Principles of Audio System Grounding and Signal Integrity

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Agenda

- Noise and interference: what is it?
- Introduction – basic principles of residential and light-commercial AC power
- Interconnection – analog signal integrity in audio interconnection cables
- Sources of interference – inductive/magnetic coupling, capacitive/electric coupling
- What to do to find and eliminate problems
- Conclusions

Disclaimer

- This is NOT an authoritative lecture or training session about the National Electrical Code!
  - Some or all of you may know more about the NEC than I do!
  - Designers and installers must consult and follow the Code, and use qualified, licensed personnel.
  - Whenever there is a doubt, consult with a knowledgeable, licensed electrician.

Some material taken from:

- Bill Whitlock, President, Jensen Transformers

"An Overview of Audio System Grounding and Interfacing," September, 2012, Audio Engineering Society Central Indiana Section.

https://centralindianaaes.files.wordpress.com/2012/09/indy-aes-2012-seminar-w-notes-v1-0.pdf

Grounding and Interfacing

- Many myths and misinterpretations
  - Cables don’t magically “pick up” noise
  - The “earth” is not a magically perfect “ground”
  - Better “shielding” is not always the answer
  - Just because a box or cable is expensive does not mean it has good interconnect properties
  - *Physics is not negotiable!*

Electrical Noise

- ALL electronic materials and devices have inherent noise.
  - Johnson/Thermal noise: $v_{rms}=\sqrt{(4kTR\Delta f)}$
    e.g., 10k resistor, 20kHz bandwidth, @ room temp: $v_{rms}= 1.8\ \mu V$.
- Dynamic Range: Ratio of the maximum undistorted output signal to the residual output noise, or “noise floor.” Good audio systems require 120dB range (ratio 10^6).

Electrical Noise (cont.)

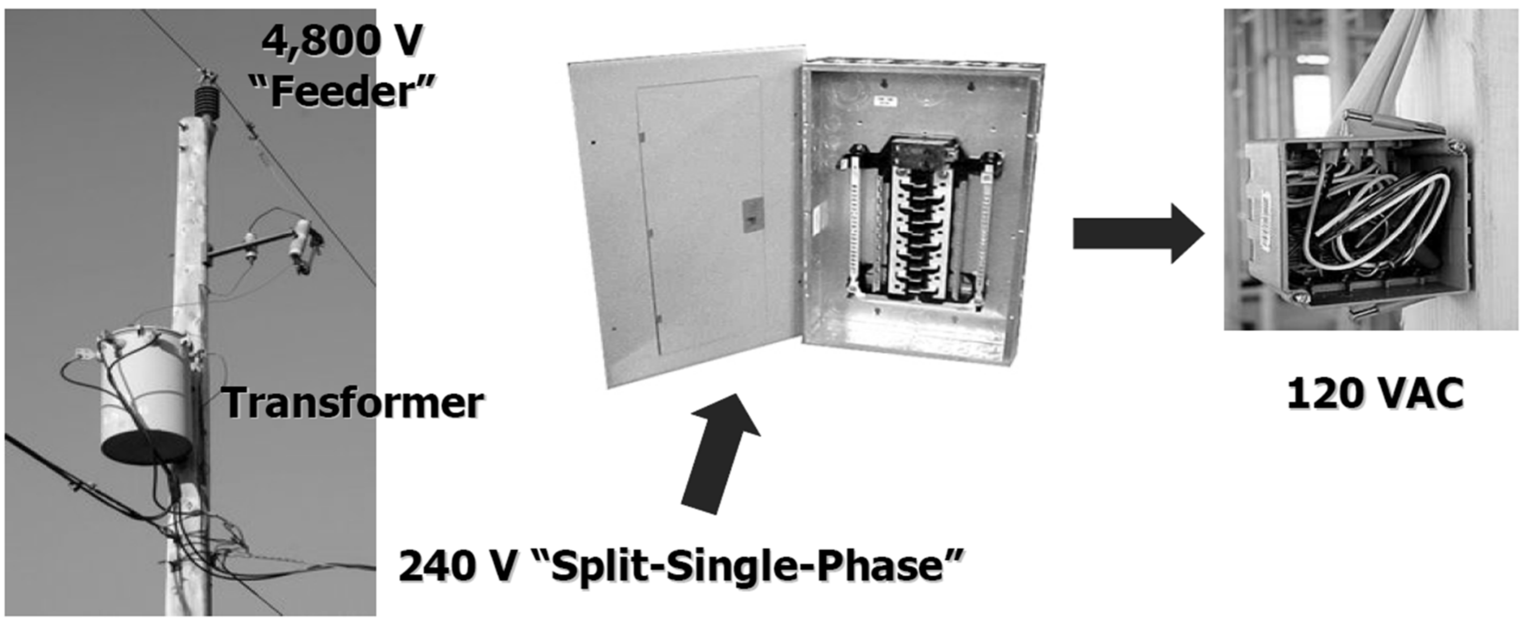
- Once in-band noise becomes part of an analog signal, it is essentially impossible to remove it.
- Therefore, the *weakest link* principle applies: the dynamic range of an audio system is constrained by the dynamic range of each stage.

Things to remember…

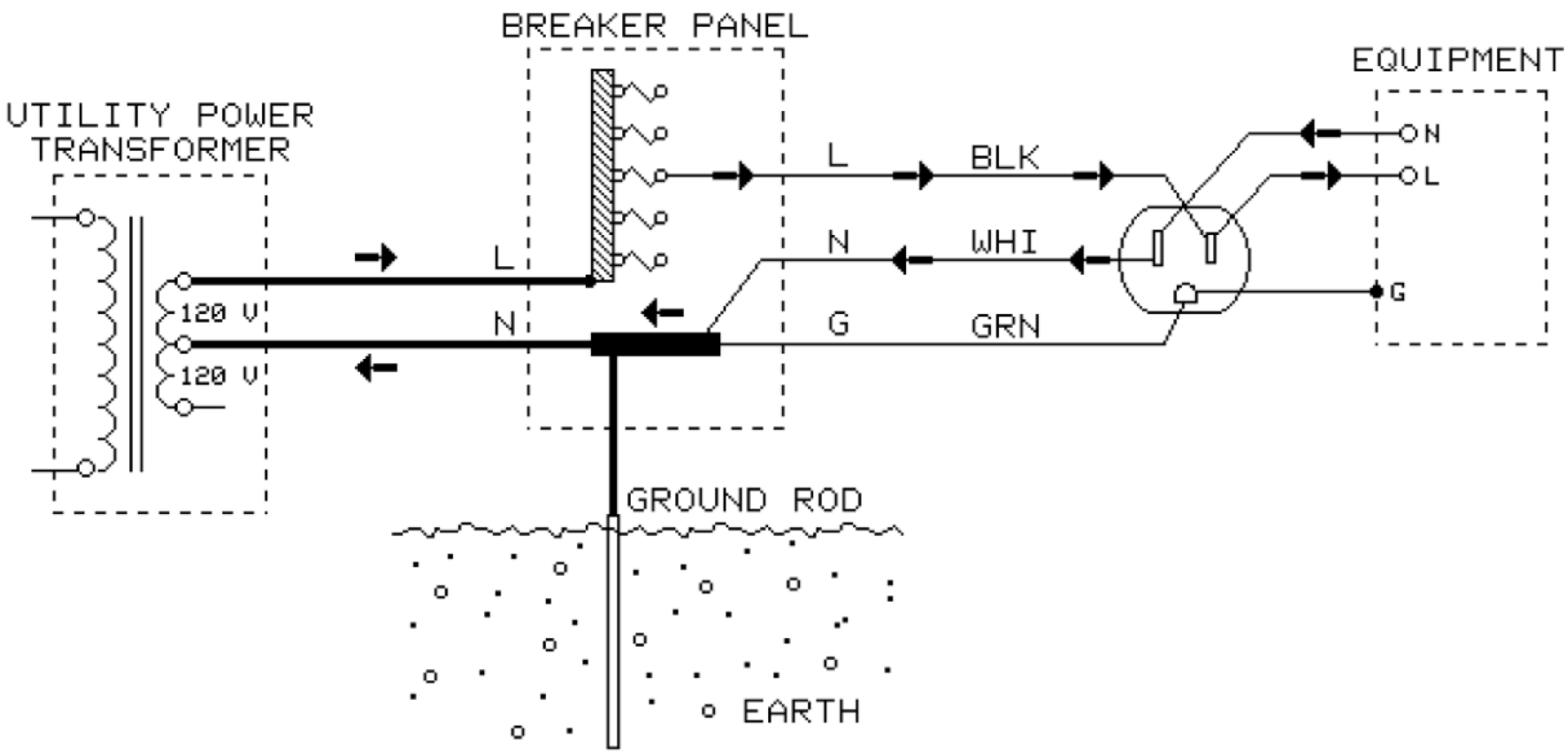
- Circuit principles are key: identify the circuit and all AC-coupled and DC-coupled paths.
- The protective ground (third prong) is there for life safety protection. Engineers shall NEVER defeat this purpose.
- Always employ good gain structure: never attenuate a signal that will have to be amplified again later in the audio chain.

Residential Power in U.S.A.

Delivery of Utility AC Power



Residential 3-Wire Service



What’s up with “GROUND”?

- Unfortunately, the use of the term “ground” is widely used to refer to a *common return path* in a circuit. It almost never literally means the physical earth (soil) ground, unless this is clearly stated.
- The ONLY reasons physical earth (soil) ground is considered is lightning protection and antenna (ground plane) propagation.

Mythical Soil

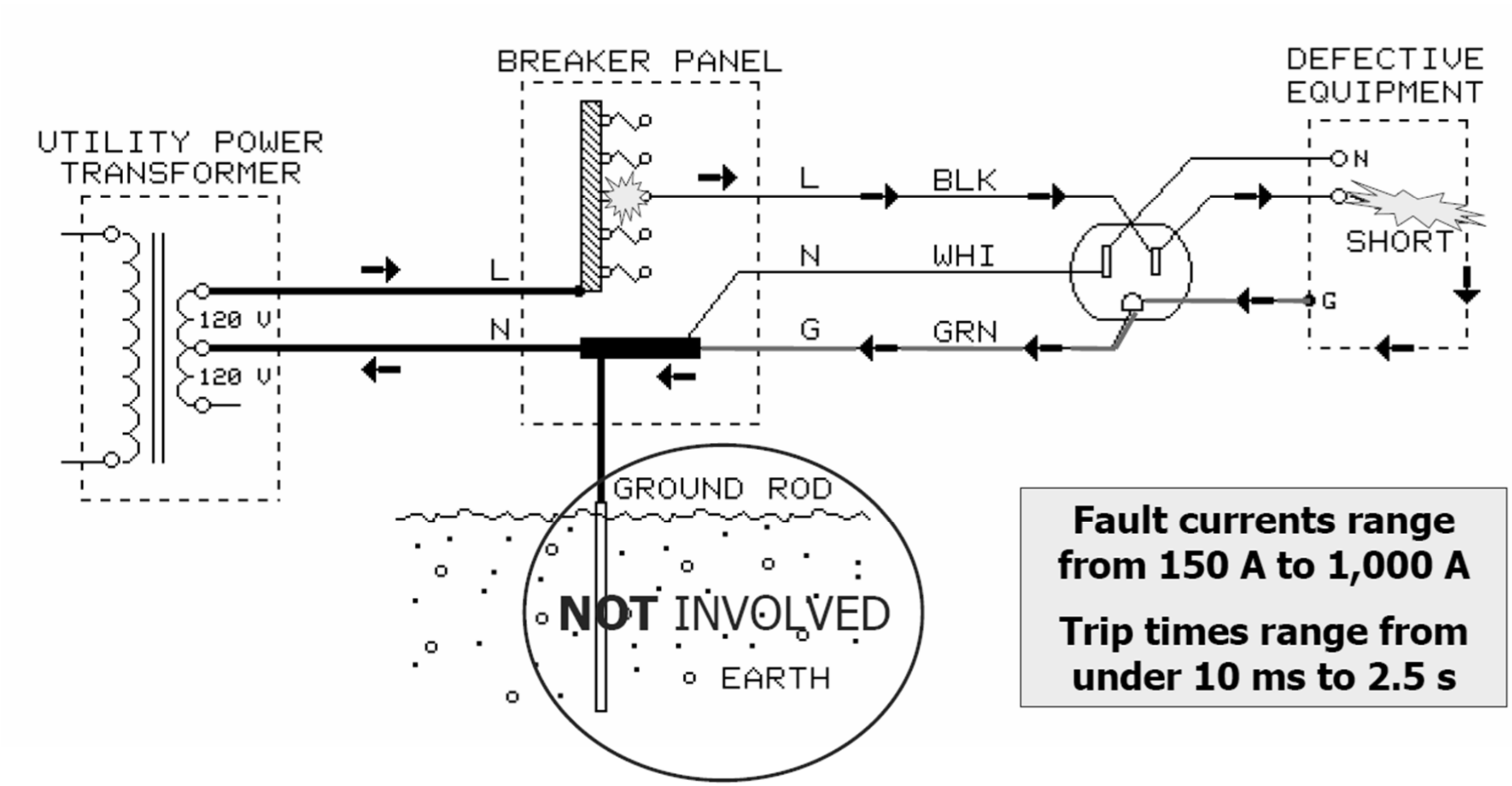
- A common statement by some audiophiles is that earth ground is essential for good quality sound.
- Apparently the earth can suck up all the stray electronic noise?
- Soil is generally a very poor conductor: not something with magical properties!

What's up with "GROUND"? (cont.)

- Automobiles have audio systems: are they grounded to the earth?
- Portable battery-powered electronics: is an earth ground necessary?
- Aircraft (and spacecraft!) have electronics: is an earth ground used? Of course not!

Why we use three wires:

FAULT Current Trips Circuit Breaker



Fault currents range from 150 A to 1,000 A

Trip times range from under 10 ms to 2.5 s

Protective Ground

- NOTE that the protection comes from the circuit loop wiring and the circuit breaker: the physical soil of the earth is NOT involved in the protective action AT ALL.
- The soil/earth ground provides a path for lightning to discharge before entering the premises. It is not essential for audio equipment at all.

Watch out: the 3-to-2 Adapter

- Some old residential electrical systems have two-prong outlets. In SOME cases the outlet box is served by metal conduit that is bonded to the ground bus at the service panel. A 3-to-2 adapter can be used to provide the protective ground continuity required by a three-prong appliance.

3-to-2 Adapter (cont.)

- HOWEVER, some individuals may try to remedy noise interference issues by “lifting” the protective conductor of a three-prong device by deliberately using the adapter <u>with the ground NOT connected.</u>
- If an engineer does this and there was a fire or injury in a system connected this way—the engineer is legally liable! NEVER do this!

A Particularly Bad Scenario

- One device has 3-prong power cable, connected to another device with a ground “lifter” in place.
- When a fault occurs in the “lifted” device, the resulting fault current can flow in the interconnect cable, likely causing it to overheat, melt, and catch fire.

GFCI

- If a protective safety ground is not available, always use a Ground Fault Circuit Interrupter (GFCI).
- By code, a GFCI need not have an actual protective ground wire back to the service panel.

Myths vs. Facts

- *“A stout copper wire has zero impedance”*
  - In fact, a wire will have finite DC resistance (milliohms per foot), and finite inductive impedance ($j\omega L$). The inductive impedance of a power conductor wire may be tens of ohms in the AM radio frequency band.
  - Inductance doesn’t depend much upon the diameter of the wire.

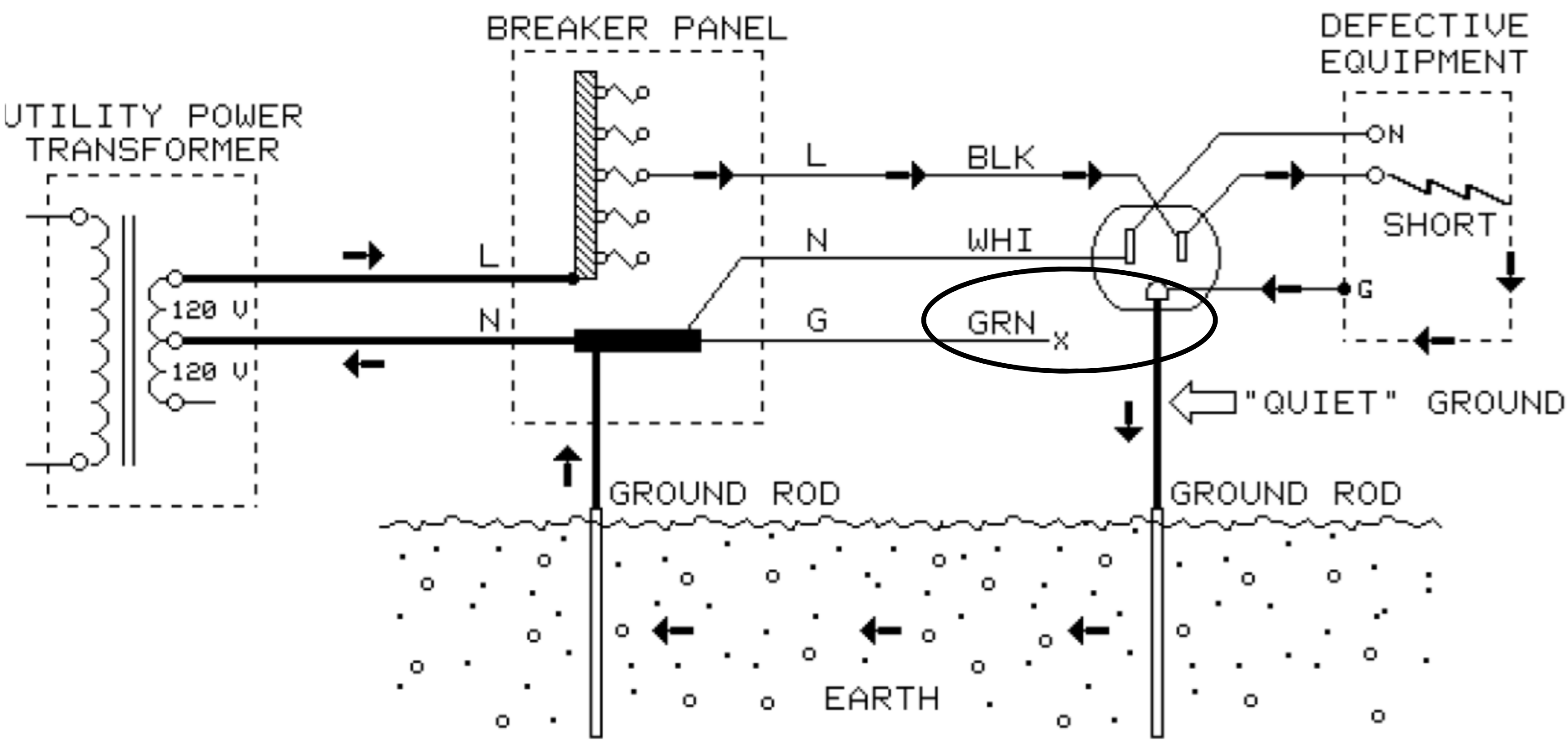
Myths vs. Facts (cont.)

- *“All earth/protective grounds need to be at zero volts, so use lots of ground rods.”*
  - In fact, soil resistance between separated ground rods is tens or hundreds of ohms (!), and varies with soil conditions, moisture, corrosion, etc. A wire connecting the ground rods will have a much lower resistance—and this is required by the code!

Myths vs. Facts (cont.)

- *“A ground loop is the fault of protective ground wires.”*
  - In fact, a ground loop is caused by ALL signal interconnection wiring, and so choosing an interconnection that is immune to ground loop issues is the solution, NOT eliminating protective grounds.

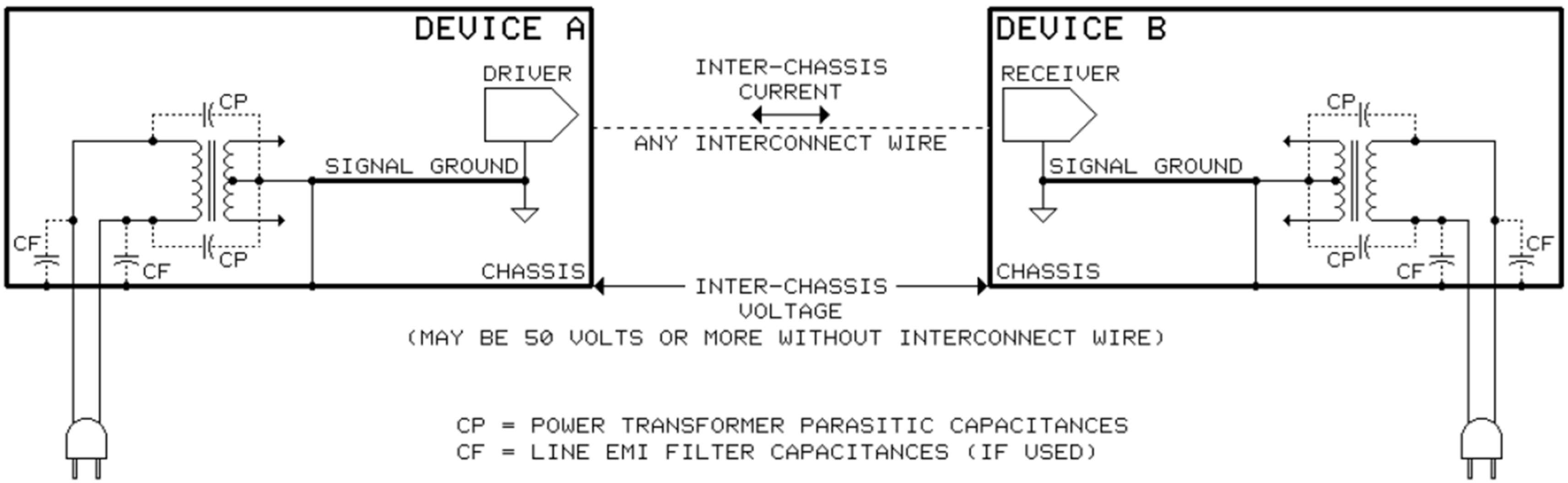
NEVER NEVER NEVER!!



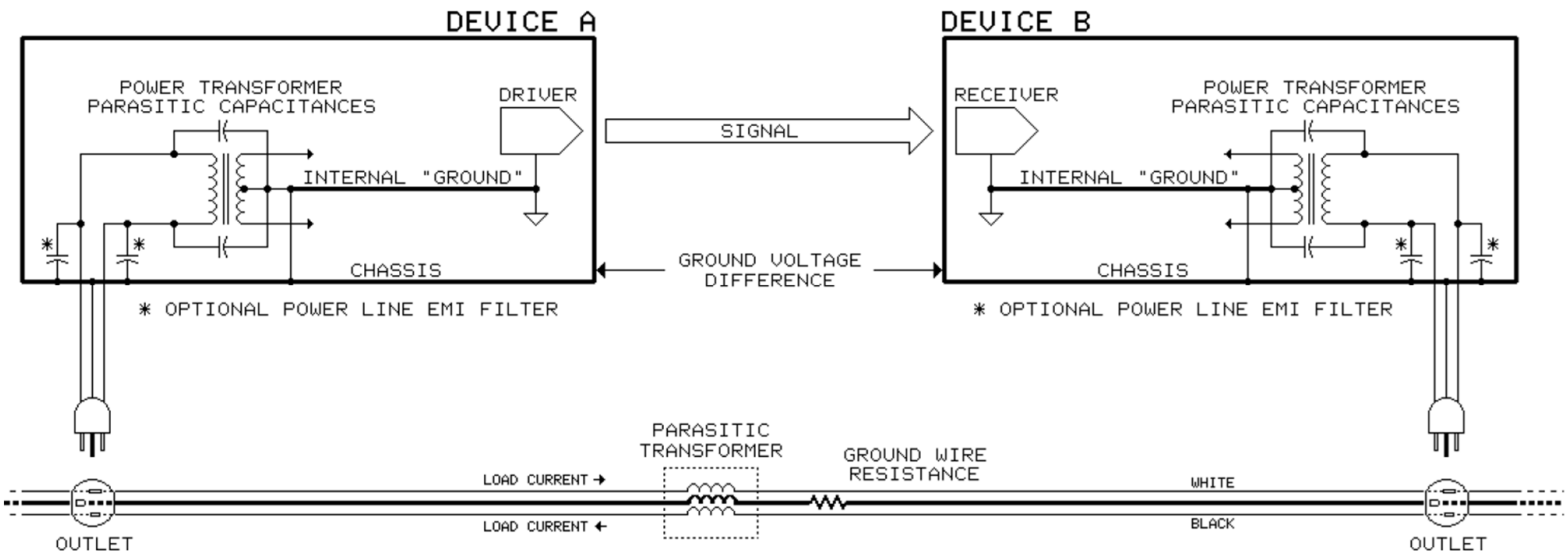
Audio Circuit Review

- Goal of interface: maximize voltage transfer (not power transfer)
- Current requires a circuit: audio frequency noise is due to current in the interface, and electric and magnetic field coupling.
- Nominal consumer level: 316 mV rms
- Nominal professional level: 1.23 V rms

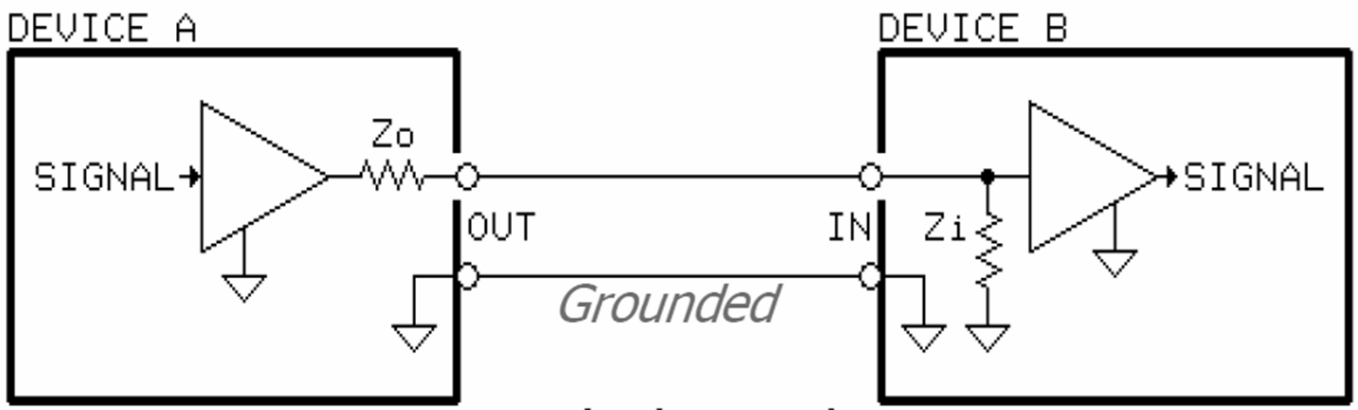
Audio Interconnect: 2 conductor (no earth ground)



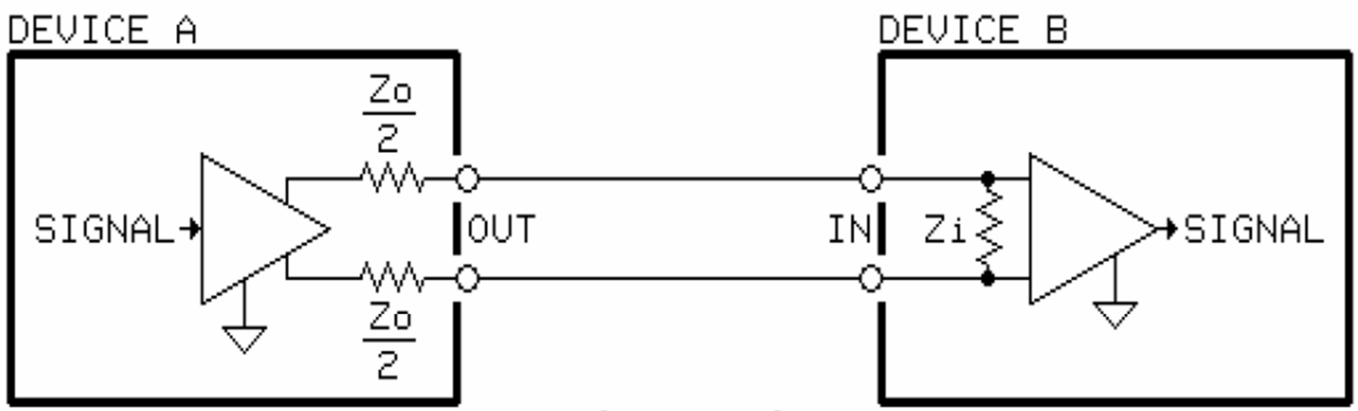
Audio Interconnect: 3 conductor (earth ground)



Unbalanced vs Balanced

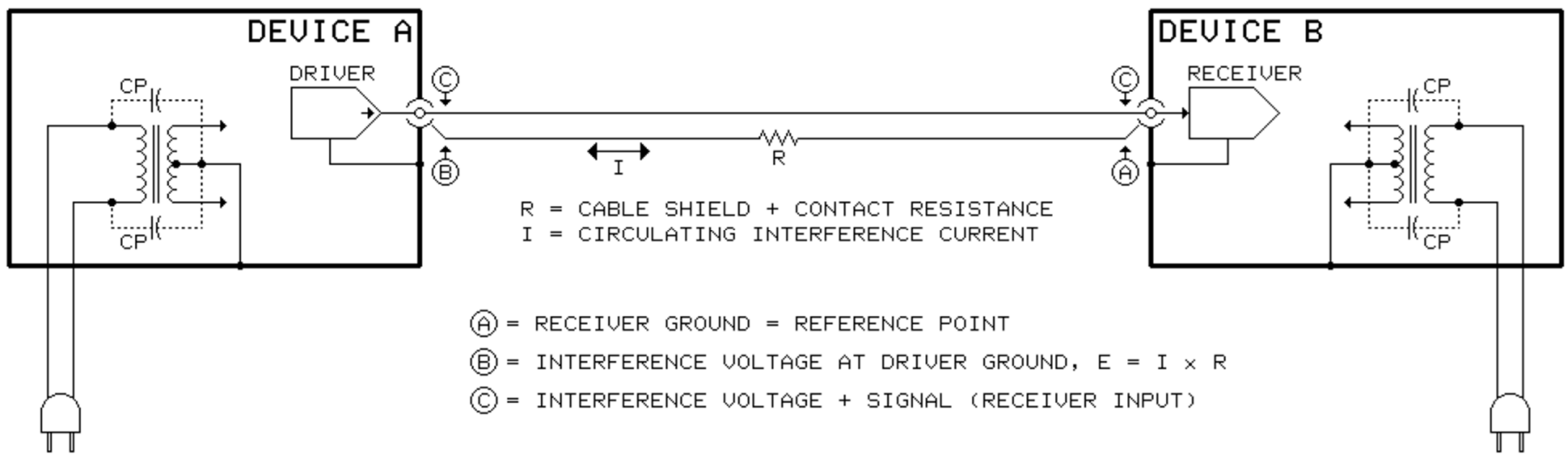


Unbalanced



Balanced

Unbalanced Interconnect: Inherently Noisy



Some numbers…

Leakage Current Effect - A Calculated Example

- A 25-foot cable (foil shield, #26 AWG drain wire) has an end-to-end shield resistance of 1 Ω
- Measured leakage current between the ungrounded devices is 316 μA (well under the UL limit of 750 μA)
- From Ohm's law, noise voltage E = I x R = 316 μA x 1 Ω = 316 μV
- Consumer −10 dBV reference level = 316 mV
- Signal to Noise ratio = 20 x log (316 mV/316 μV) = **60 dB**
  - **This is 35 dB worse than an audio CD!**
- Same length of **Belden #8241F** cable, with its shield resistance of only 0.065 Ω, makes S/N 84 dB, an **improvement of 24 dB!**

Audio cables: Check specs

Belden 8412
20 AWG stranded
0.59 uH/m
98.4 pF/m
Shield DC R: **10 ohm/km**

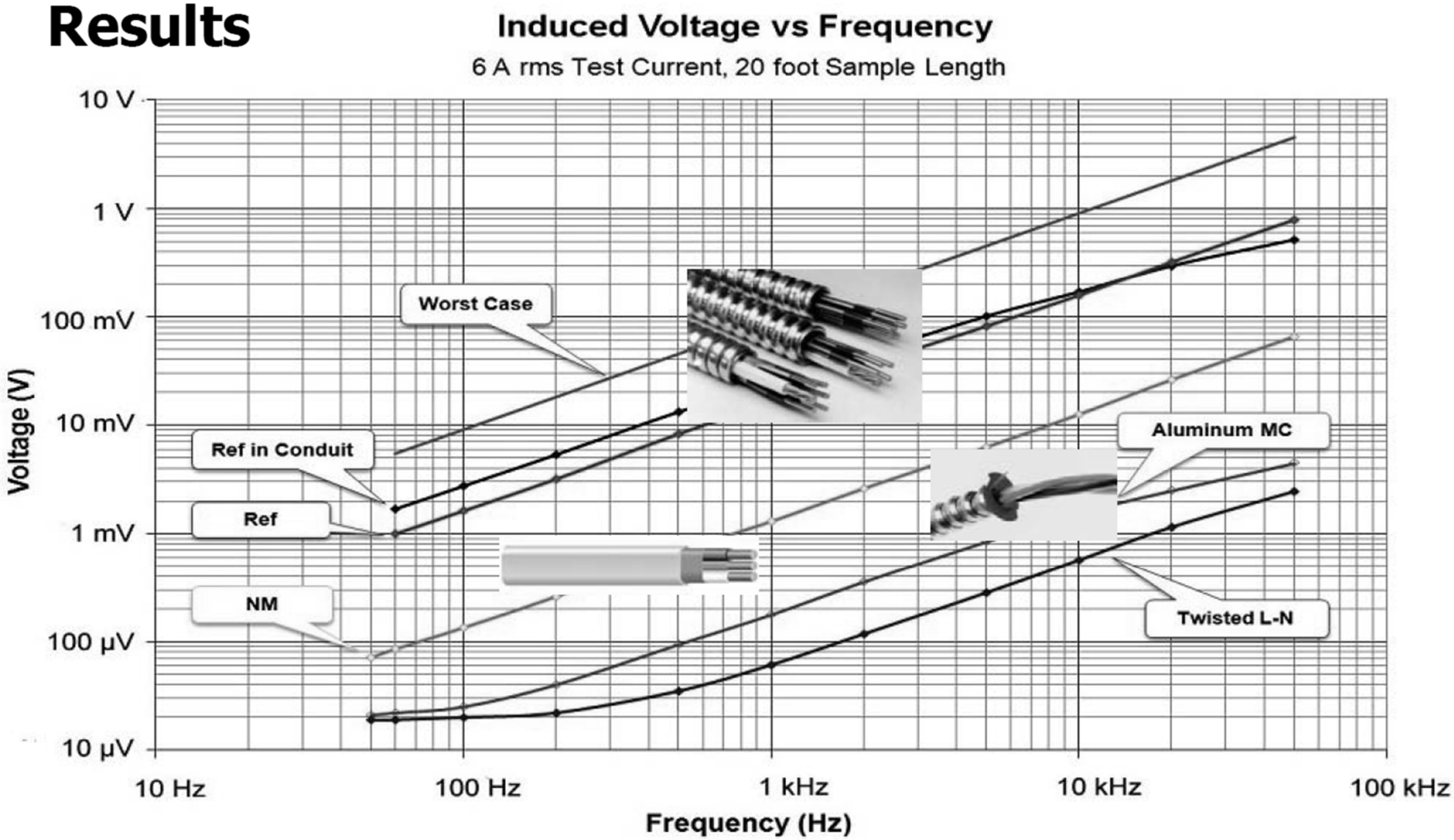
Belden 2221
26 AWG stranded
0.55 uH/m
42.7 pF/m
Shield DC R: **21.6 ohm/km**

Belden 8451
22 AWG stranded
0.56 uH/m
112 pF/m
Shield DC R: **47.6 ohm/km**

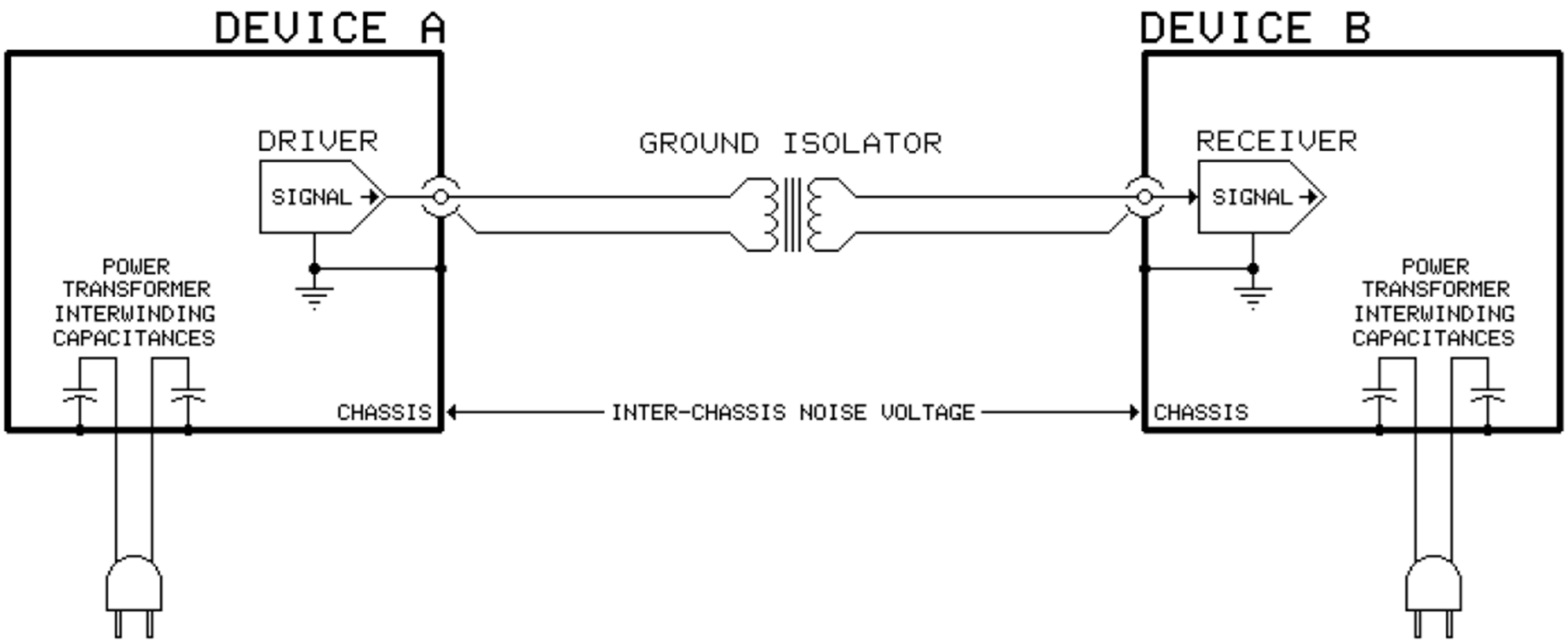
Belden 1883
24 AWG stranded
0.56 uH/m
101.7 pF/m
Shield DC R: **60.7 ohm/km**

Coupling to Protective Ground

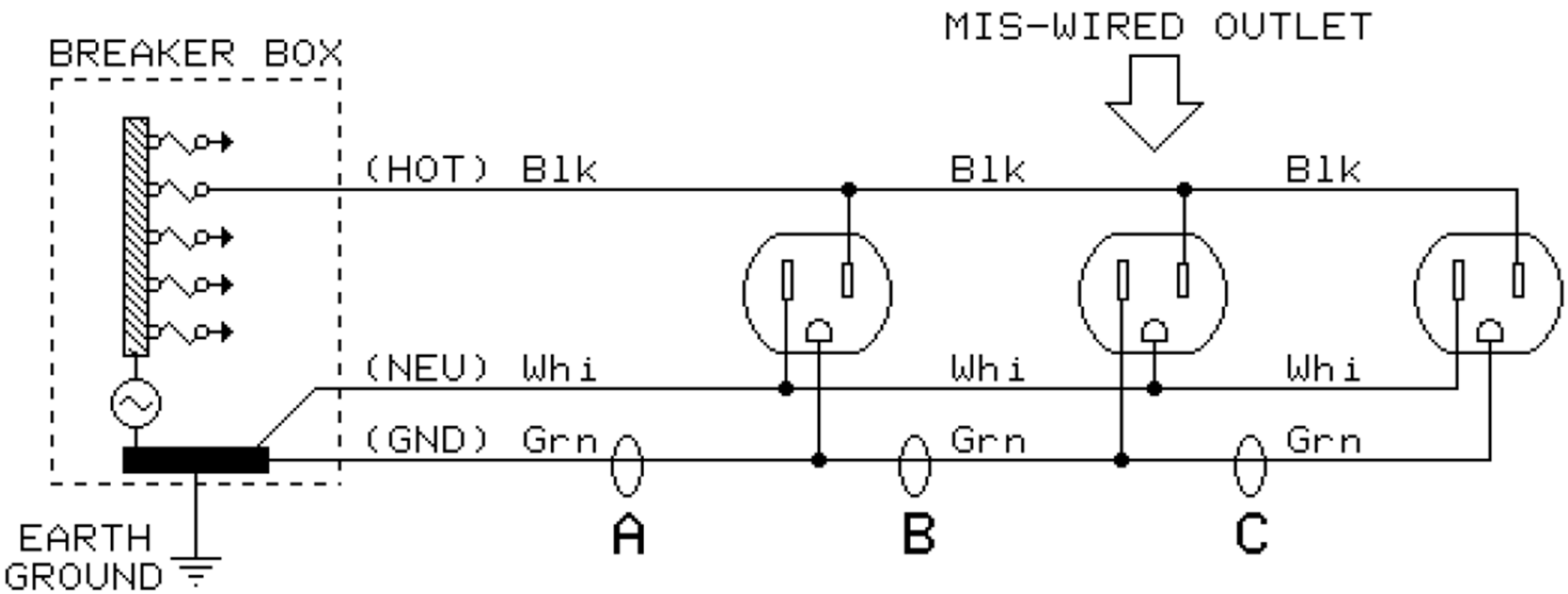
Results



Solution: Audio Transformer



Wiring Error: BIG Noise Issue



Thank you