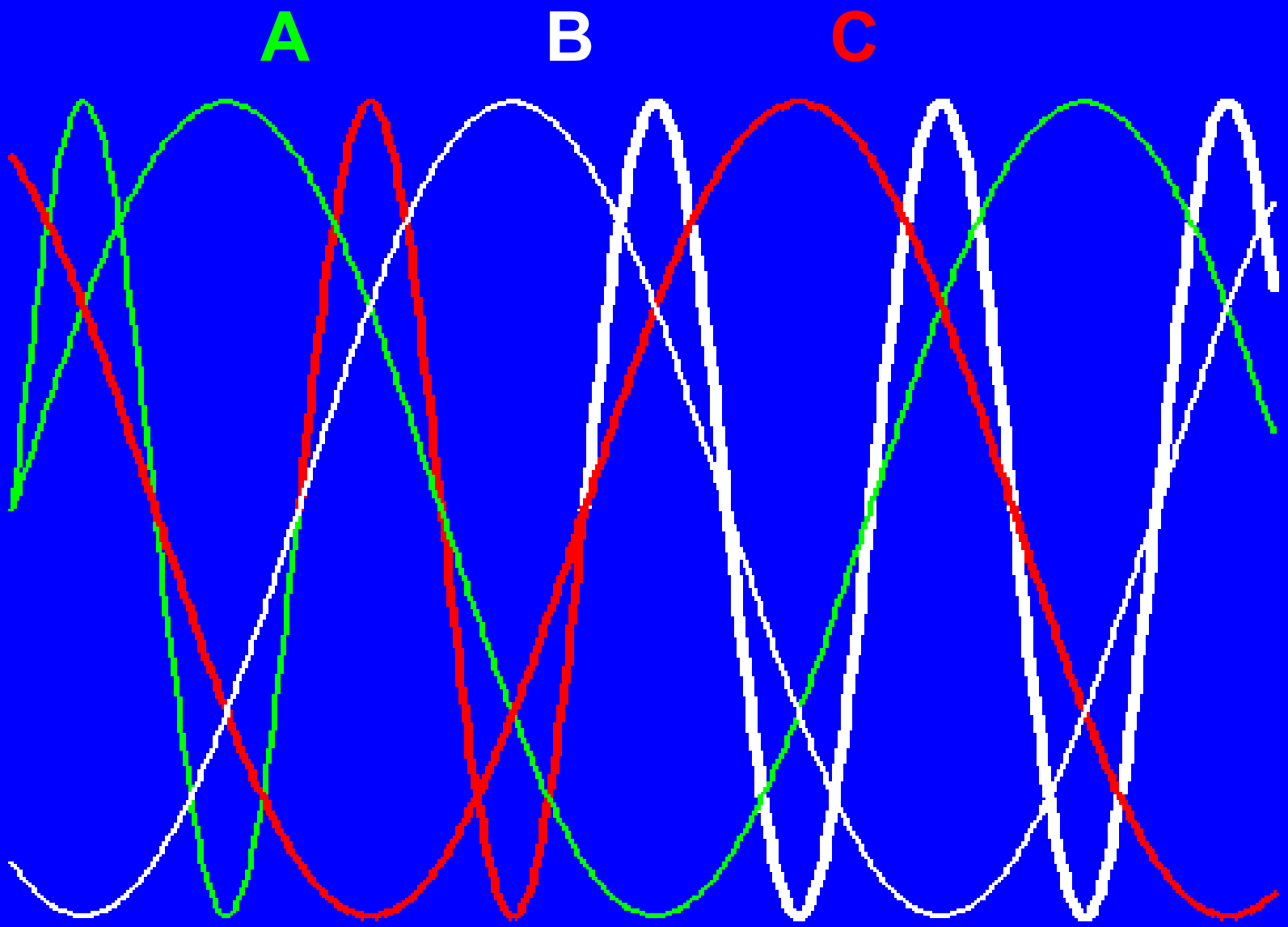


- Is common in mixed business/residential areas where both single phase and 3-phase power are needed
  - A-B-C feeds industrial users (240-240-240)
  - Center-tapped leg feeds residences (120-0-120)

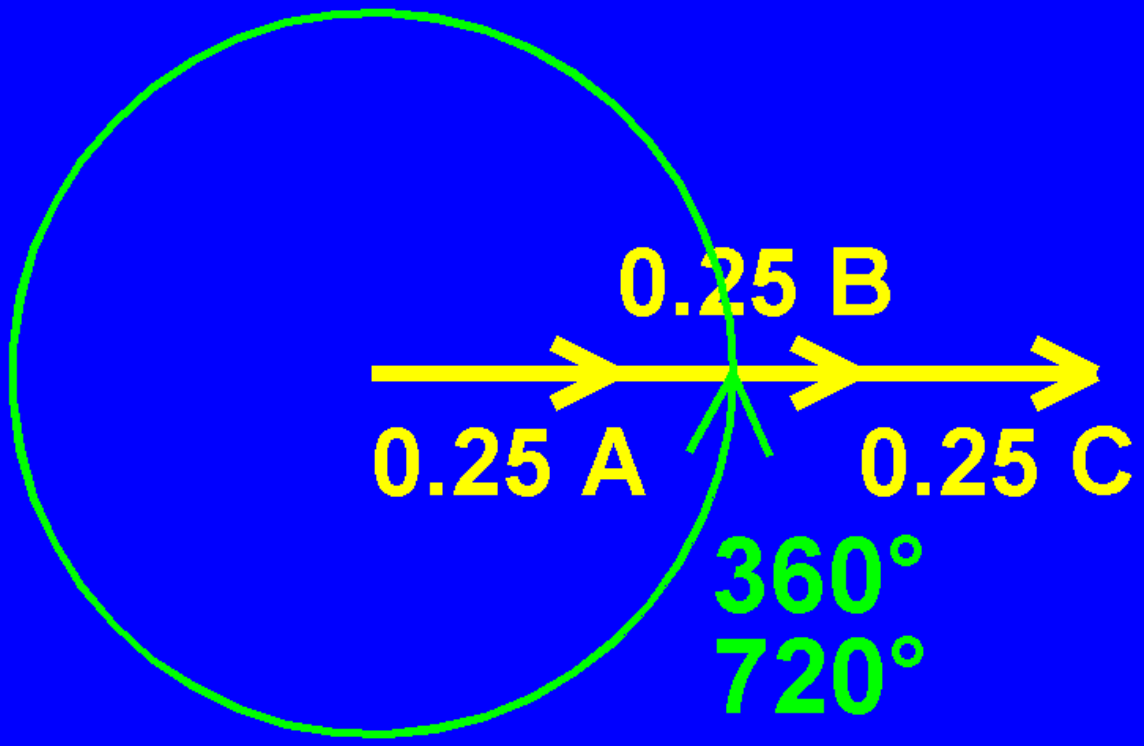
Neutral Current In 3-Phase Systems

- If currents in the phases are sine waves and equal, they cancel
- But they're NOT sine waves, haven't been for at least 40 years, because virtually all power systems are dominated by electronic loads!
  - Fluorescent and LED lighting
  - Anything with a DC power supply
  - Controllers for variable speed motors
  - Other power control equipment

Phase Currents – Fundamentals and Third Harmonics



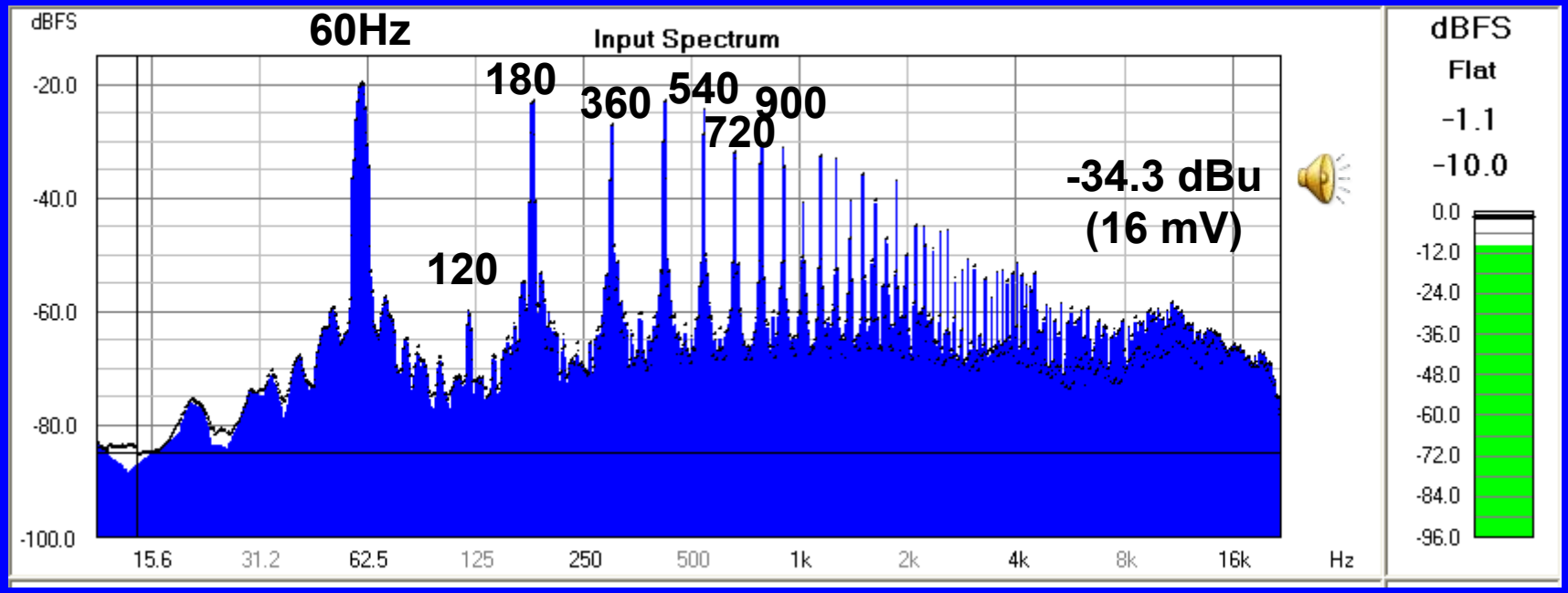
25% 3rd Harmonic on the Phases becomes 75% 3rd Harmonic on Neutral



What Happens in the Neutral?

- Triplen harmonics ADD!
  - Third, sixth, ninth, etc
- Neutral current can be up to 1.7X the phase currents, even in a perfectly balanced system!
- Potentially dangerous overheating
  - Neutral conductors (and contacts)
  - Transformers
- Systems need bigger copper in neutrals, and *harmonic-rated* transformers

Typical Noise Spectrum on “Ground”

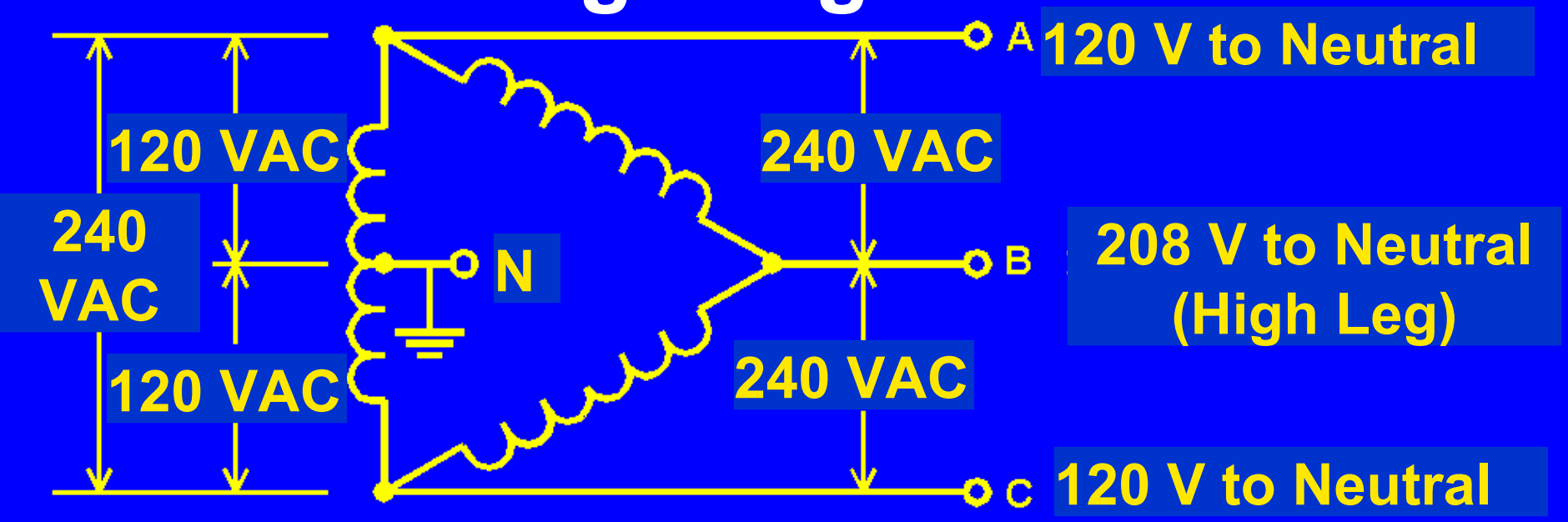


Measured between Green Wires of outlets on opposite walls of my ham shack, into a high impedance

Remember “The Towering Inferno”?

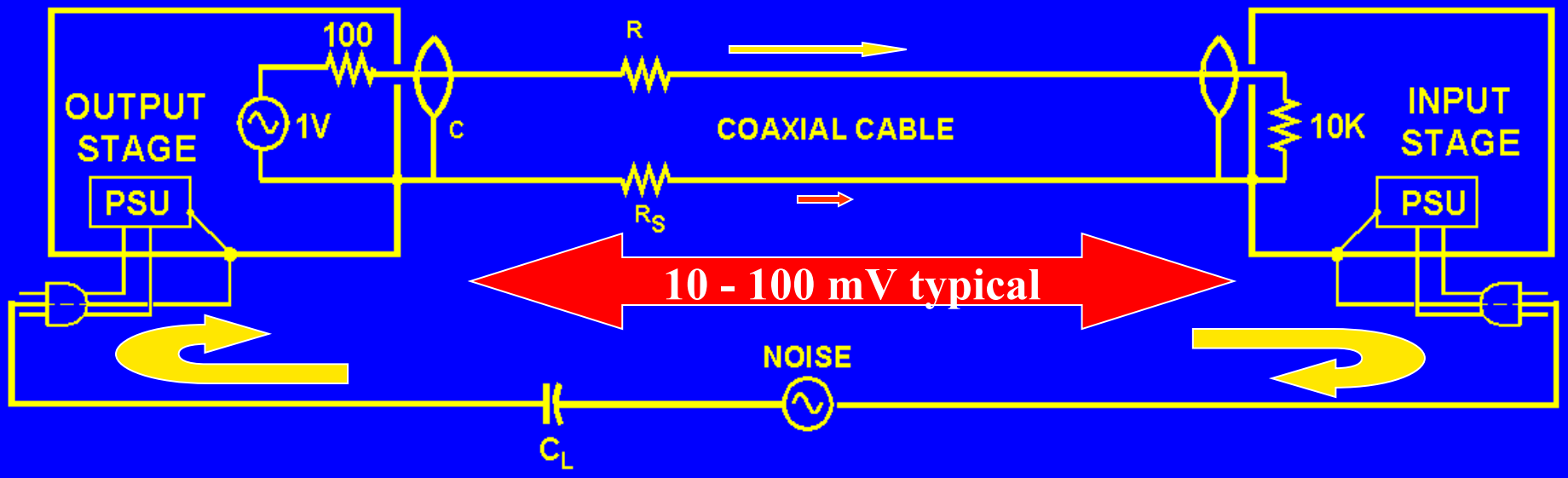
- 3-phase Neutrals in buildings were undersized, because “sine wave currents cancel”
- But they’re not sine waves – can be nearly double phase currents
- So they overheated, insulation started burning
- Cables ran up through chases between floors in the high rise

“High Leg” Delta



- 3-phase customers get no neutral, so their neutral current (those harmonics) shows up on the neutral of single-phase customers
- THAT’S where the harmonics come from!

Recognizing This As A “Ground Loop”



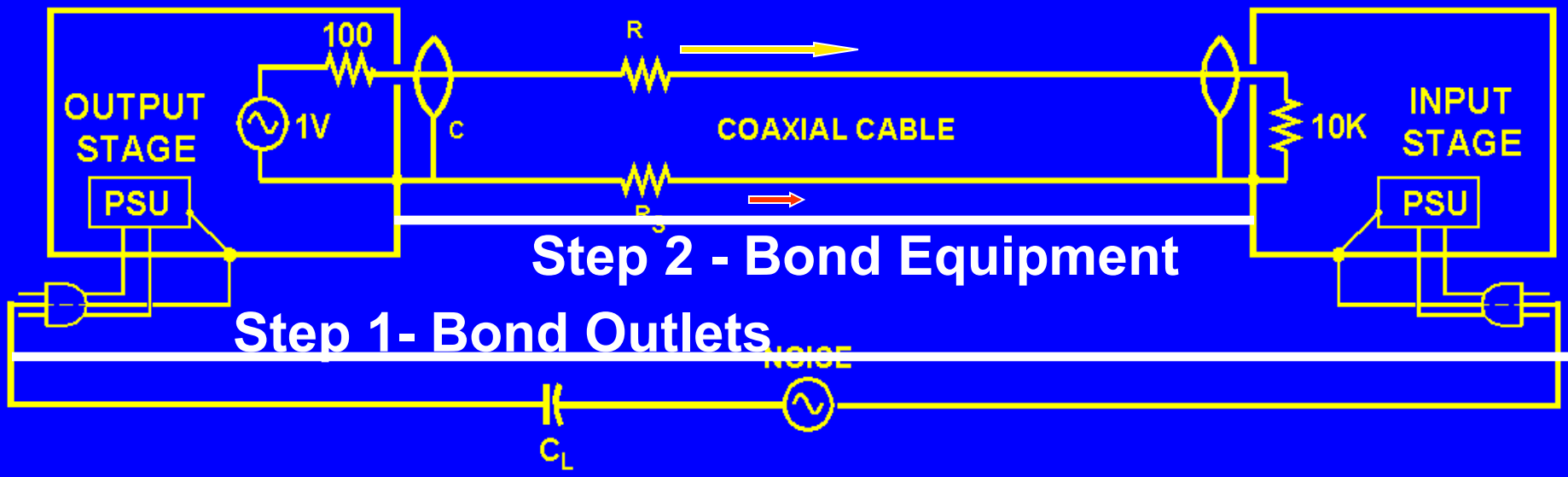
These two connected boxes are plugged into different power outlets. That connection between their green wires back to the breaker panel forms a “ground loop!” That 10-100mV is IR drop from the harmonic currents in their Green Wires

“Ground Loops” – A Simple Solution

- Proper bonding for lightning safety also shorts out the buzz!
  - Bond every chassis together
  - Get all power for our equipment from the same outlet, or from outlets that share the same “Green Wire”
  - If from different outlets, bond their “Green Wires”

We don’t need no stinkin’ transformers!

Fixing “Ground Loops”



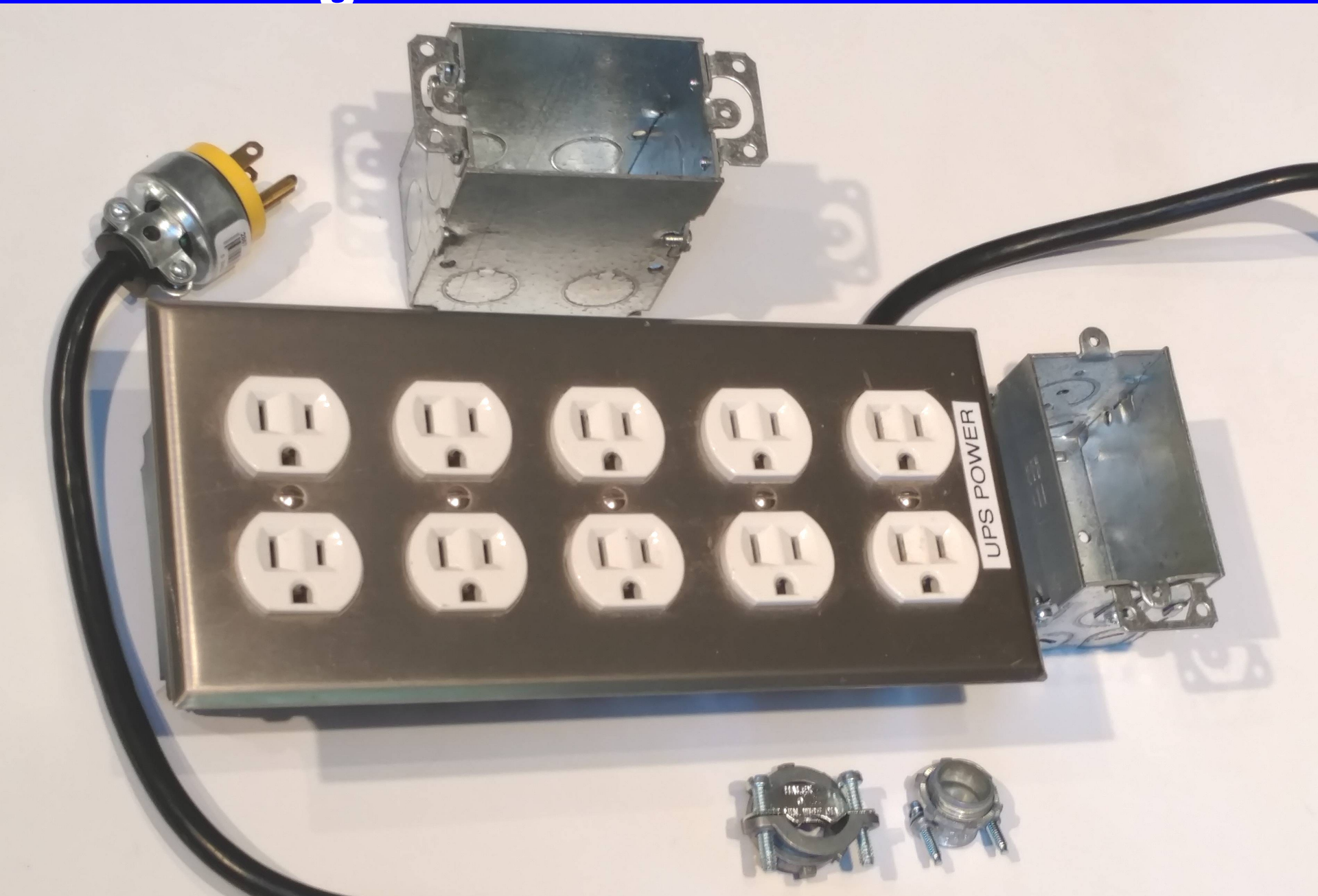
- The fix is simple bonding!
- Bonding outlet grounds together
- Bonding chassis to chassis
- We short out the noise with short, fat copper!

Power Distribution

- Get all the power for your ham station from outlets connected to the same “green wire”
  - A 15A circuit can run three 100W radios (transmitting simultaneously) and two computers
  - If you need more outlets, bolt multiple quad boxes together
  - If installing new wiring, always run #12 (or even #10) for 20A circuits
- Put 240V outlet in a steel backbox bolted to the 120V box(es)

A Contractor-Installed Quad Box in My Shack with 20A Outlets

Use Gangable Boxes for More Outlets



Use Gangable Boxes for More Outlets

Building Multi-Outlet Boxes

- Buy gang-able boxes from the local big box store
- Remove mounting ears
- Remove side panels for interior boxes
- Screw boxes together using mounting screws removed from side panels
- Buy high quality duplex outlets
- Pre-wire them with short lengths of #12
- Feed power cable through strain relief mounted in one of the knockouts

Building Multi-Outlet Boxes

- Wire power cable to one of the outlets
- Mount outlets to the box, carefully centering each of them
- It may be necessary to tweak outlet centering when mounting the cover plate
- Large cover plates like this can be found from internet vendors
- Power cable should be #12 or larger

Power Distribution for Multi-Multi

- Get all the power for as many stations as possible from outlets connected to the same “green wire”
  - Add boxes, bolted together as needed
  - When outlets can’t be bolted, bond them together with steel conduit or heavy tinned braid
  - When fed by different green wires, bond together all outlets for all stations

A Practical Bonding Method

- Use single Power Poles to make it easier to move equipment around
  - Connect a short jumper from each grounding terminal to a single Power Pole
  - Make Power Pole jumpers the right length to connect equipment
  - Pick one piece of gear (the radio?) to serve as Star for the operating desk and connect multiple short jumpers to it
  - Or use a terminal block or grounding bar behind the gear as the “Star”

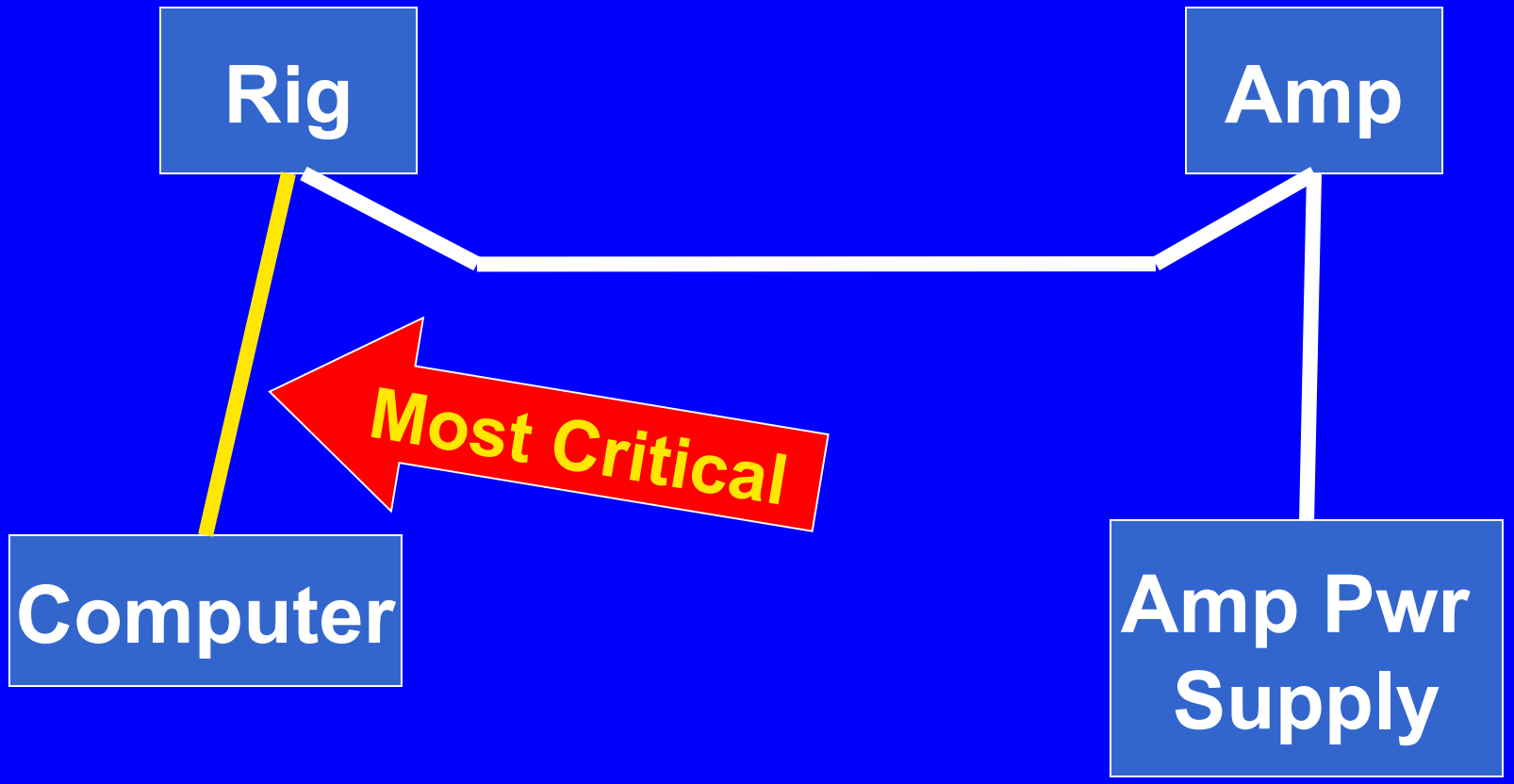
Bonding To Kill Buzz

- Audio noise (buzz) is proportional to resistance of the bonding path
- Make conductor BIG
  - Double the size = 6 dB less buzz
  - Two conductors in parallel = 6 dB less buzz
- Make bonding conductor SHORT
  - Half the length = 6 dB less buzz

Bonding To Kill Buzz

- No need to get heroic – doing what's right for lightning protection is plenty good enough if we've followed those guidelines

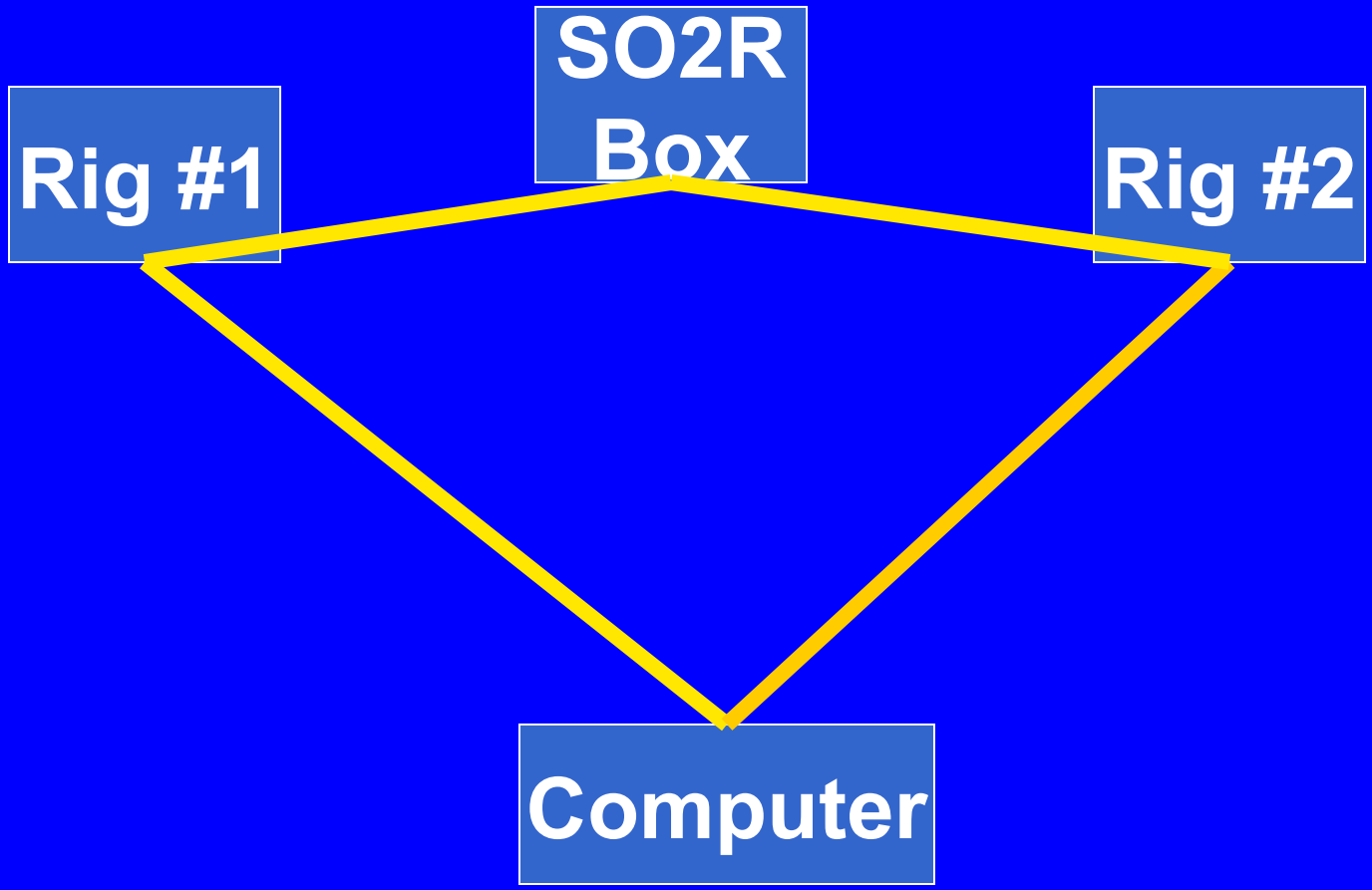
Equipment Bonding – A Basic High Power Station



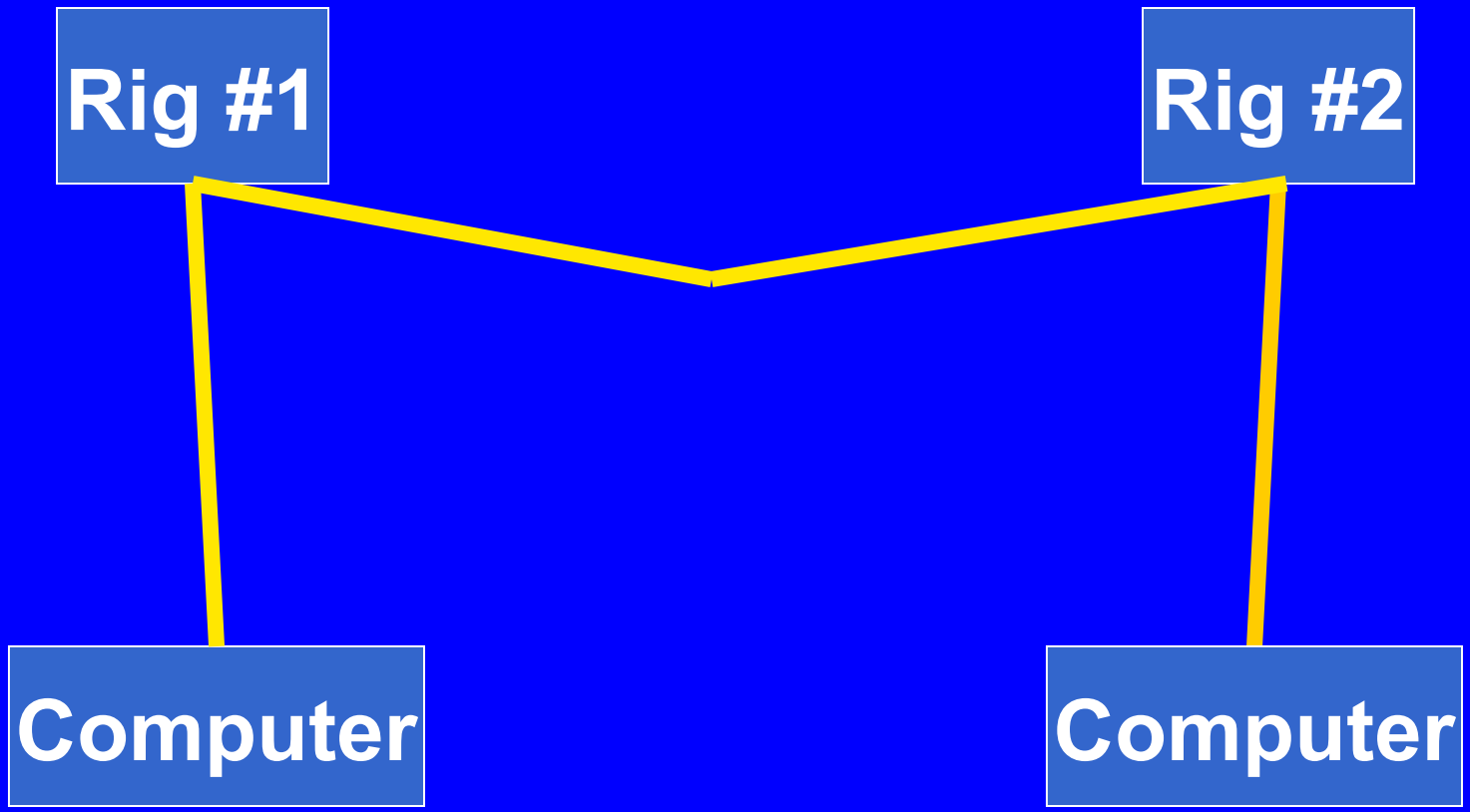
Multi-Transmitter Bonding

- Bond all transmitters together
- Bond all power outlet green wires together
- Use bigger copper for longer runs
  - Multiple #10 stranded in parallel

Equipment Bonding – SO2R Station



Equipment Bonding – Two Rigs, Two Computers



SO2R Box Bonding

- Bond transmitters together
- Bond computer(s) to transmitters
- Bond SO2R box to computer(s) and transceivers
  - This can be difficult – many SO2R boxes are poorly built
    - Chassis and connectors insulated by paint
  - Bonding all equipment connected to the SO2R box will usually kill the buzz

When There's No Metal to Bond To

- Bond to a D-connector retaining screw, or to USB connector shell

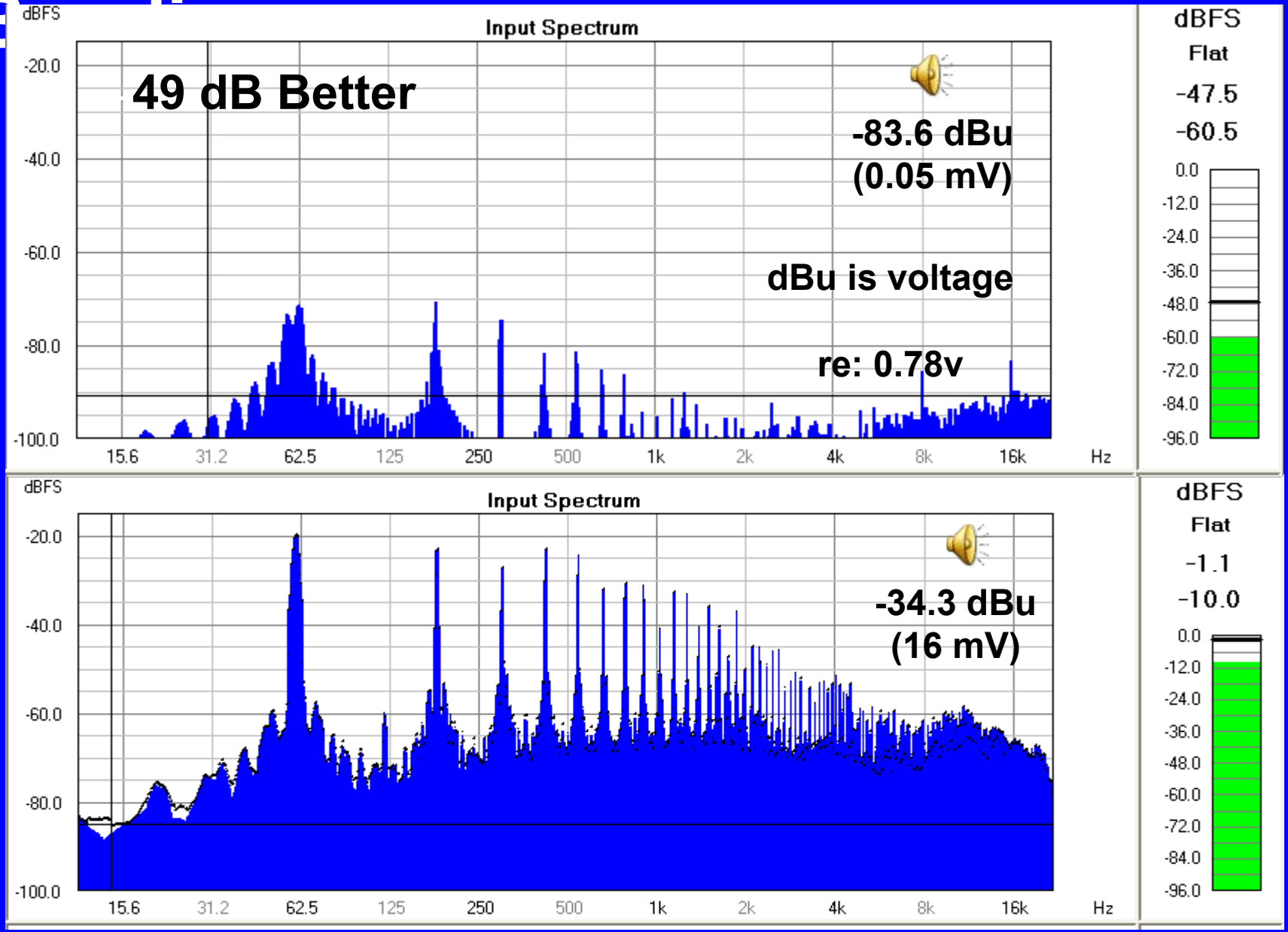
Or

- Use a double-insulated power supply (legal 2-wire power cord) for the SO2R box and bond only the rig, amp, and computer(s)
  - An un-regulated linear wall wart whose voltage and current ratings match the SO2R box's requirements
  - Regulated wall warts are often noisy

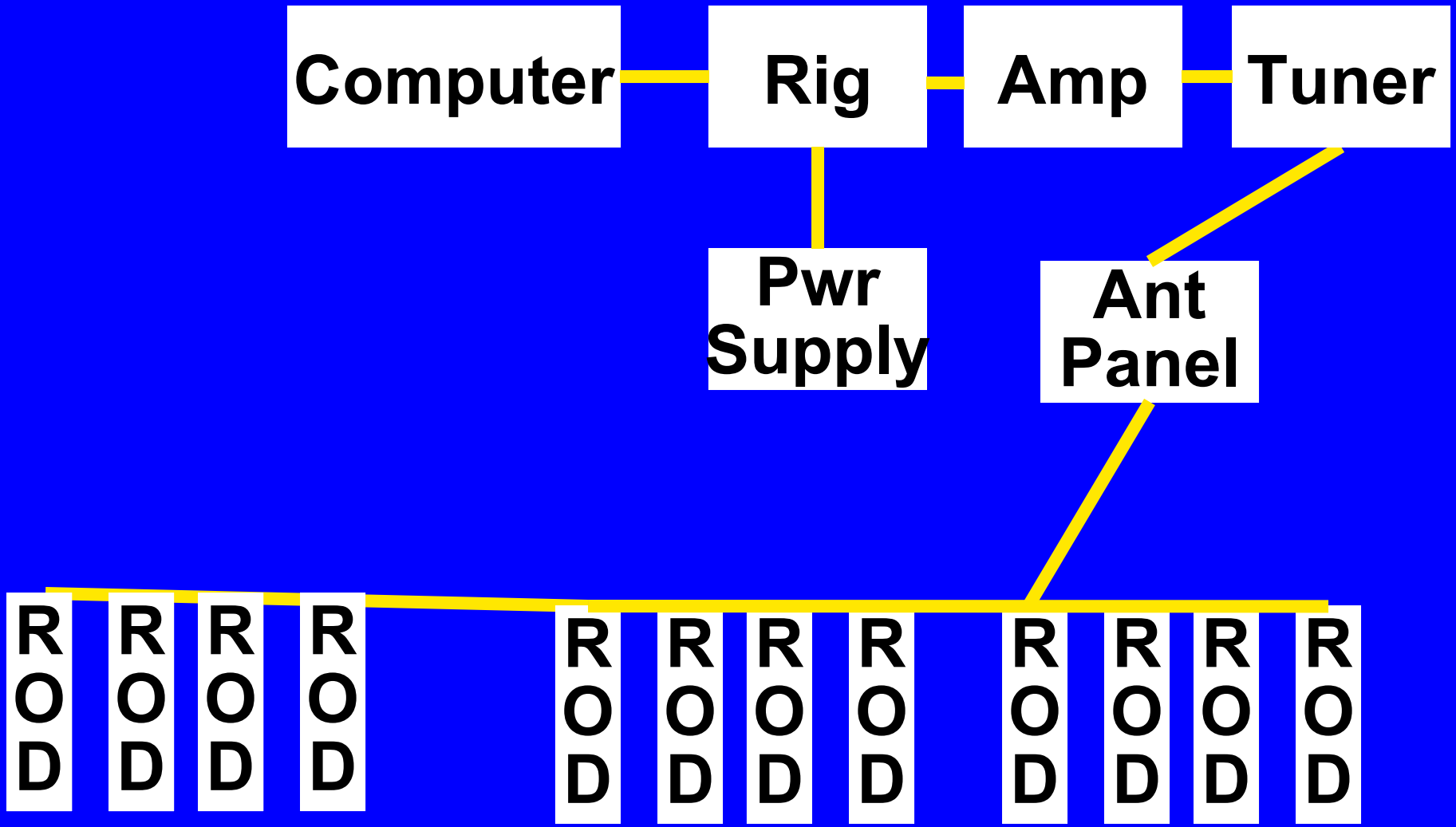
How Well Does This Work?

- Should eliminate most hum and buzz
- No need to replace crummy cables
- AND it puts a band-aid on power-related pin 1 problems!
  - No shield current, no pin 1 problem
  - RF pin 1 problems still possible

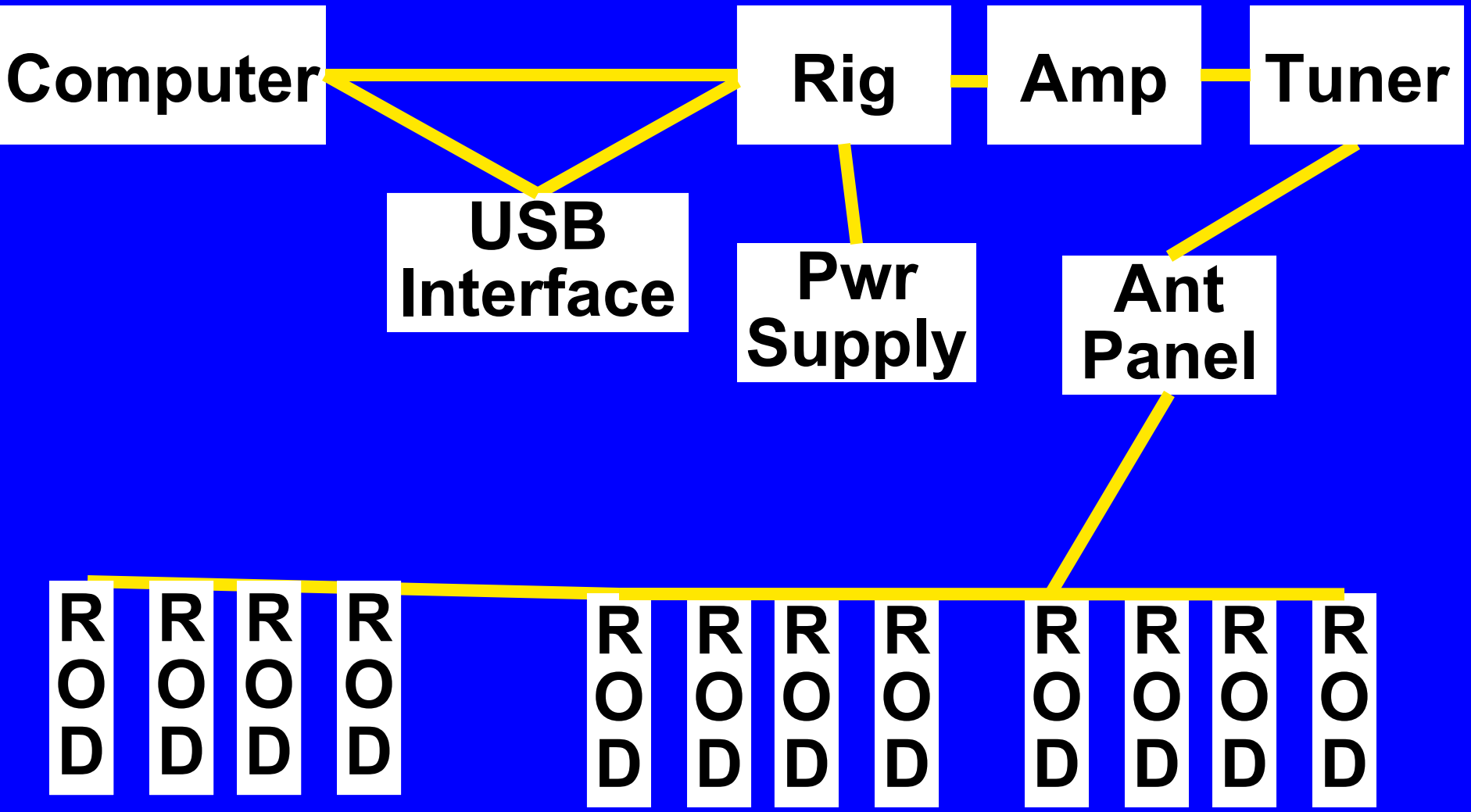
Noise Reduction From Simple B



Proper Bonding For The Shack – Start With Interconnection Paths

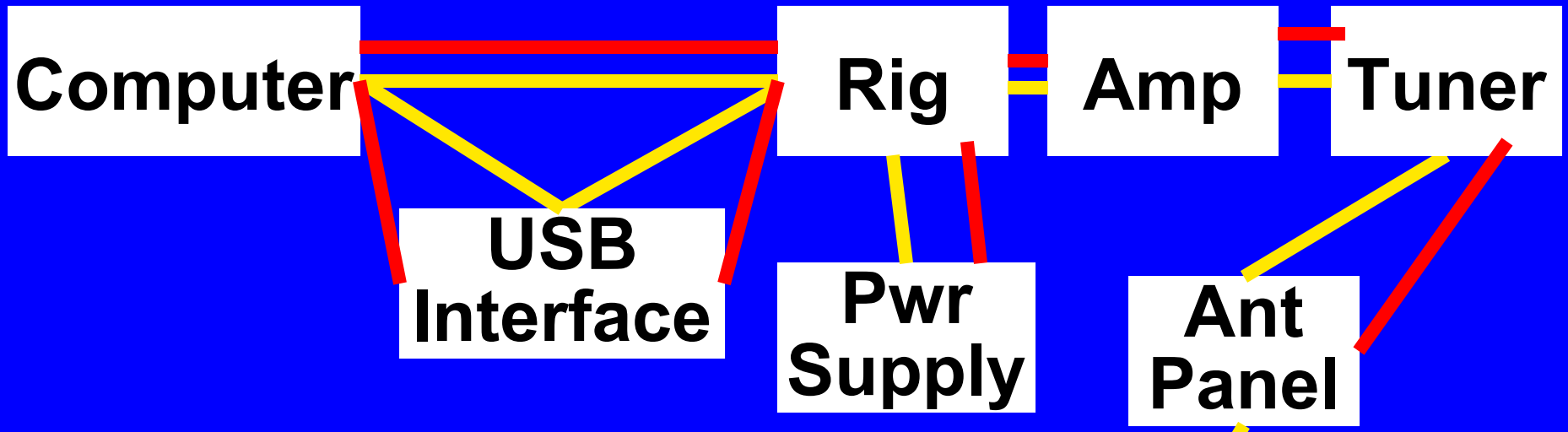


Proper Bonding For The Shack – Start With Interconnection Paths

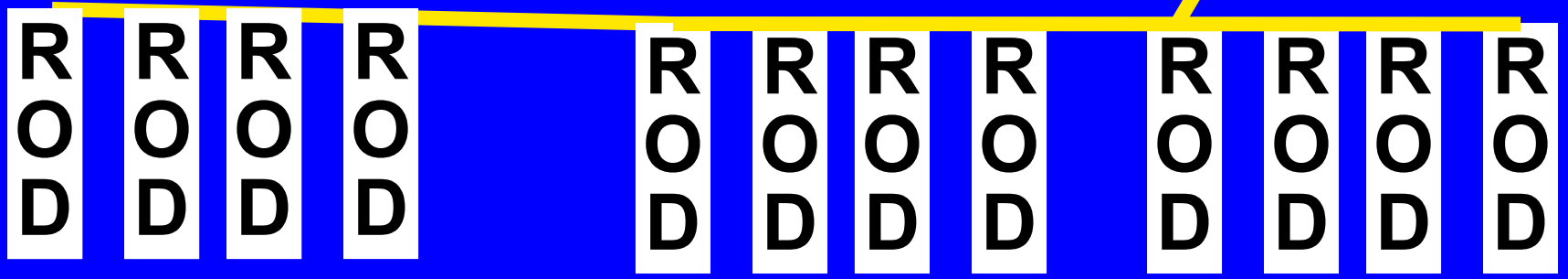


Thinking About Loops

Red Lines are Connecting Cables

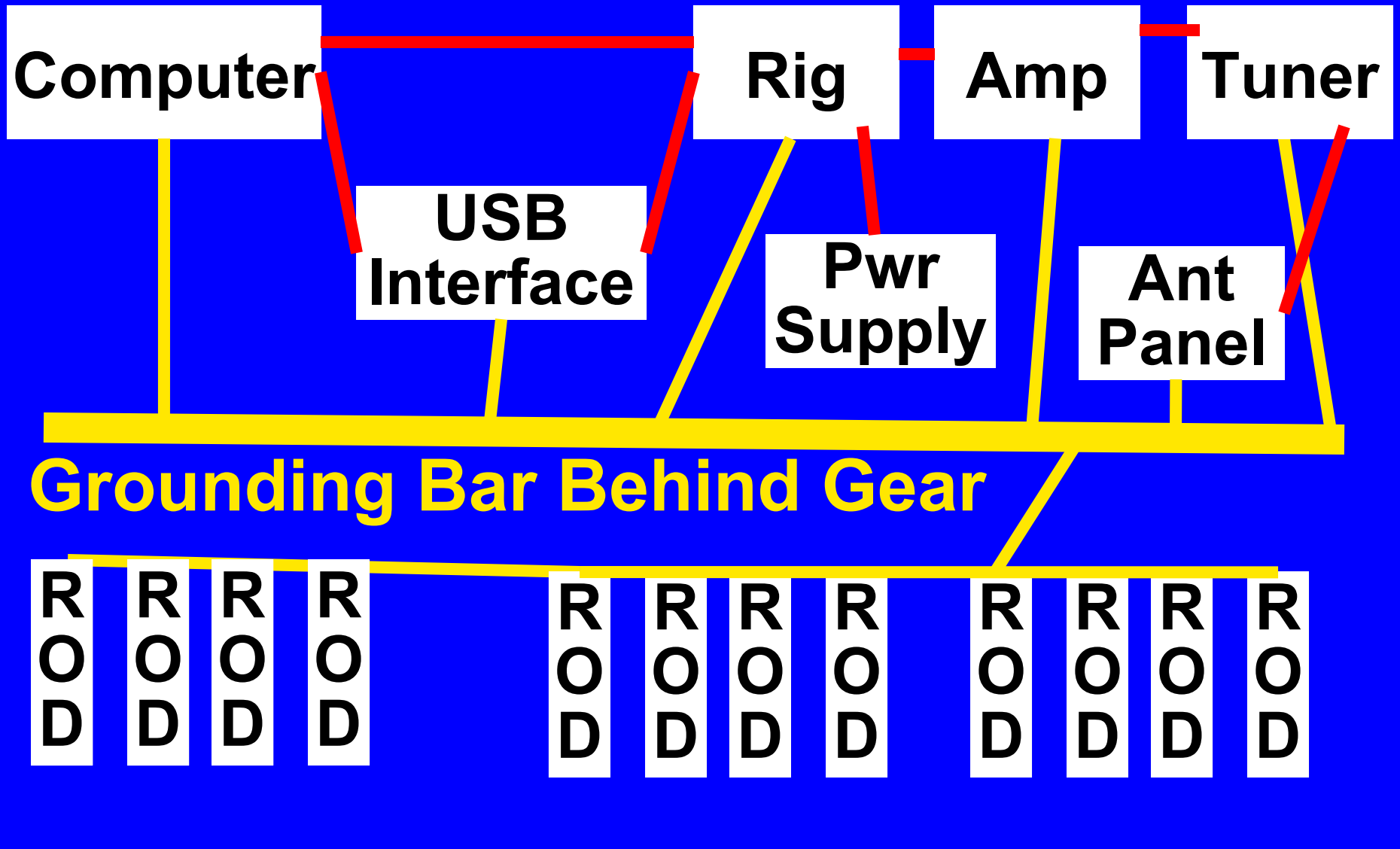


Yellow Lines Are Bonds



Bar Behind Gear Creates Loops

Red Lines are Connecting Cables

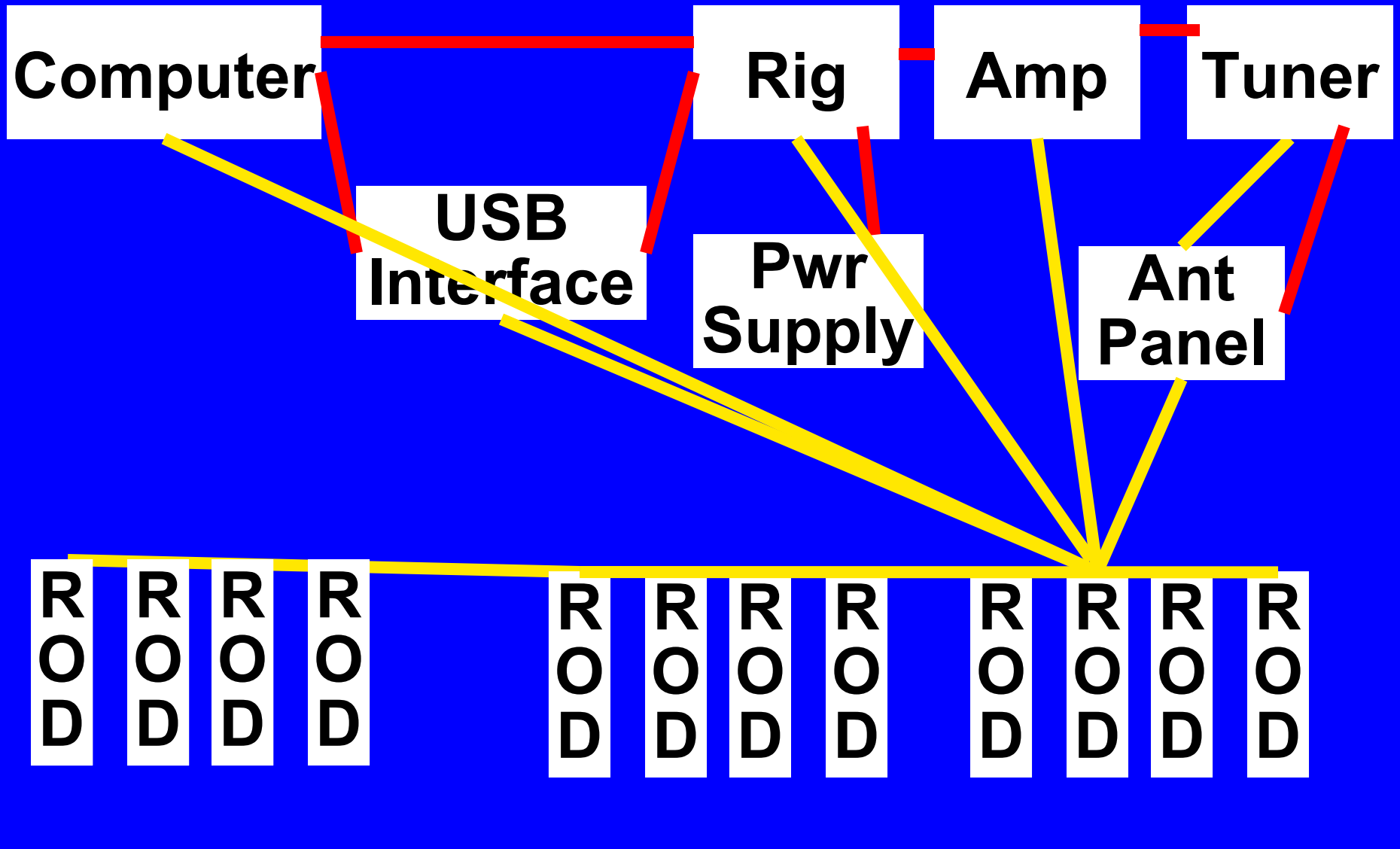


Ground Bar At Back of Desk

- We have unbalanced connections (cable shields) between gear, so bonding to the bar creates a loop
- Magnetic coupling to the loop
  - Leakage flux from transformer
  - Lightning
- Bonding path between gear is longer, so more resistance, more hum, buzz, and RFI

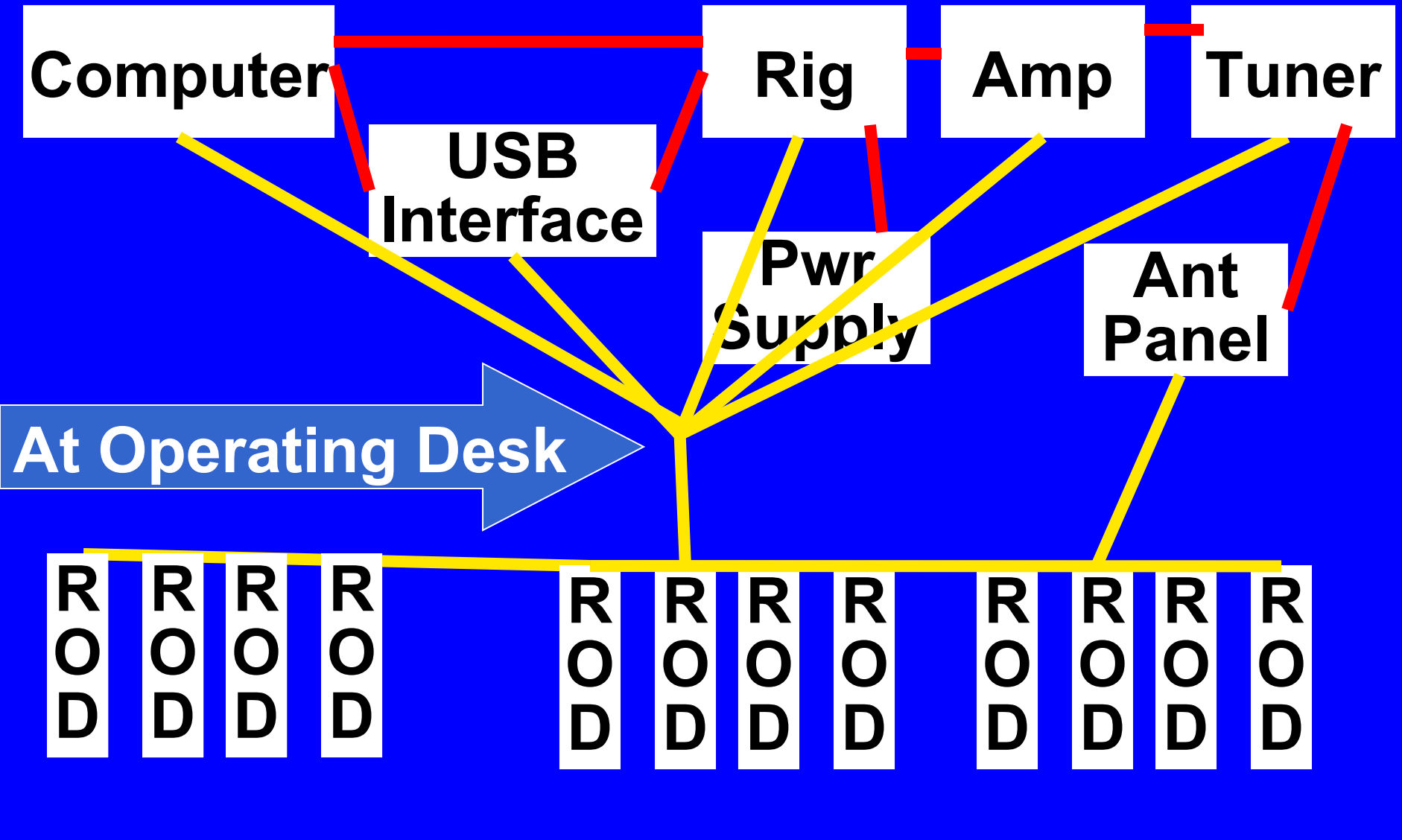
Single Point Creates Loops

Red Lines are Unbalanced Cables



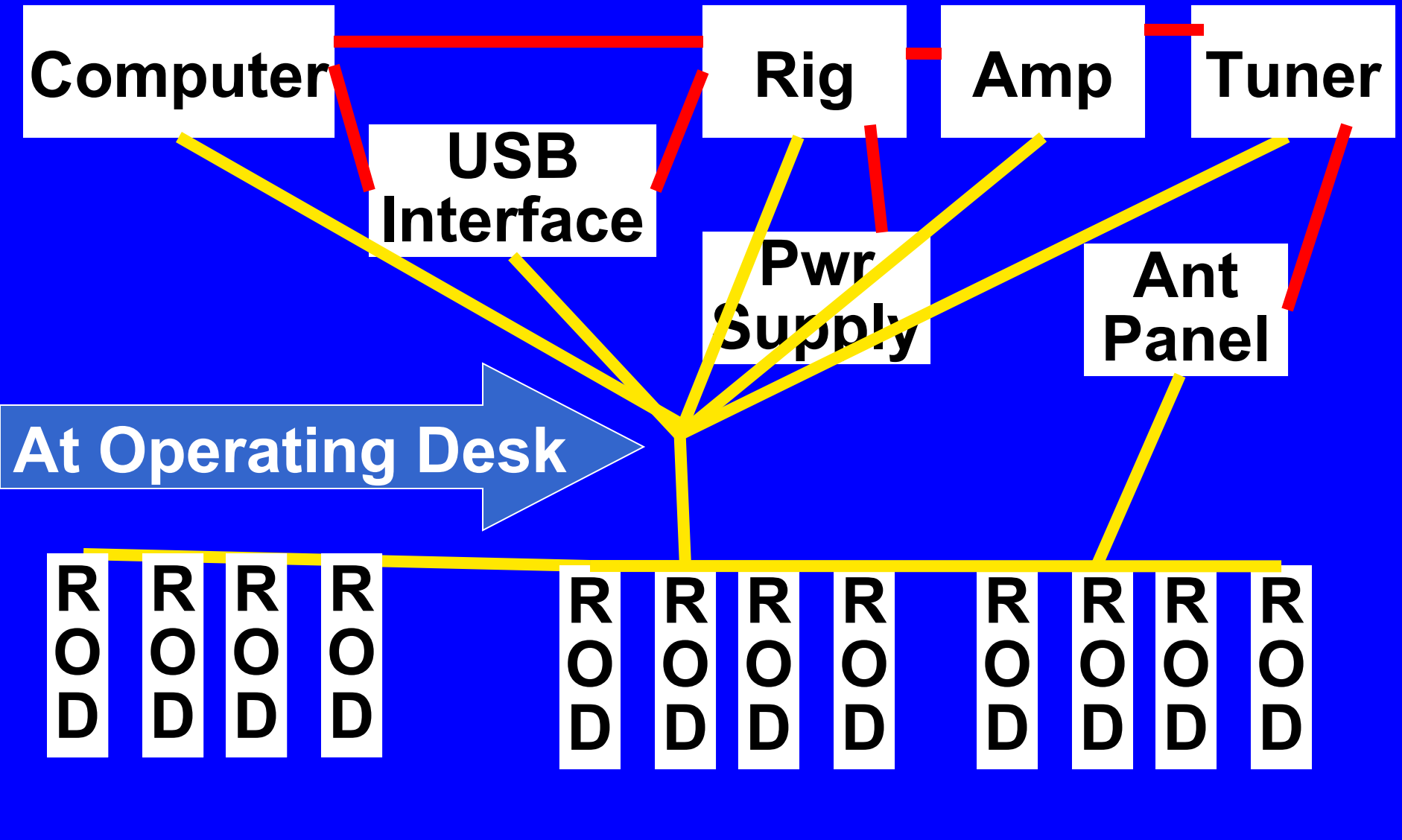
Single Point Creates Loops

Red Lines are Unbalanced Cables



This is OK, But Not Better!

Red Lines are Unbalanced Cables



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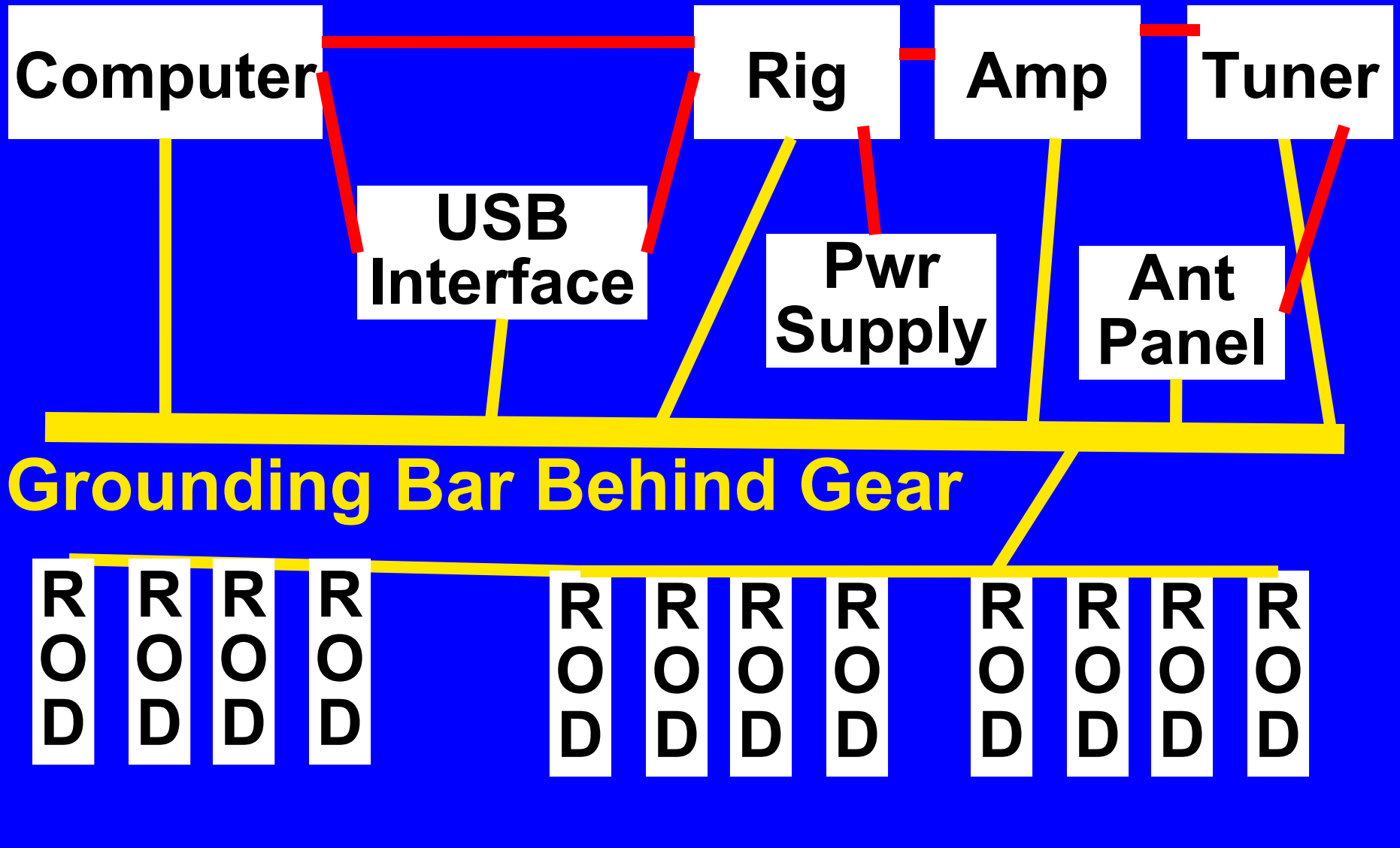
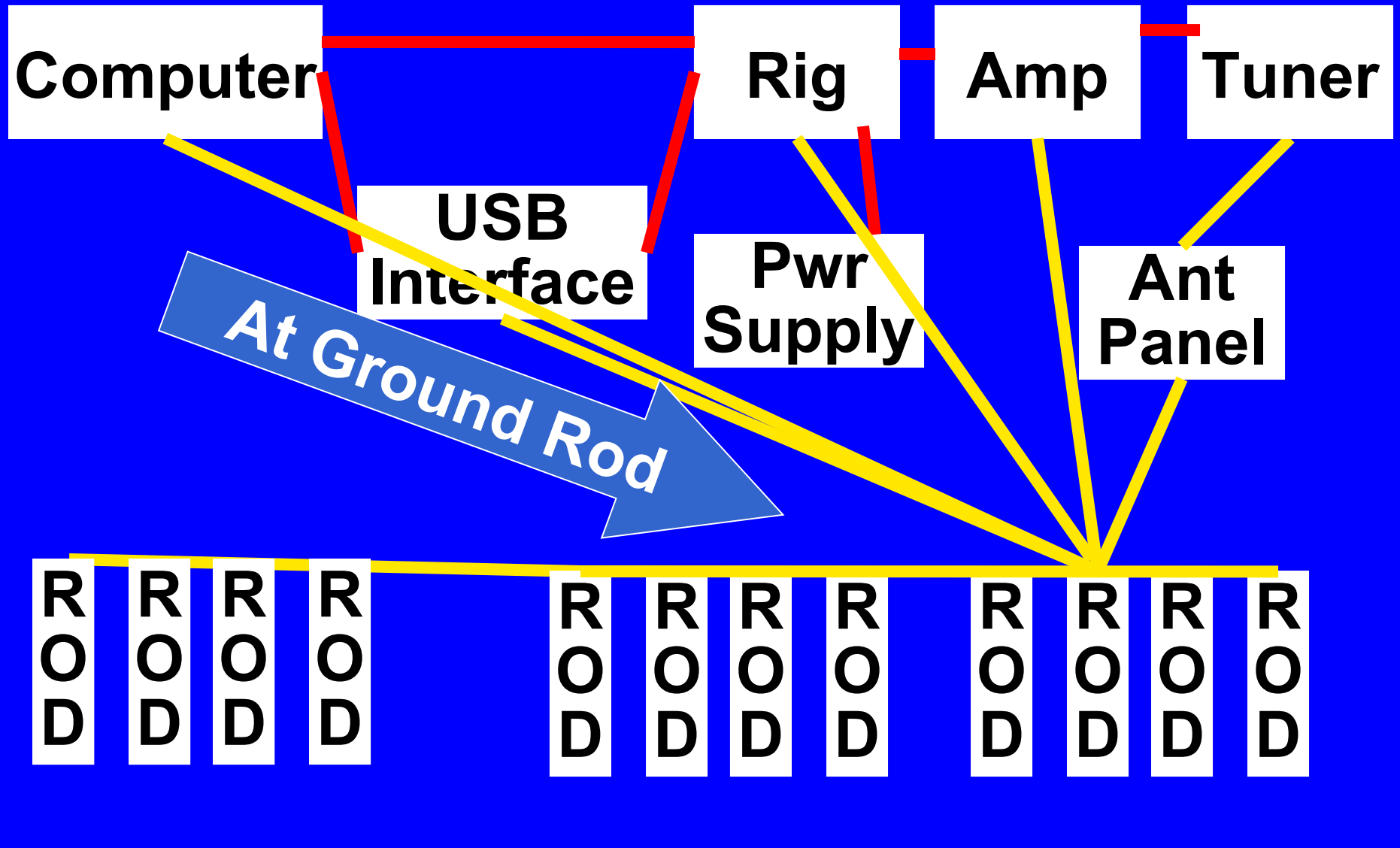
Red Lines are Unbalanced Cables



This is Terrible!

Red Lines are Unbalanced Cables



Single Point at Ground Rod

- The much longer path creates much larger loops
- Magnetic coupling is proportional to the loop area
- Bonding path between gear is much longer, so more resistance, more hum, buzz, and RFI
- Nearby lightning could wipe out this station!

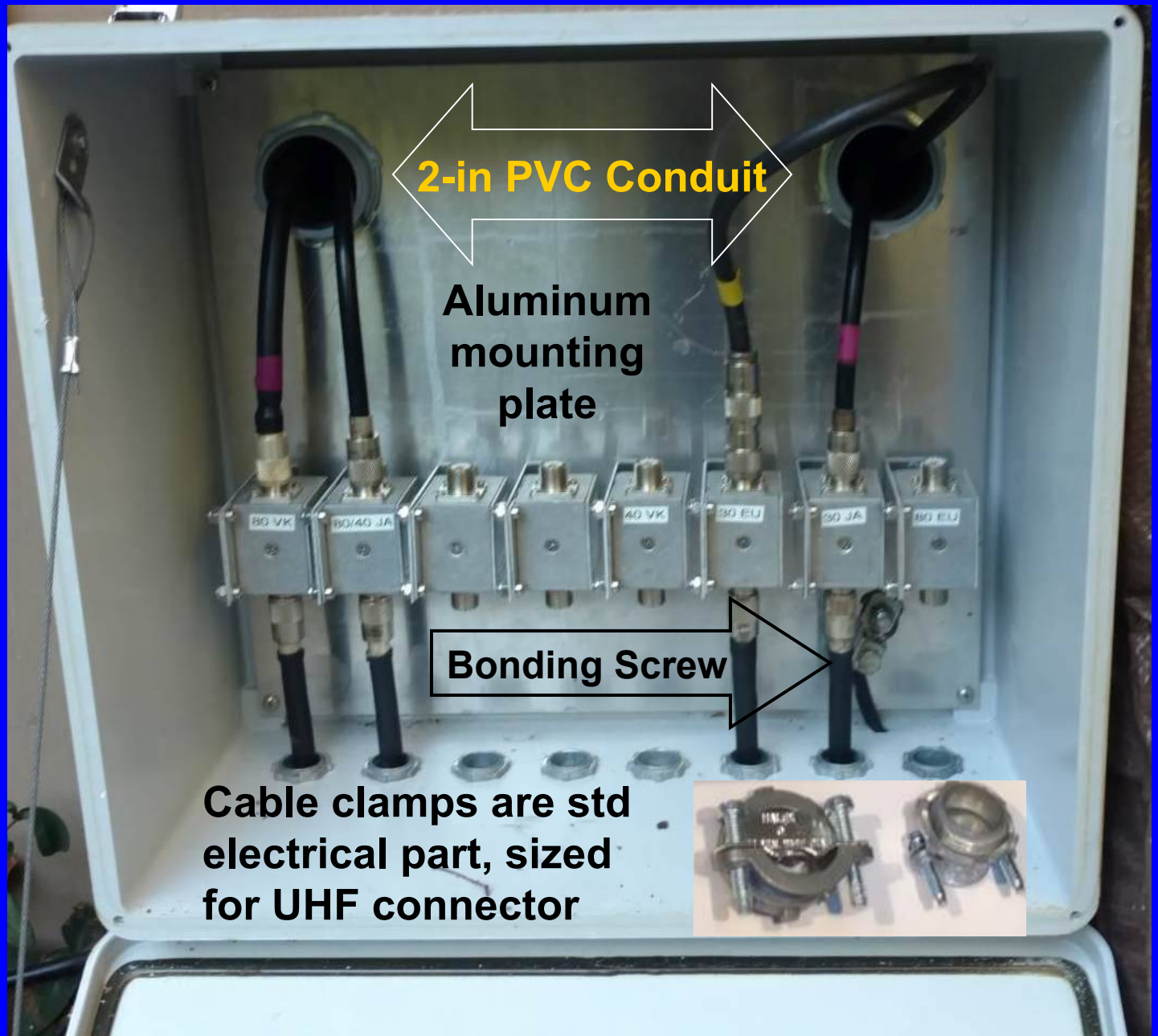
Killing Pin 1 Hum, Buzz, RFI

- Proper Bonding
  - Ohm's Law causes most audio current to flow on low impedance bonding conductors rather than much smaller interconnect cables
  - Forces most RF currents to bonding conductors
- Add ferrite choke(s) to interconnect cables if still some RFI (unlikely)
  - That's topic of another talk

What Coax Arrestors Do

- Bonds shield to entry panel
  - Bond to nearest rod and operating desk
  - Provides lightning safety
- Shorts coax on a strike to protect receiver input
- Locate arrestor panel with minimum coax to receivers
  - Induced voltage can build along coax
- No protection if far from receiver

Arrestor Panel In Hoffman Box



Details On Arrestor Panel

- 3 kW Array Solutions Arrestors
  - (Morgan/ I.C.E. design)
  - Now mfd and sold by KF7P
- Mounted to Aluminum backplate
- I.C.E. Design:
  - Shunt discharge inductor on antenna side
  - DC blocked (there versions without caps)
  - Shunt GDT (gas-discharge tube)
  - Shunt resistor on radio side

What MOV Surge Protectors Do

- Shorts the strike to Green wire
  - Raises the chassis to very high potential
  - VERY likely to fry circuitry in “protected” equipment and any equipment connected to it
  - Like Ethernet, USB, HDMI, etc
- MOVs are often built into computers, printers, other equipment
- MOVs are a great reason for WiFi

Wired Ethernet and Lightning

- Large potential differences possible between equipment powered from widely separated outlets
- Things can fry when Ethernet cable applies that voltage to their Ethernet ports
- Made much worse with shunt-mode surge suppressor, which dumps strike onto green wire (all MOV suppressors)

Wired Ethernet and Lightning

- Use only when interconnected equipment is close together, and powered from outlets whose green wires are bonded together
- Avoid unless low/stable latency is required, like remote operation
- My only wired Ethernet is short jumper between cable modem and WiFi router

Lightning Damage – USB, Ethernet, Control Circuitry

- Damage likely if all connected equipment is not bonded
- Damage more likely if connected equipment plugged into widely separated outlets

MOV Surge Protectors

- Because they dump the strike onto the Green Wire, MOV protectors that plug between equipment and outlets, or even built into equipment, raise the chassis of the equipment to a very high voltage.
- This makes it more likely that they will FRY connected equipment than protect it

A Safe Surge Protector For Use At Equipment

- Series-mode protectors store energy from the strike in a very large inductor
- Discharges field slowly as small current after strike
- Doesn't raise the chassis voltage, so won't fry connected equipment
- They're not cheap
- They've protected my computers, audio gear, and station for more than 20 years

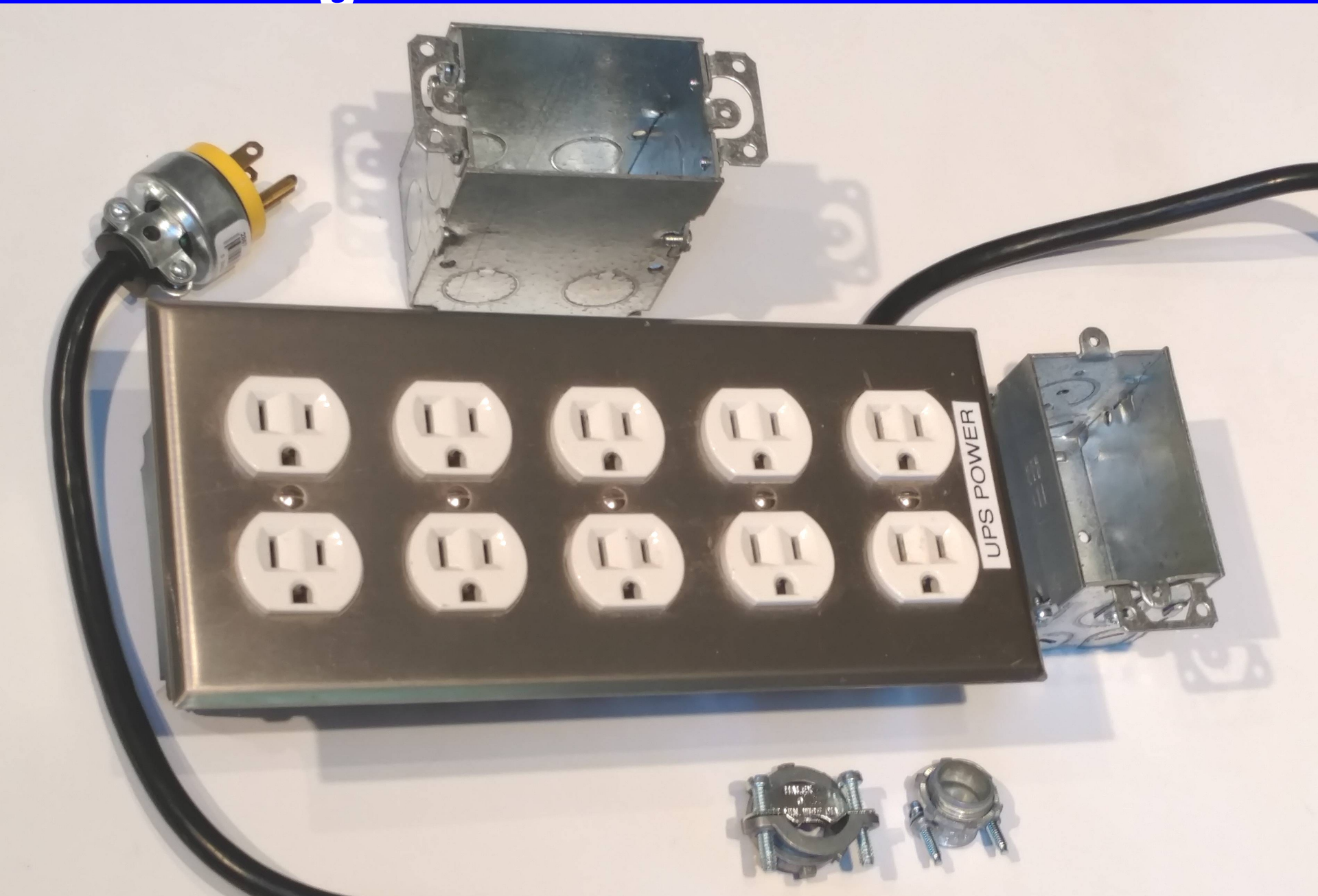
Series Mode Protectors

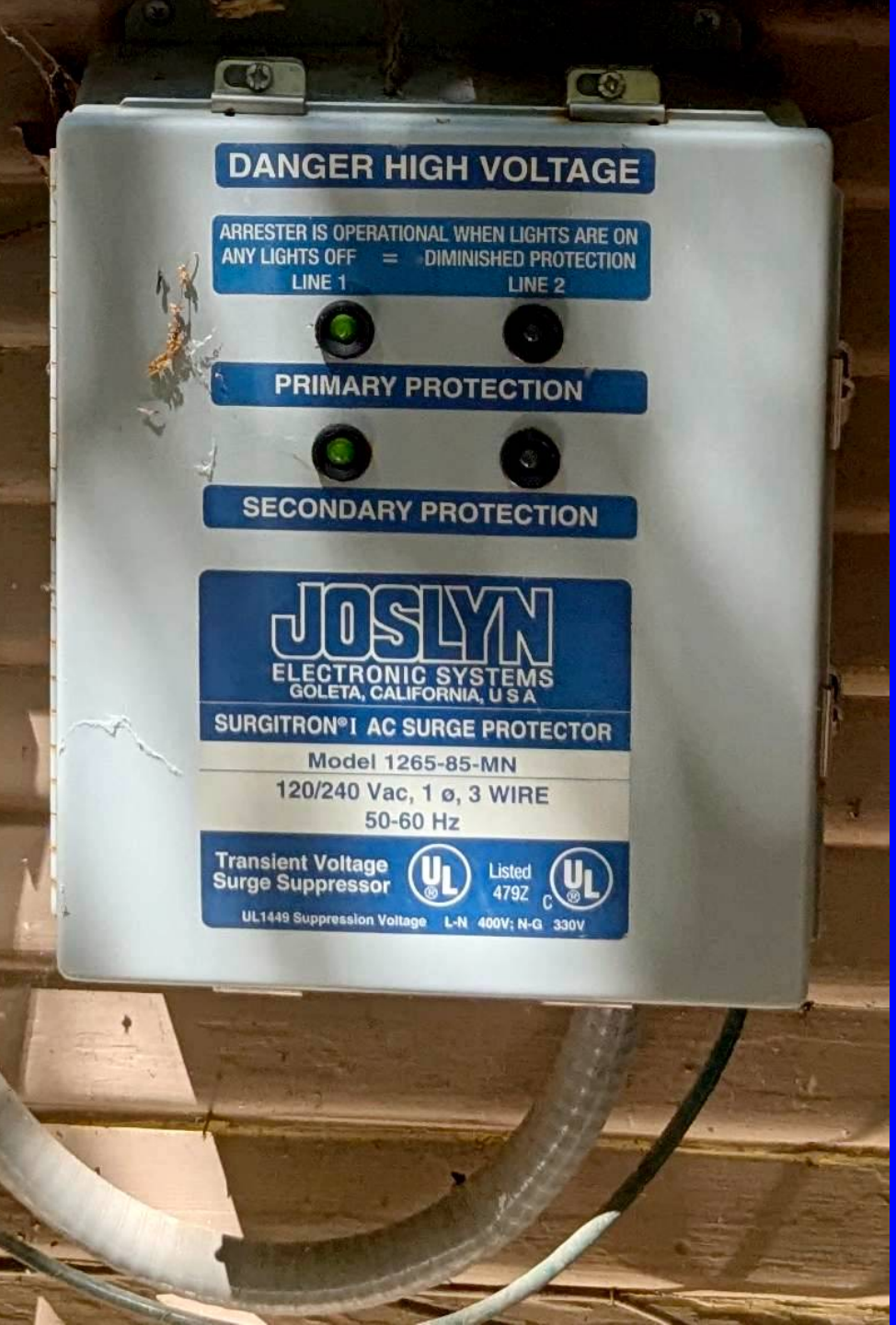
SA-1810 15A $699

SA-20 20A $649

I use SA-20s, with multi-outlet boxes. Full Compass (WI) and Sweetwater (IN) are good distributors. There are no protectors for 240V circuits -- the very large inductor that would be required for 240V is not practical.

Use Gangable Boxes for More Outlets





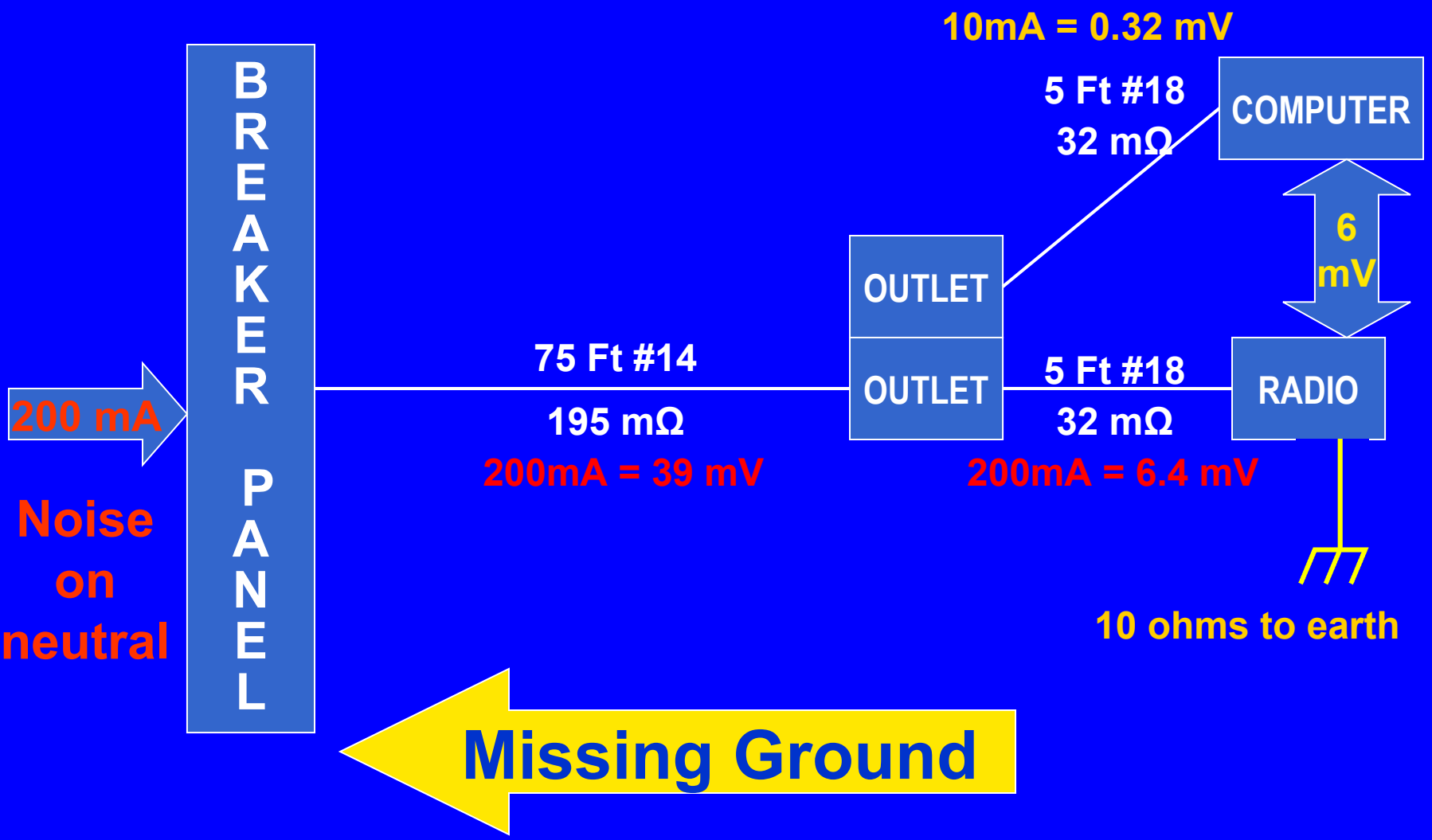
- **Top quality "Whole House" protectors are a very good idea, and MOVs are are the right device to use at the service entrance. This one is at my home.**

Still Have Hum/Buzz?

- Find problems with building grounds
- More than one neutral to ground bond
  - Washer, dryer, oven
  - In second breaker panel – bonding screw is present by default, must be removed
- Mis-wired outlet anywhere in home
  - Check each with outlet tester
- Missing ground at breaker panel or power entry

Typical Outlet Testers

Another Cause of Buzz



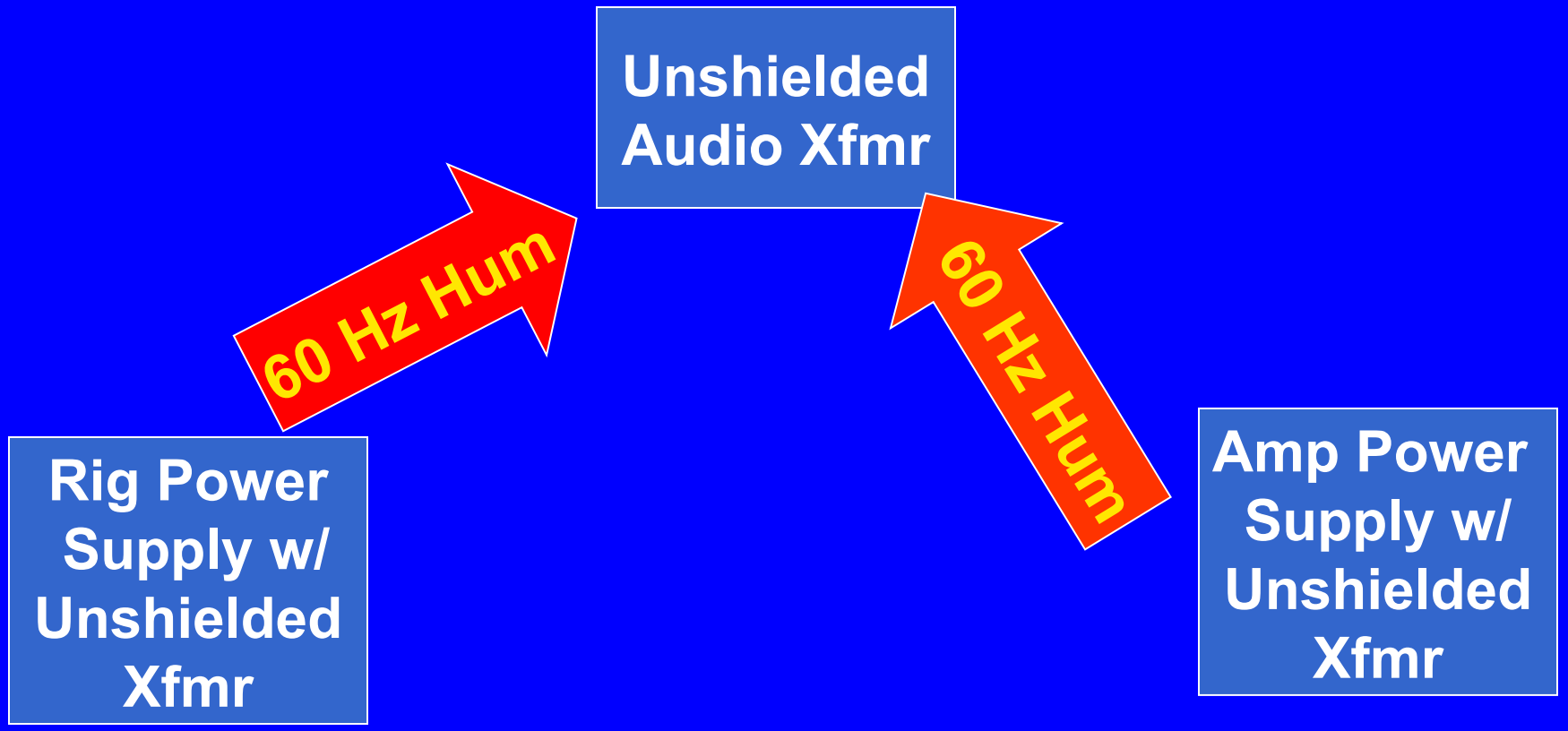
Hum (pure 60 Hz) vs. Buzz

- Nearly all hum is magnetically coupled
- Nearly all buzz is coupled by Pin 1
- Two sources of hum
  - Leakage flux from power transformers
  - Magnetic fields caused by wiring errors in the power system

Hum From Power Transformers

- Big transformers in power supplies couple hum into audio transformers
  - Move power xfmr away from audio xfmr
  - Rotate the power supply to put the field at 90° to the audio transformer's field
  - Rotate the audio transformer
  - Shield the audio transformer (expensive)
  - Get rid of the audio transformer – we don't need it if bonding is done right!

The Problem with Cheap Audio Transformers



An unshielded audio transformer can cause a hum problem!

Audio Transformers

- We do need a transformer to bring audio in from another building on wires
  - Remote operation, etc.
  - Need *mu-metal shield* to reject magnetic fields
  - Need *dual Faraday shields* to reject RFI
- Lundahl – http://lundahl.se
  - Sweden, good, better, best
- Jensen – http://jensen-transformers.com
  - SoCal, better, best, super best

Audio Transformers

- A dumb (expensive) fix for “ground loops”
- Sitting duck for magnetic fields
  - Must be well shielded!
  - Shielding is expensive (typically $100-$200)
- With proper bonding
  - We don’t need a transformer!
  - We don’t need an opto-isolator!
- An ***unshielded*** audio transformer can cause more problems than it solves!

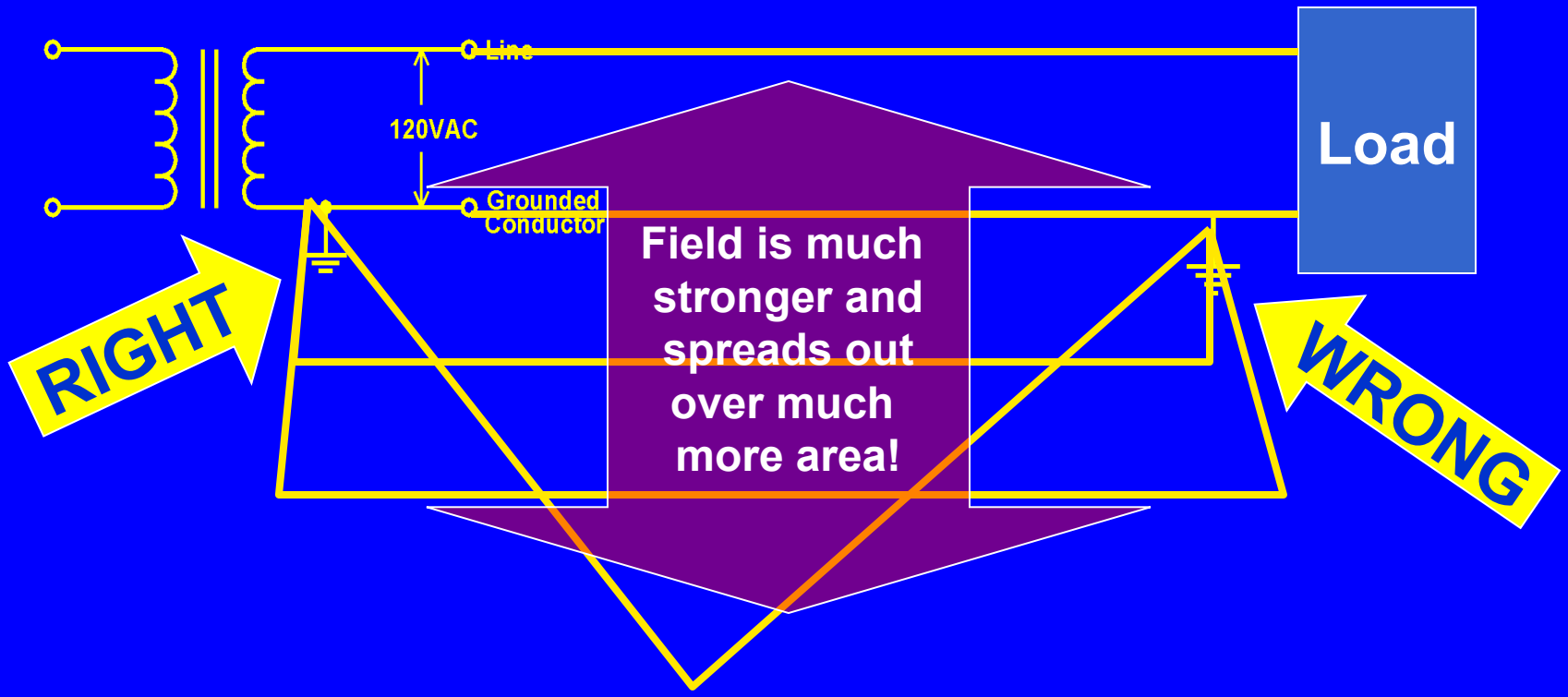
A Double-Bonded Neutral Creates An Interfering Magnetic Field

- Usually heard as “hum” (pure 60 Hz)
  - Mis-wired outlets
  - Built-in appliances
    - Washer, dryer, kitchen stoves
  - HVAC systems

Field with Single-Bonded Neutral (Right)

- Magnetic field mostly confined to the very small area between conductors – that is, between the wires

Field With Double-Bonded Neutral (Wrong)

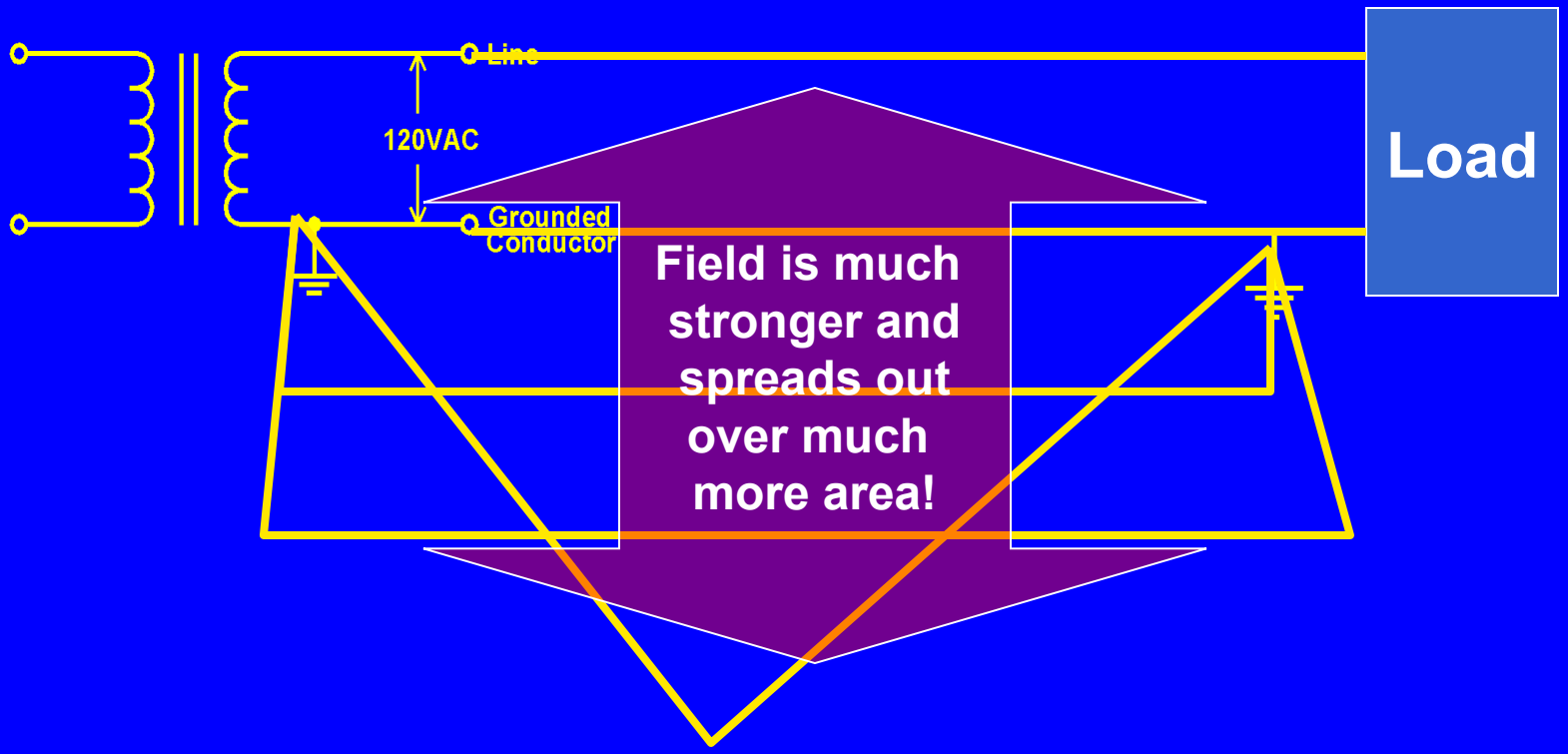


- Field may engulf large areas of a building!

Double-Bonded Neutral

- Neutral must be bonded to ground ONLY at the breaker panel or service entrance, NEVER anywhere else
- Finding the additional bond
  - Might be at our load or at an appliance
  - Might be at a second panel (wrong)
  - Use AC voltmeter to look for zero volts between neutral and ground (that's bad – it indicates an extra bond)
  - Should see 20mV – 2 volts (normal IR drop in neutral due to return current)
  - This will be *buzz*, not *hum*

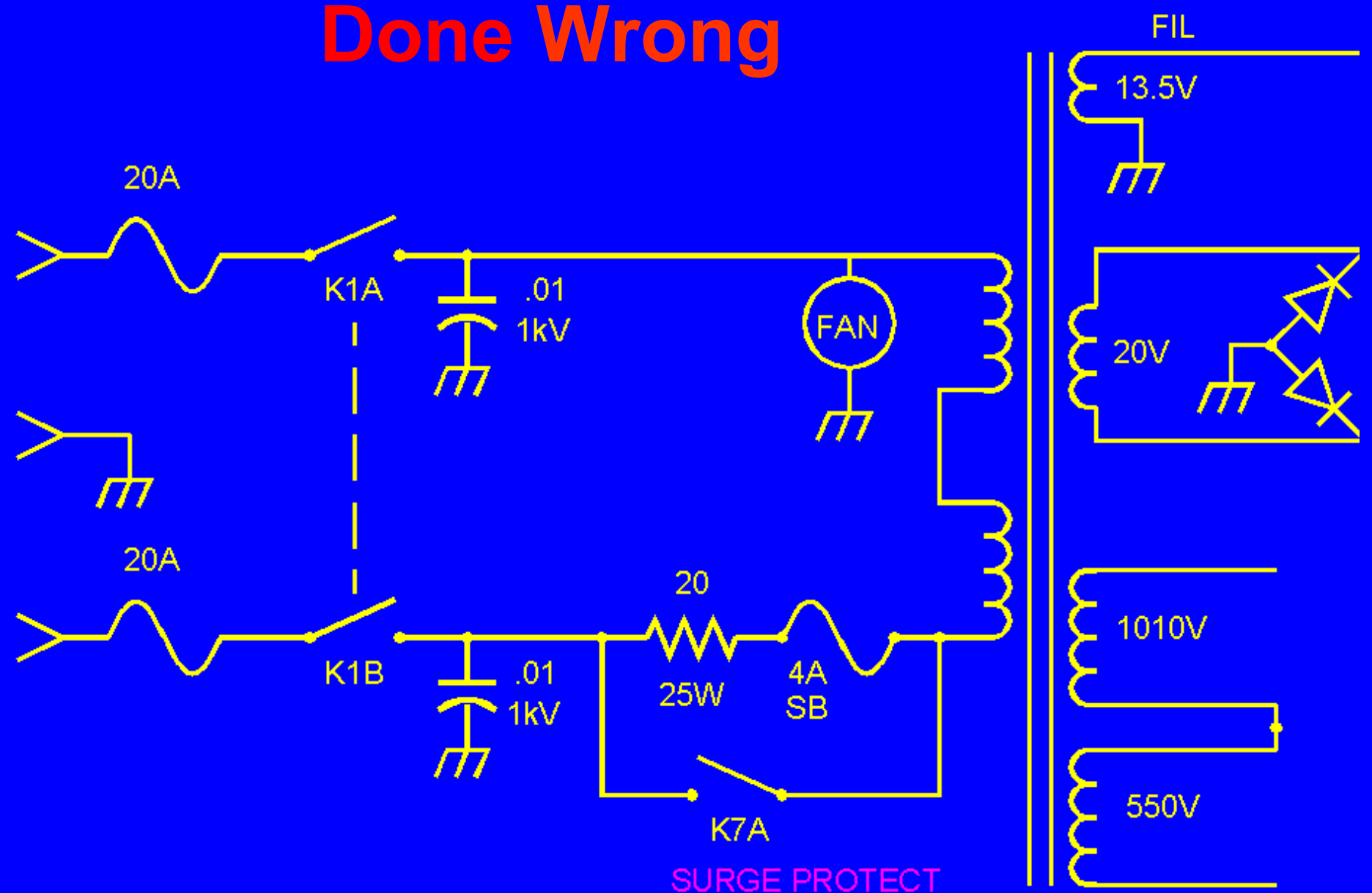
Load Connected Hot to Ground (Also Wrong)



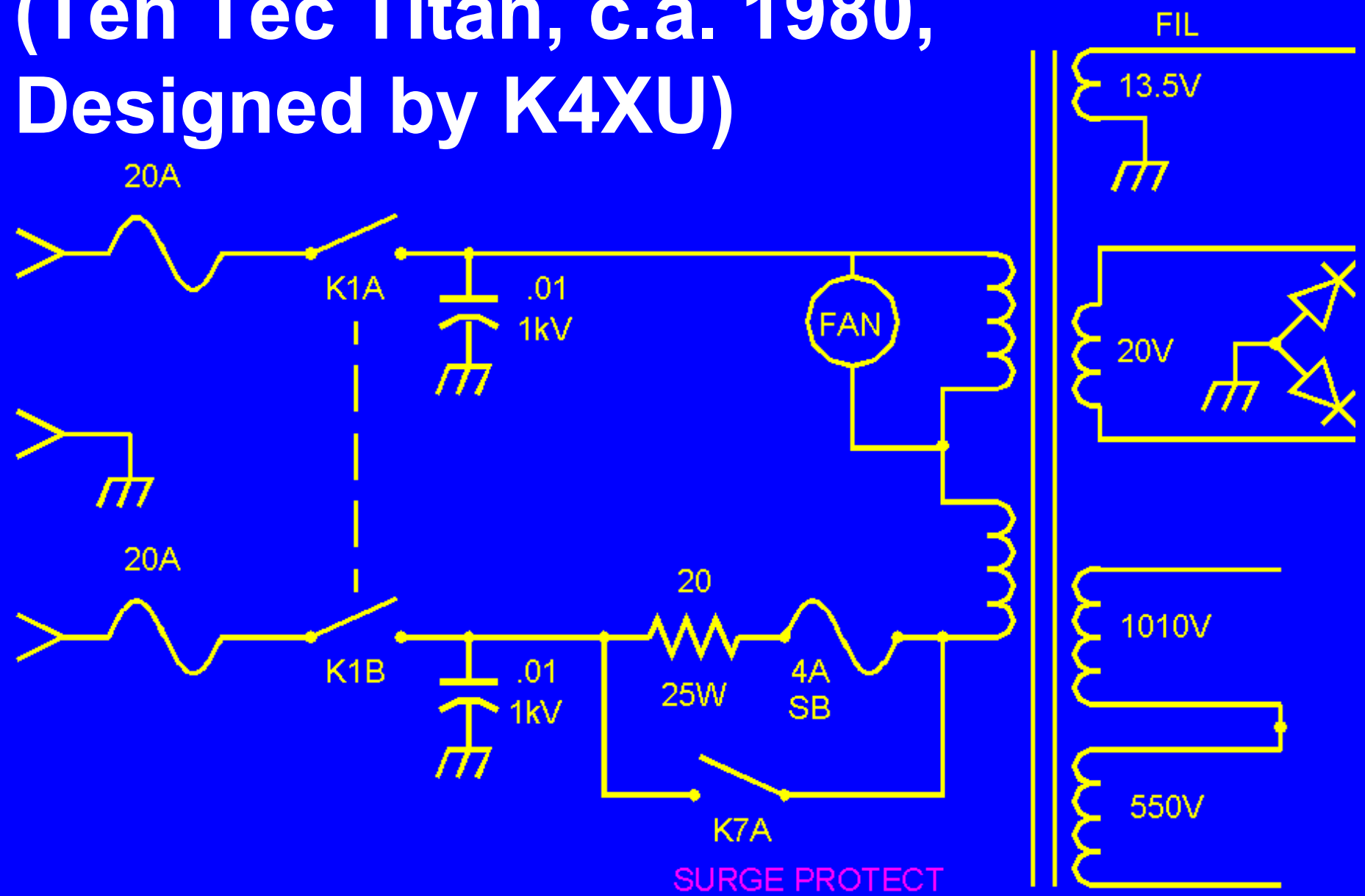
- Field may engulf large areas of a building!
- Puts hum voltage on green wire (chassis)
- Fans in some older power amps

120V Fan in Power Amp

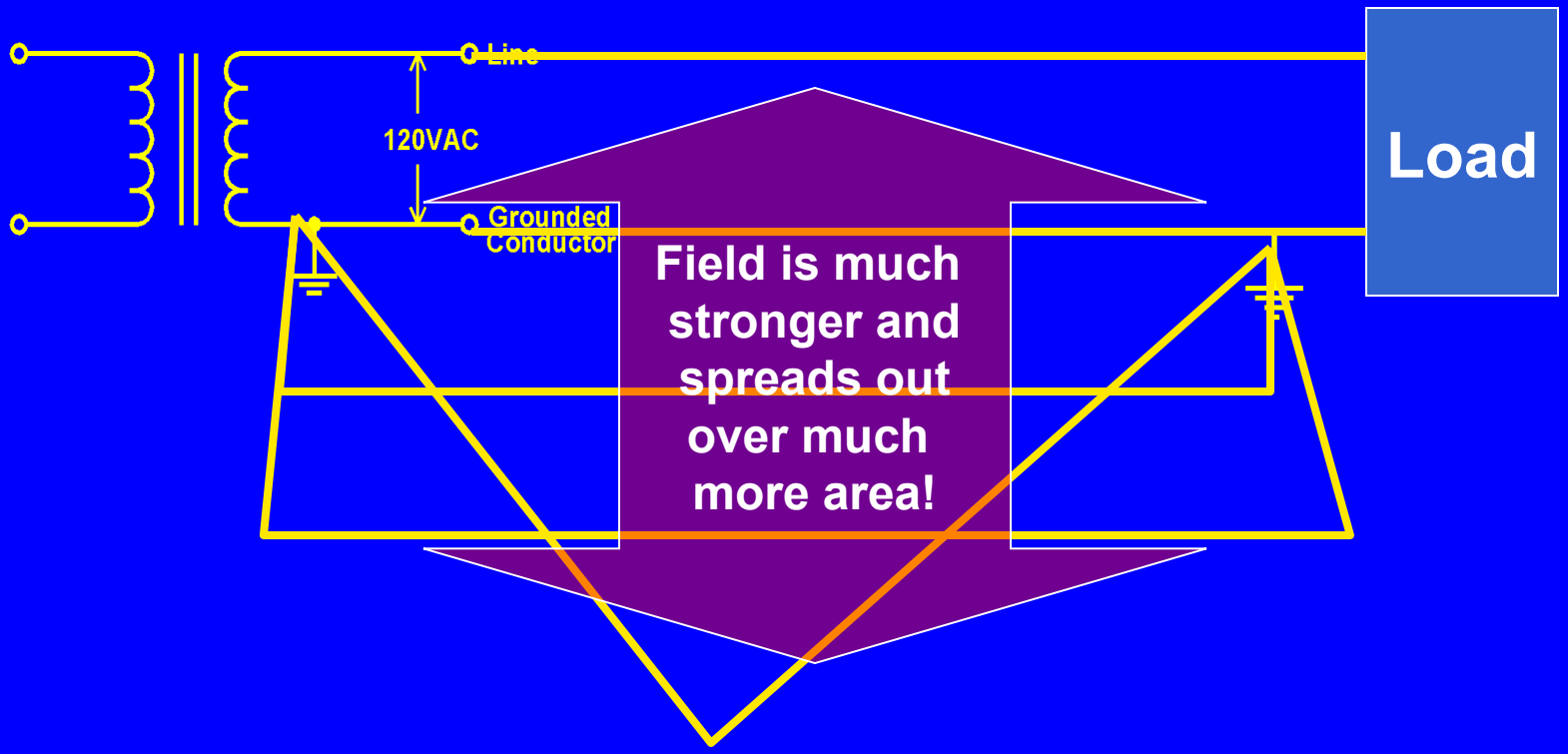
Done Wrong



120V Fan in Power Amp Done Right (Ten Tec Titan, c.a. 1980, Designed by K4XU)



Load Connected Hot to Ground In Alpha 77, 500 mA



- Field may engulf large areas of a building!
- Puts hum voltage on green wire (chassis)

Measuring AC Line Currents

- Every ham should own a clamp-on AC Ammeter
- We need to measure small currents, not large ones
- We need to measure a few tens of mA on Green, hundreds of mA, up to 25A on line and neutral
- Meters may be calibrated for peak, average, or RMS
- More than 10 mA on Green is a problem!

Stand-Alone AC Ammeters

Fluke (above) has Hall Effect sensor to also measure DC current

We Need A Break-Out Cable

Measuring AC Line Currents

- A calibrated clamp-on to feed a VOM or scope can be useful
- Can show waveforms and transients
  - How well depends on bandwidth of probe and VOM or scope
  - Many (most?) don't extend above power harmonics

Current Probes For Meter or Scope

Larger coil provides greater sensitivity

Other Power Problems

- Fix magnetic field problems
  - Hot to ground loads
    - NEVER do this – causes current to flow on ground
  - Current on green wire to station ground
    - Station ground better than power system ground?
    - Power system ground not bonded to station ground?
    - Power system not properly grounded?

Power For A New Shack

- One 20A 240V circuit
- Bring 4 wires to the shack
  - Both sides of 120V (Black, Red)
  - Neutral (White)
  - Ground (Green)
- One or two 240V outlets (for SO2R)
  - Both sides of 240 plus ground (green)
- Use #10 for reduced IR drop

Power For A New Shack

- Add 120V quad boxes, at least two per leg (wired 120, neutral, green)
  - Feed from the same 20A-240V circuit
  - More than enough power for all the radio (and computer) equipment in any single-op legal limit station
- Mount all outlets in steel back-boxes
  - Back-boxes must be bonded together
  - Steel conduit between boxes (EMT is fine) provides excellent bonding

Power For A New Shack

- Lowest cost alternative
  - Only one run from breaker panel to shack
  - Most of the cost is labor
  - Wire, outlets, backboxes are cheap
  - Use good quality 20A outlets
  - Use #10 copper for everything
    - 30A circuit will run two legal limit amps TX at the same time (Multi-2)

Power For A New Shack

- A 30A 240V circuit split to 120V 20A outlets will require a small sub-panel in (or near) the shack
  - Will run two legal limit amps, rigs, and computers at the same time (Multi-2)
  - #10 AWG is legal for 30A, but #8 would be better

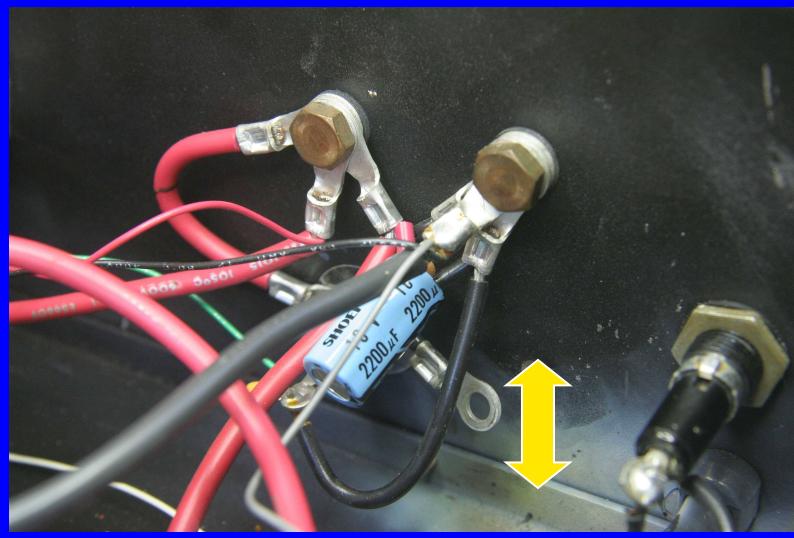
Bonding in Shack DC Power Supplies

- Properly built supplies have all circuitry on the DC side of the transformer isolated from the chassis
- If it is bonded to the chassis, it will be at or near the V- output terminal
- This bond should be removed for use in our stations

Astron Green Wire Bonding Failure

- Green wire is bonded to the mounting lug of an old-fashioned terminal strip that is insulated from chassis by paint
- On some models, this is also where V- is bonded
- On these models, this failure can cause the PSU to be unstable (oscillate)
  - This is a known problem with Astron supplies

Removing The Power Supply V– Bond



- In many Astrons, the bond is from the V– terminal to the chassis ground screw near it
- In many Astrons (like this one), paint gets in the way of the bond, so many Astrons that appear to be bonded are not!

Fixing The Astron Green Wire Bond

- Unscrew the terminal strip, scrape the paint to make a good connection
- Remove the V– bond if there is one
- Leave the green wire from the 120V plug connected
- Re-mount the terminal strip

Power, Grounding, Bonding, and Audio for Ham Radio

Safety, Hum, Buzz, and RFI

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