Audio Engineering Society
Conventions and Conferences

**Toronto Section Presentation - 27 Apr 2010**

# Hum, Buzz, & Ground Loops: New Insights into an Old Problem


*by*

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Senior Member, Institute of Electrical & Electronic Engineers





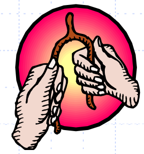
## About the Presenter

Bill has designed pro audio electronics since 1972 and was head of electronic development for Capitol Records from 1981 to 1988 prior to joining Jensen Transformers.

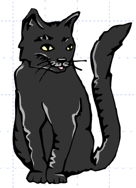
His landmark paper on balanced interfaces appeared in the June 1995 AES Journal, the best selling issue ever printed. Other writing includes several magazine columns, three chapters for the Ballou “Handbook for Sound Engineers,” and numerous magazine articles and Jensen application notes. Since 1994, his seminars have taught tens of thousands at industry trade shows, universities (including MIT in 2007), and professional society meetings. He’s active in AES standards and was a major contributor to AES48.

His patents include the InGenius® balanced input IC and the ExactPower® waveform-correcting AC voltage regulator. He’s an AES Fellow and a Senior Member of the IEEE.

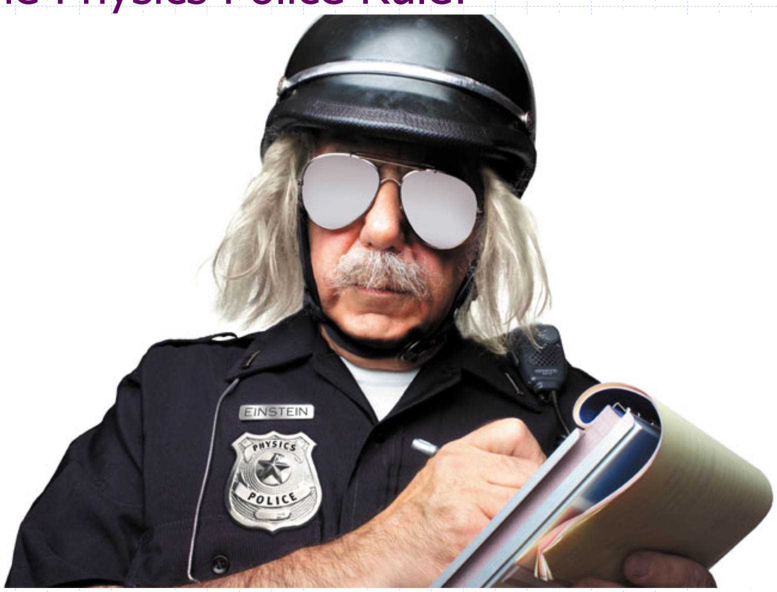
# Myth and Misinformation



- Is all noise "picked up" by cables — presumably from the air like a radio?
- Equipment makers are often clueless – don't know ground loops from ...
- Basic rules of physics are routinely overlooked, ignored, or forgotten

# The Physics Police Rule!

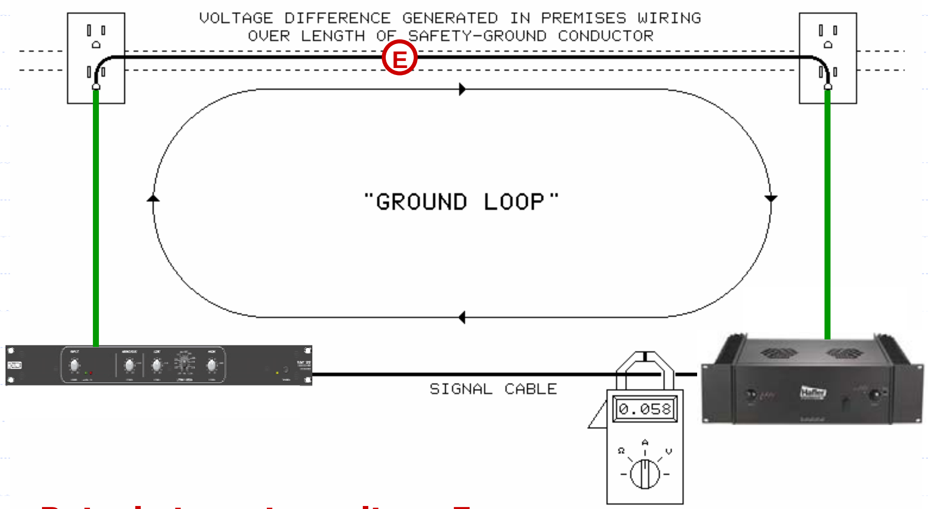



*Courtesy of Coilcraft*

## What is "Ground?"

- **Utility Power**: an electrical connection to **SOIL**
- **Electronics**: a common return path for various circuits, *whether or not connected to soil*
  - **A "equi-potential" FANTASY invented by engineers to simplify their work**
  - A "ground" circuit most often serves, either intentionally or accidentally, more than one purpose
- Meaning of "ground" has become vague, ambiguous, and often quite fanciful

## Pictorial of a "Ground Loop"




**But what creates voltage E ...**

## Ground Loop Solution?


PS Audio offers this as a solution to ground loops "caused" by those pesky equipment grounds!!

## Is It Safe?

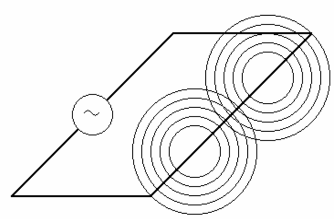
- This device is claimed to eliminate ground loop problems
- Uses a pair of back-to-back rectifier diodes in series with safety ground
- Essentially an open circuit until voltage difference reaches about ± 0.6 V (~ 400 mV rms)
- Will it survive a 100 A fault for 2.5 seconds or a 1,000 A fault for 10 ms* without opening up?
- **It is NOT UL Listed!**

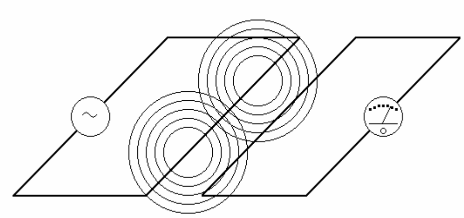

*Ebtech*

* These currents and times are based on a UL study that measured fault currents and breaker response times in over a thousand homes.

Don't Lose Your Customers This Way!!


## Magnetic Fields & Coupling





Fluctuating field surrounds every wire carrying AC current

Field induces voltage in any nearby conductor (transformer principle)

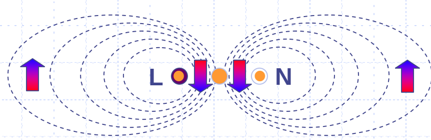
**Faraday's Law at work!**

## A Parasitic Transformer

- Load current in line and neutral produces opposing magnetic fields
- Imperfect cancellation **magnetically induces** voltage over length of safety ground conductor
  - Highest voltages with random wires in steel conduit
  - Lower voltages with uniform geometry of Romex®
- 1 volt difference between outlets not unusual
- Voltage is proportional to circuit **load current**
- Mechanism favors harmonics of 60 Hz

## Magnetic Fields in Romex®

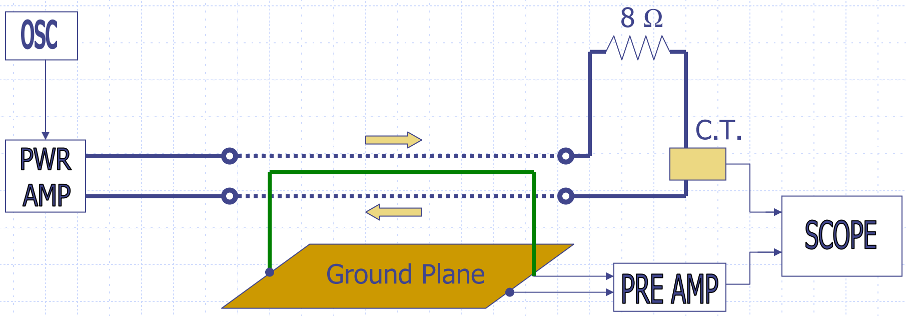
**Current in L and N are equal but opposite directions**




**Safety Ground "Sees" Zero Magnetic Field at Exact Midpoint**

*(cross-section view)*

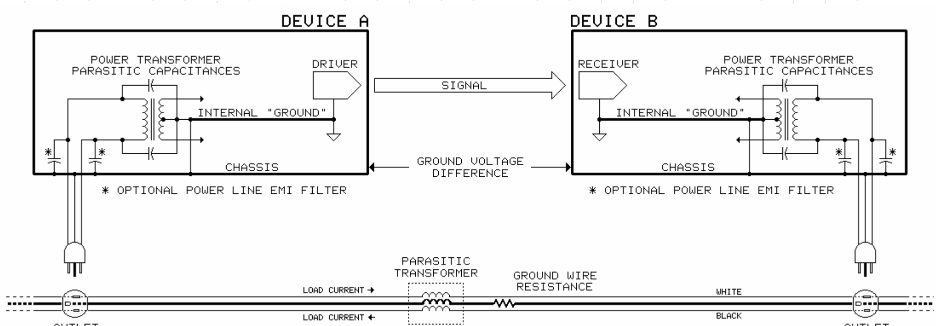
*Instantaneous L and N currents are flowing into page and out of page*



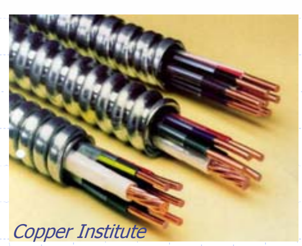

PARASITIC TRANSFORMER DEMONSTRATION

(Syn-Aud-Con 2007)

# The Parasitic Transformer




**UNCONTROLLED GEOMETRY OF THIS WIRING CAN INDUCE SIGNIFICANT VOLTAGE DIFFERENCES BETWEEN OUTLET SAFETY GROUNDS!**

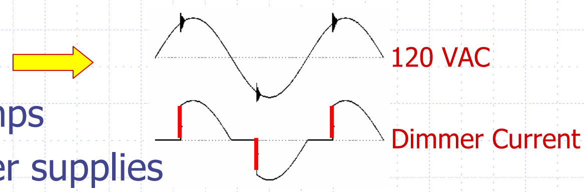


## It's Not Just 60 Hz

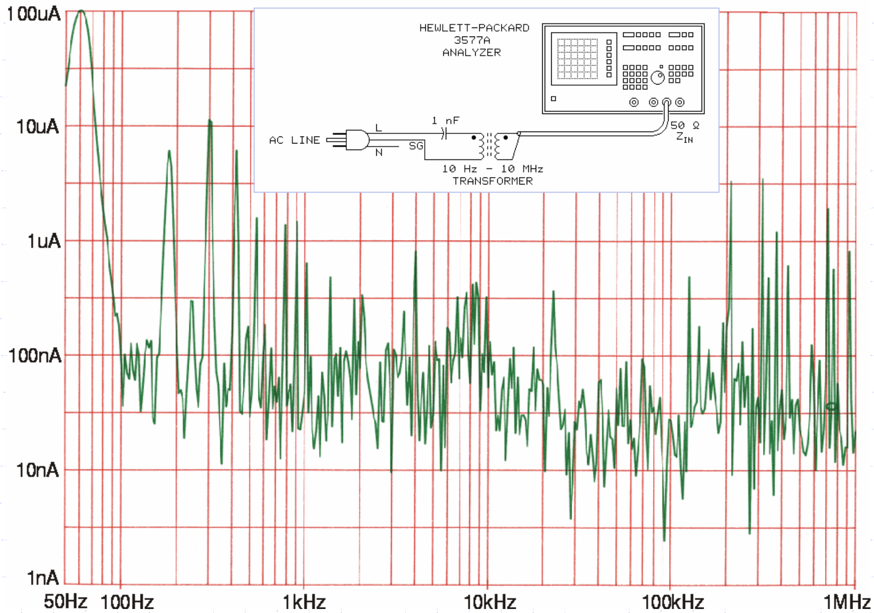
- Many power-line loads, especially electronics, draw current non-uniformly during each cycle
- 120 VAC distortion typically 2% to 6% THD
- High harmonics caused by abrupt current step
- **Leakage current** & **parasitic transformer** favor higher frequencies (+20 dB per decade)

## High-Frequency Noise Sources

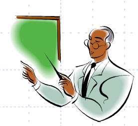
- Light dimmers
- Fluorescent lamps
- Electronic power supplies
- Arcing of switches, relays, or motors
- Power-line insulator corona discharge
- AM radio (power lines are huge antenna)



# Typical Power-Line Spectrum




# The Facts Of Life

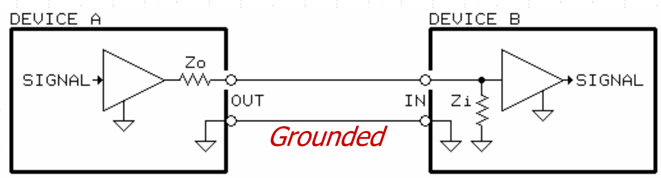


- Harmless voltage differences will **always** exist between grounds of properly wired outlets
- Harmless leakage currents will **always** flow in signal cables connected to equipment with 2-prong plugs
- Problems arise only at vulnerable points in our systems!

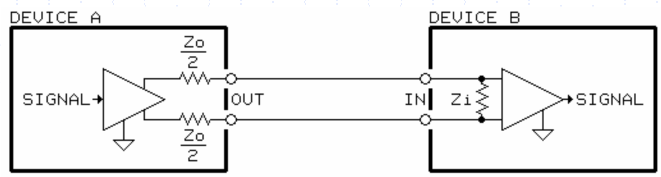
## Unbalanced vs Balanced Interfaces

- An *interface* consists of a line **driver** (device output), the **line** or cable, and a line **receiver** (device input)
- **Two** conductors are always required to complete a signal (or any) current path
- Status depends **ONLY** on the **impedances** (to ground) of the two signal conductors
- In **un**balanced interfaces, one impedance is zero (grounded) and the other is higher
- In balanced interfaces, both have nominally **equal** (and non-zero) impedances
  - Requires that driver, line, and receiver each maintain nominally equal impedances to ground

## Unbalanced vs Balanced Interfaces




Unbalanced




Balanced

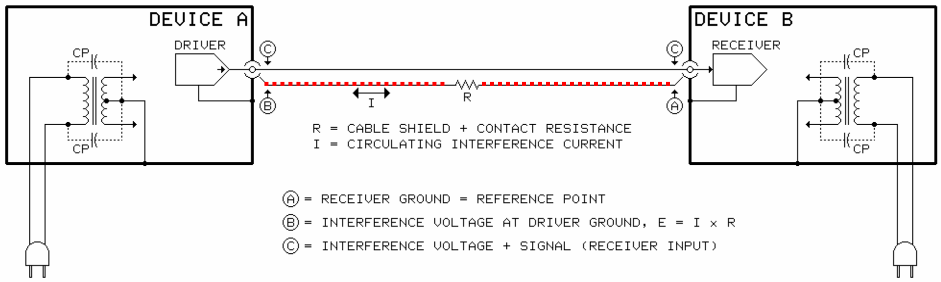
## The Unbalanced Interface

- **Extremely susceptible to noise coupling**
- After 50 years, consumer audio still uses it, in spite of ever-increasing dynamic range needs
- Virtually all **video** interfaces are unbalanced
  - Power line coupling results in classic "hum bar"
- The RS-232 **digital** interface is unbalanced
  - Symptoms usually called "unexplainable"

## Big Problem with Unbalanced

- When two devices are connected, ground loop current will flow in signal cable
- Virtually all flows in the grounded conductor, typically the shield of audio/video cables
- Its resistance creates a small **noise voltage** drop over the length of the cable
- Noise is ***directly added to signal*** seen by receiver (the interface is a series circuit)

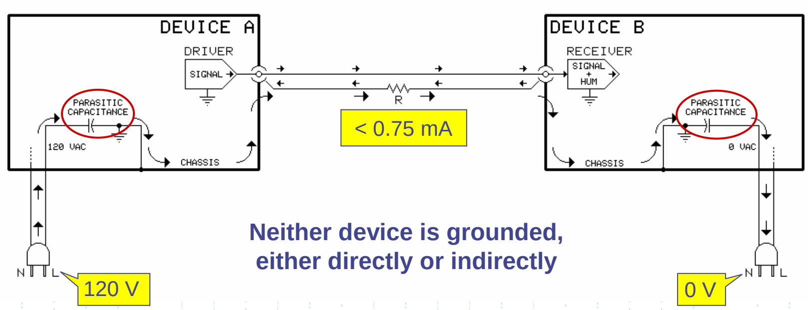
## Common-Impedance Coupling




**Two currents (power-line and audio) flow in the same impedance, which allows them to couple!**

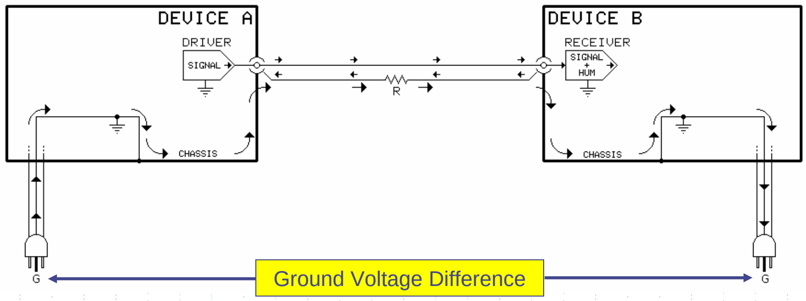
Signal received (C to A) consists of signal sent (B to C) from device B **plus** ground-loop noise (A to B)

## Leakage Current Effect




**Generally OK if interconnect cable is under 6 feet long**

## Ground Voltage Difference Effect




**Even a few millivolts here can be a noise disaster!**

## THE BALANCED INTERFACE

- Highly immune to noise coupling – the **only** technique used in phone systems to this day
- **Its true nature is widely misunderstood:**

"Each conductor is always equal in voltage but opposite in polarity to the other. The circuit that receives this signal in the mixer is called a differential amplifier and this opposing polarity of the conductors is essential for its operation."

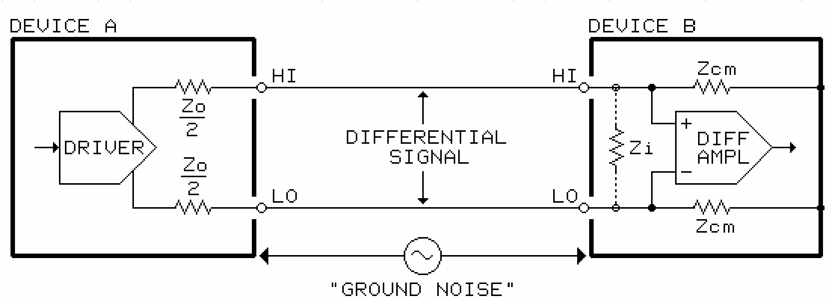
Like others in print, this explanation is not only **WRONG, but fails to even mention <u>the</u> defining property of a balanced interface!**

## Signal Symmetry ≠ Balance

"Only the common-mode impedance balance of the driver, line, and receiver play a role in noise or interference rejection. This noise or interference rejection property is independent of the presence of a desired differential signal. Therefore, it can make no difference whether the desired signal exists entirely on one line, as a greater voltage on one line than the other, or as equal voltages on both of them. Symmetry of the desired signal has advantages, but they concern headroom and crosstalk, not noise or interference rejection."

*from "Informative Annex" of*
*IEC Standard 60268-3*

## Balanced Interface Circuit

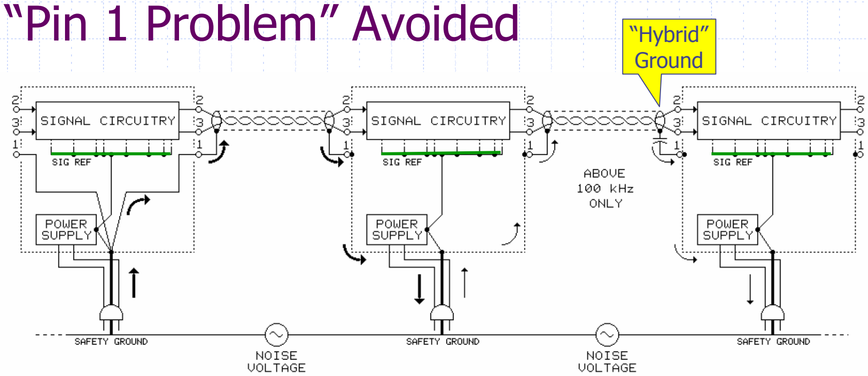



**Signal** is "differential-mode" or "normal-mode"
**Ground voltage difference** is "common-mode"

# Pin 1 Problems - "Designed-In" Defects

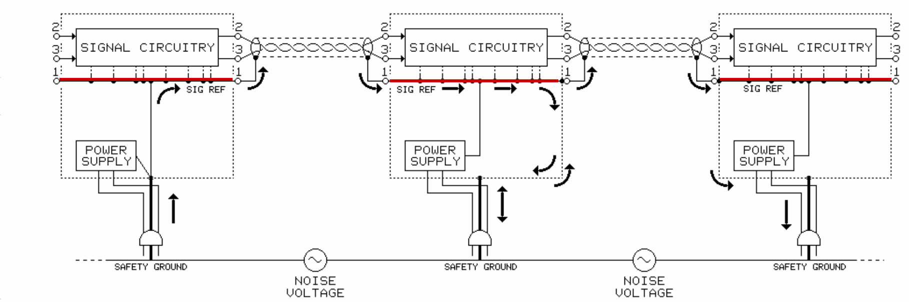
- **One of two common design defects that tarnish the reputation of balanced interfaces**
- Common-impedance coupling <u>inside</u> devices effectively makes the shield connection a low-Z audio input!
- Dubbed "the pin 1 problem" (XLR pin 1 = shield) by Neil Muncy in his 1994 AES paper
- The problem has been inadvertently designed into a surprising number of well-known products
- **Shield current (power-line noise) is allowed to flow in wires or PCB traces shared by amplifier circuitry**

# "Pin 1 Problem" Avoided




**Problem is avoided by making shield currents flow in paths NOT shared by signal circuitry inside equipment**

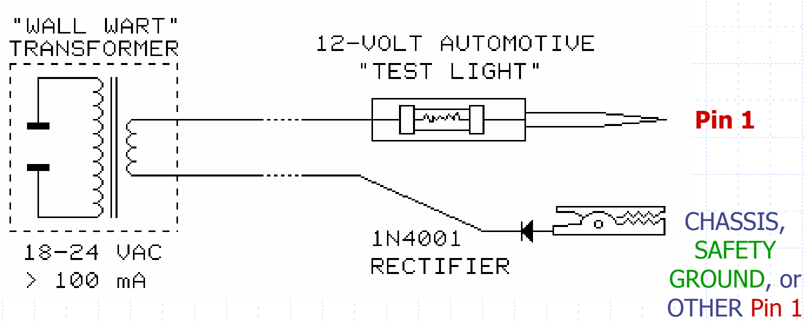
## "Pin 1 Problem" Designed-In




**Problem occurs when shield current flows in signal reference "ground" inside equipment**

Note the power supply connections in devices 2 and 3. Power-line noise will couple to the signal path this way, giving the box a "**sensitive equipment**" reputation!

## "Pin 1 Problem" Testing




"Hummer" forces about 50 mA of rectified 60 Hz through suspect shield connections

*(concept by John Windt, June 1995 AES Journal)*

## Using the "Hummer"

1. Monitor one output and disconnect any other I/O cables and chassis connections
2. As a reference, listen to the output <u>without</u> the hummer connected
3. Connect hummer clip to chassis and touch probe to shield contact of each I/O connector
4. Good "clean" designs will produce no output hum or change in the noise floor
5. Other paths to test include safety ground to I/O shields and input shields to output shields

## Poor Common Mode Rejection

- **The <u>other</u> common design defect that tarnishes the reputation of balanced interfaces**
- In theory, all external noise sources generate common-mode voltages at the balanced input
- Three sources of Common-Mode voltage:
  - **Voltage between grounds of driver and receiver**
  - Voltage induced in cable by magnetic field
  - Voltage induced in cable by electric field
- High CMRR was taken for granted before simple, and cheap, IC diff-amps appeared around 1970
  - Suddenly, all transformers became "ugly iron"
  - Manufacturers never talked about, or likely even realized, how CMRR varied widely, depending on the signal source!

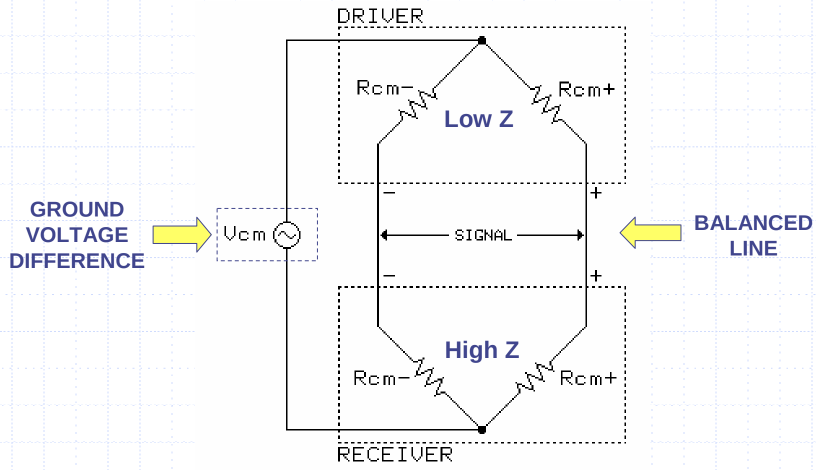
## Common-Mode Rejection

- Ideal receiver responds only to difference voltage and has no response to common-mode
- Real-world receiver is "diff-amp" or transformer
  - Limited common-mode rejection
- Common-Mode Rejection Ratio or **CMRR** is the ratio, in dB, of **differential** to **common-mode** gain
  - Higher CMRR figures mean better rejection
- **CMRR is exquisitely sensitive to impedances at both the driver and receiver!**

## A Wheatstone Bridge

- Common-mode impedances (to ground) of driver and receiver form a Wheatstone bridge
- If not *balanced*, a portion of the ground noise *Vcm* will be *converted* to differential signal
- Balance critically depends on ratio match of driver and receiver common-mode impedance pairs
  - Most sensitive to tolerances when all arms are same impedance
  - Least sensitive if upper and lower arm impedances widely differ
  - Standard practice is low Z at driver and high Z at receiver

## Balanced Interface = Wheatstone Bridge




## CMRR: Marketing vs Reality

- Zo of **real** drivers typically set by ±5% series resistor and ±20% (or worse) series capacitor
  - Zo **imbalance** is typically about 10 Ω at 60 Hz
- Zcm of conventional "active balanced" receivers typically range from 10 kΩ to 50 kΩ
  - Low Zcm means actual interface CMRR is easily degraded by normal, real-world driver Zo imbalances
  - **SSM-2141 CMRR drops 25 dB with only a 1 Ω imbalance**
- Zcm of good input transformer or the InGenius® IC is typically 10 MΩ to 50 MΩ ... 1,000 times higher
  - **Their CMRR unaffected by a 500 Ω imbalance!**

## An Example of Bad Design Advice!

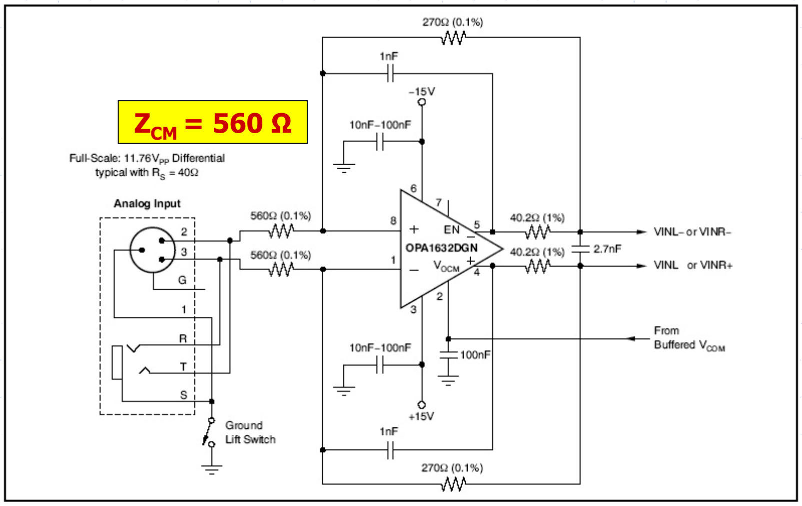
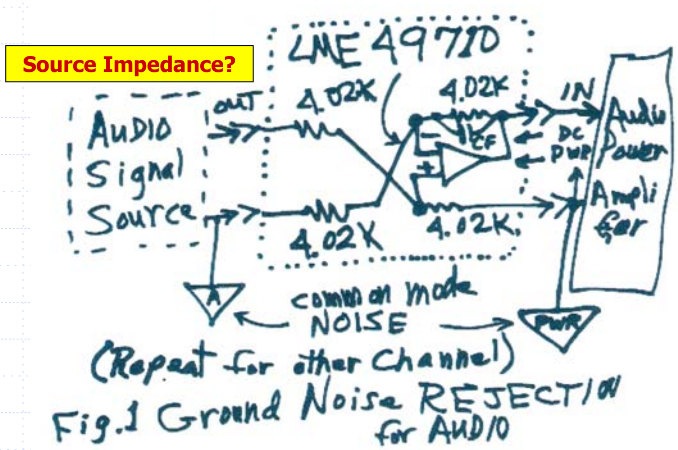



Figure 50. Differential Input Buffer Circuit Utilizing the OPA1632

Texas Instruments, PCM4222 Data Sheet, March 2007

## And Another ...

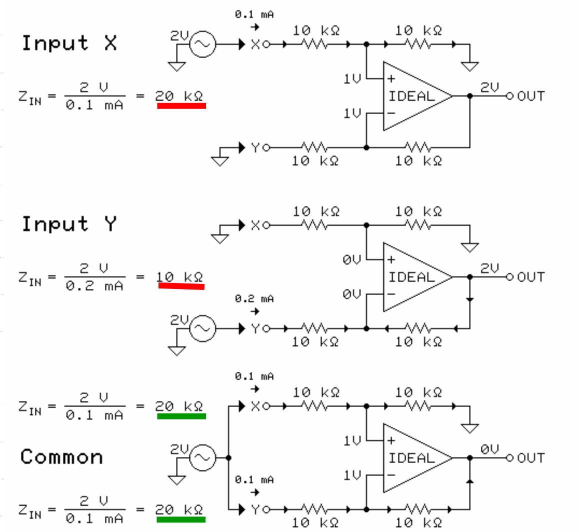



Bob Pease, "What's All This Noise Rejection Stuff, Anyhow?" Electronic Design, 1 Oct 2009

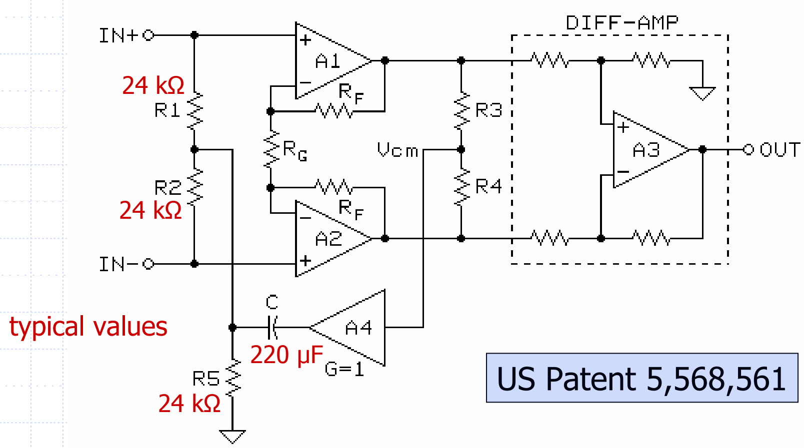
## **MYTH:** The Diff-Amp Needs “Fixing”

Driven separately, input impedances not equal …
NO PROBLEM!

COMMON-MODE input impedances are equal … OK!




## Bootstrapping the Common-Mode




US Patent 5,568,561

## InGenius® IC

THAT Corporation — Making Good Sound Better®

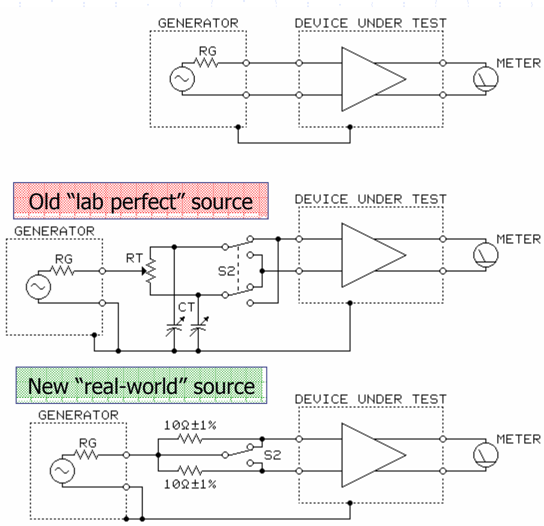
- R1, R2, and R5 necessary to supply amplifier bias currents (sources may have no dc path)
- CM voltage extracted by R3 and R4
- A4 buffers CM voltage and "bootstraps" R1 and R2 via external C, typically 220 µF
- Common-mode input impedances increased to 10 MΩ at 60 Hz and 3.2 MΩ at 20 kHz!
- $R_F$ and $R_G$ covered by patent for high-gain applications like microphone preamps
- Allows bootstrapping of RFI suppression capacitors, too
- Matches SSM2141 footprint
- Cost in $2 to $3 range

## CMRR and Testing

- **Noise rejection in a <u>real</u> interface depends on how driver, cable, and receiver *interact***
- Traditional CMRR measurements **ignore** the effects of driver and cable impedances!
- Like most such tests, the previous IEC version "tweaked" driver impedances to **zero imbalance**
  - IEC recognized in 1999 that the results of this test did <u>not</u> correlate to performance in real systems …
- My <u>realistic</u> method became "IEC Standard 60268-3, Sound System Equipment - Part 3: Amplifiers" in 2000
- **The latest generation Audio Precision analyzers, APx520/521/525/526, support this CMRR test!**

# Audio Precision Model APx525

# IEC CMRR Test – Old vs New




IEC Normal-Mode Test

0 dB reference to which common-mode gain is compared

IEC Common-Mode Test 1988 Ed 2

RT and CT are trimmed for same reading as S2 is toggled. This "perfect" reading is used to calculate CMRR.

IEC Common-Mode Test 2000 Ed 3

S2 is toggled and highest reading noted. This reading is used to calculate CMRR.

## How Much CMRR is Necessary?

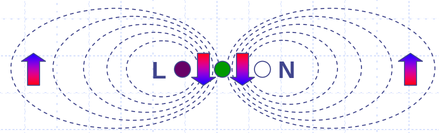
- Professional reference signal level is +4 dBu = 1.23 V
- A 1.23 V ground voltage difference (common-mode voltage) might exist in a hostile electrical environment
- In this case, signal-to-noise ratio = **Interface CMRR**
- Total dynamic range is SNR + "headroom"
- Assuming 20 dB of headroom (clip at +24 dBu):
  - 80 dB CMRR gives 100 dB dynamic range (comparable to CD)
  - 60 dB CMRR gives 80 dB dynamic range
- If ground voltage difference were a more benign 123 mV (20 dB less), we'd gain an extra 20 dB
  - 60 dB CMRR gives 100 dB dynamic range (comparable to CD)
- **50 dB is rarely adequate in most systems!**

## Cable Immunity to Magnetic Fields

- Voltage is induced in conductors exposed to ac magnetic fields, but for pairs it may be unequal
  - ***Twisting*** improves match by averaging physical distances to external field source
- Effective **magnetic** shielding, especially at power frequencies, is very difficult to achieve
- Only magnetic materials like steel conduit provide significant audio frequency shielding — ordinary shielded cables have no effect

## Magnetic Fields from Power Cords

**Current in L and N are equal but of opposite polarity**



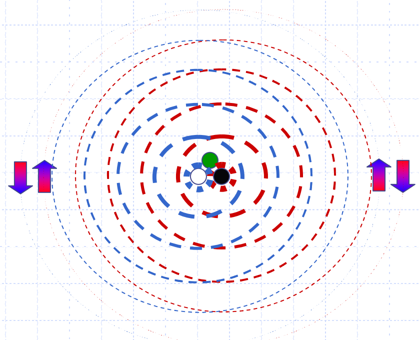

**Strong magnetic fields exist only very close to the conductors**

*(cross-section view)*

*Instantaneous L and N currents are flowing into page and out of page*

## Magnetic Fields from Power Cords

**Far from cords, magnetic field cancellation is nearly complete**

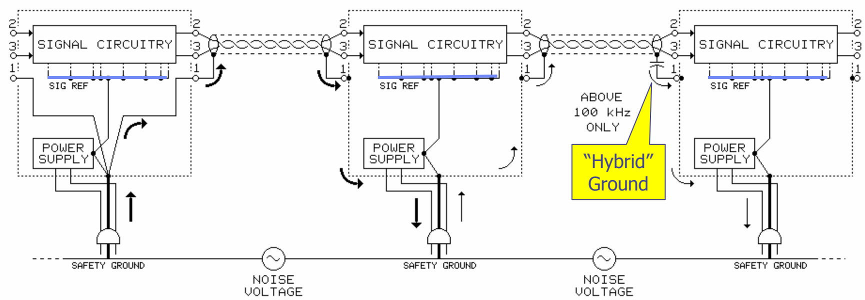


**At distance of 10 times conductor spacing, magnetic field is about 1% of close-in value**

## **S**hield **C**urrent **I**nduced **N**oise

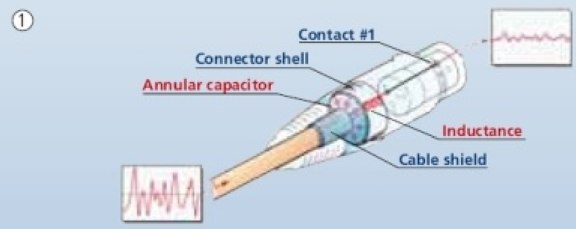
- Current flow in cable shield creates a magnetic field ***extremely close*** to the twisted pair
- Imperfections and manufacturing tolerances in real cables result in unequal induced voltages
  - Dubbed SCIN in 1994 paper by Neil Muncy
  - Best cables use braided or dual counter-wrapped spiral shields and **no** drain wire
  - **Worst cables use a drain wire**, regardless of other construction details *[Brown-Whitlock paper]*
- Can be eliminated, regardless of cable type, by simply not allowing current to flow in shields
  - **Ground shield directly at driver end only**
  - Receive end may float or be capacitively coupled to ground

## "Hybrid" Stops SCIN and Pin 1 Problems

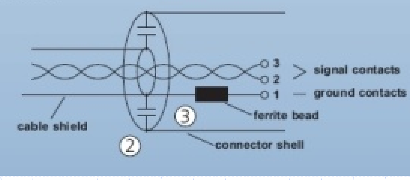



**Capacitive grounding of shield stops audio-frequency current flow, preventing SCIN and Pin 1 problems, but effectively grounds it at frequencies >100 kHz**

# The Neutrik EMC Connector



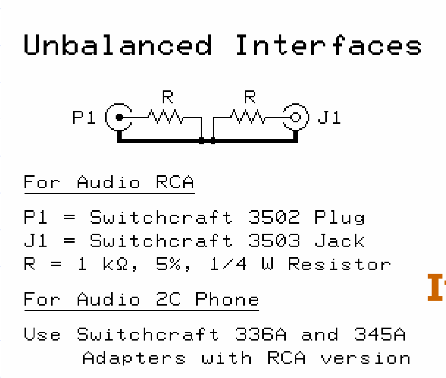

① Design guarantees a continuous RF-shield connection but avoids ground loops (no LF-shield connection)
② Circular capacitor enables low-inductive shield connection to connector housing
③ Cable shield - PIN 1 connection includes EMI suppression bead (blocks high frequencies)




# Troubleshooting - Unbalanced Interfaces

- "Dummies" can locate noise coupling point
- Also reveal the nature of the problem:
  - Common-impedance coupling in cables (classic)
  - Magnetic or electric field coupling in cables
  - "Pin 1 problems" in defective equipment

## The Unbalanced "Dummy"

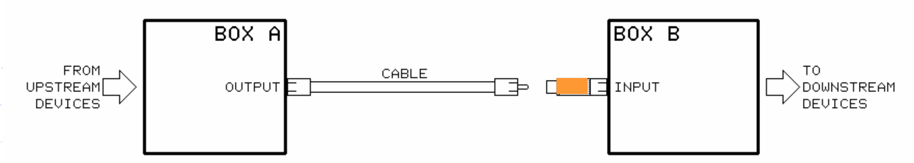




**It does NOT pass signal**

**Don't leave one in a system!**

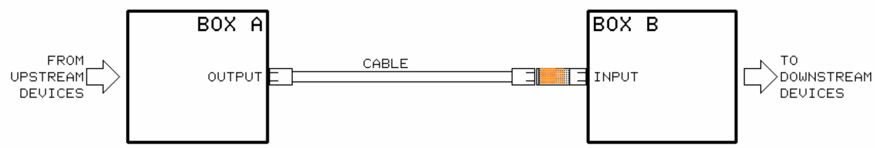
## STEP 1




Unplug the existing cable from Box B and plug the dummy into Box B

- **Noise** — problem in Box B (or downstream)
- **Quiet** — go to step 2

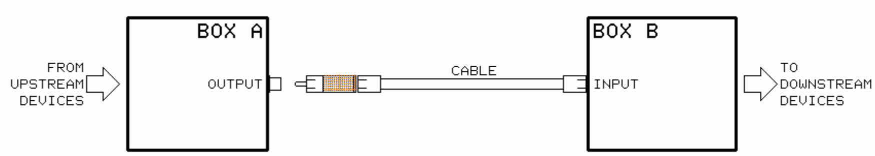
# STEP 2




Leave the dummy in Box B and plug the existing cable into the dummy

- **Noise** — Box B has a "pin 1 problem." Confirm with the "hummer" test
- **Quiet** — go to step 3

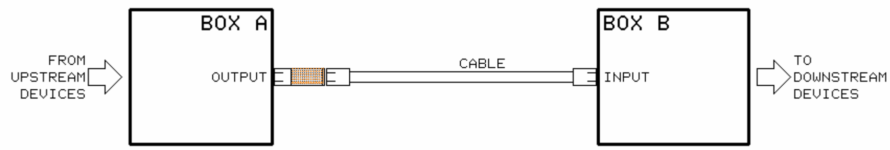
# STEP 3




Remove the dummy and plug existing cable back into Box B. Unplug other end of existing cable from Box A output and plug it into the dummy. *The dummy can't touch anything conductive!*

- **Noise** — a magnetic or electric field is inducing noise into the cable. Re-route it to avoid the field.
- **Quiet** — go to step 4

## STEP 4



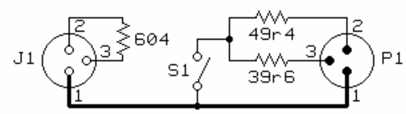

Leaving the dummy on the existing cable, plug the dummy into the output of Box A.

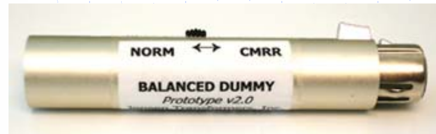
- **Noise** — classic common-impedance coupling is the problem at this interface. Install an isolator!
- **Quiet** — noise must exist at output of Box A. Use the "Hummer Test" to determine if Box A has a "pin 1 problem" at its **output**. If not, perform this 4-step test sequence on the next upstream interface.

## **Troubleshooting** - Balanced Interfaces

- Same basic concept as unbalanced "dummy" tests
- Again, tests pinpoint location and nature of problem
- Coupling mechanisms are different:
  - Shield-current-induced coupling (SCIN)
  - Magnetic or electric field coupling in cables
  - "Pin 1 problems" in defective equipment
  - Poor Common-Mode Rejection

## The Balanced "Dummy"




For Balanced Audio XLR

P1/J1 = Switchcraft S3FM adapter
with QG3F and QG3M inserts
All resistors 1%, 1/4 W metal film

Close S1 for CMRR Test ONLY

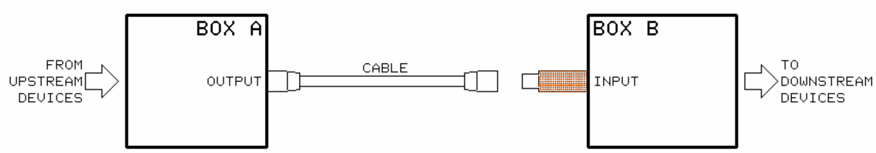
For Balanced Audio 3C Phone

Use Switchcraft 383A and 387A
adapters with XLR version

Closing S1 creates a 10 Ω source impedance imbalance per IEC test for CMRR

(actual imbalance may range from 9.8 Ω to 11.6 Ω due to tolerances)

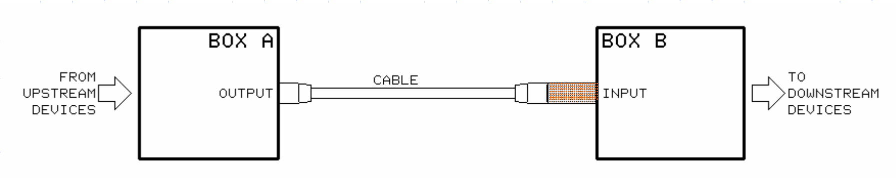
## STEP 1




Unplug the existing cable from the input of Box B and plug in only the dummy. Switch on dummy must be in "NORM" position for steps 1 – 4.

- **Noise** — problem internal to Box B (or downstream).
- **Quiet** — go to step 2.

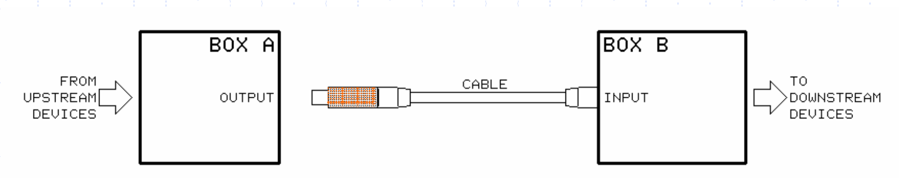
## STEP 2




Leave the dummy at the input of Box B, plug the existing cable into the dummy

- **Noise** — Box B has a "pin 1 problem." Confirm with Hummer Test.
- **Quiet** — go to step 3.

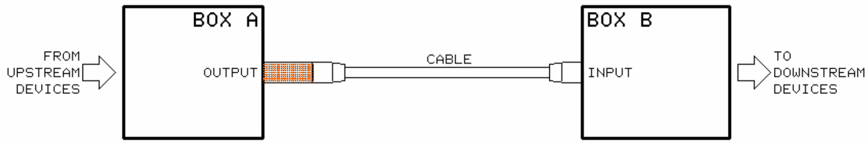
## STEP 3




Remove dummy and plug existing cable into Box B input. Unplug cable from Box A output and plug into dummy. Do not allow dummy to touch anything conductive.

- **Noise** — magnetic or electric field inducing noise into cable. Re-route cable to avoid field or take steps to eliminate field.
- **Quiet** — go to step 4.

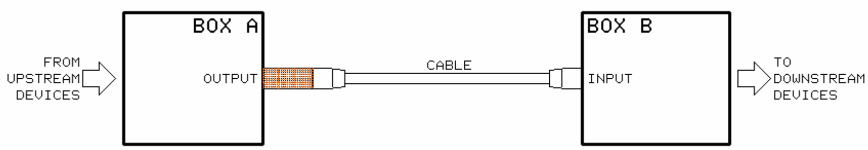
## STEP 4




Leaving the dummy on the existing cable, plug the dummy into the output of Box A.

- **Noise** — Shield Current Induced Noise or SCIN. Replace cable or reduce current in shield.
- **Quiet** — Go to step 5.

## STEP 5




Without disturbing the setup, move the dummy's switch from "NORM" to "CMRR."

- **Noise** — Inadequate CMRR at input of Box B. Replace Box B or add a transformer isolator to increase CMRR of its input.
- **Quiet** — Noise must exist at output of Box A. Use the "Hummer Test" to determine if Box A has a "pin 1 problem" at its **output**. If not, perform this 5-step test sequence on the next upstream interface.

## The Sensitive Clamp-On Ammeter

- Senses current magnetically
- Signal and power-line currents ignored since they flow "to" and "from" in the same cable
- **Finds cables carrying power line currents in ground loop**
- Current required to produce problem varies …

*AEMC 565*

*Mitchell Instruments 7E380947*

High-sensitivity models often called "**Leakage Current Meters**"

## What To Do? – Code Violations

- More than one N-G bond
  - Sub-panels the most frequent culprit
  - Neutral wire pinched (shorted) at a metal J-box
  - Causes abnormal ground voltage differences and subsequent noise problems in audio systems
- Neutral-safety ground swaps
  - Most common at outlets or outlet strips
  - No effect on ordinary appliances
  - Causes abnormal ground voltage differences and subsequent noise problems in audio systems
- Other outlet miswires
  - Can be found with $10 outlet testers

## The Neutral-Ground Bond

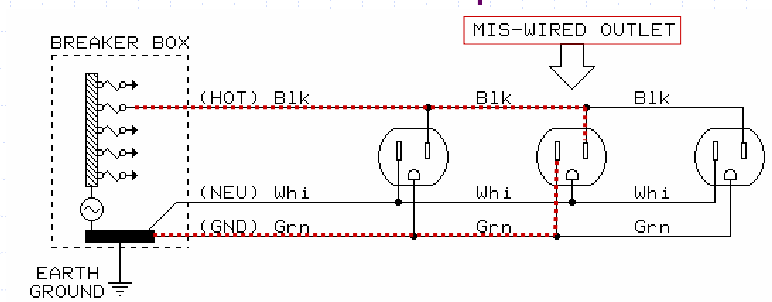
- One incoming utility wire, often bare, is the *grounded* or **neutral** conductor
- NEC requires 120-volt AC premises power distribution using a 3-wire system (since about 1960)
- **Line** (black) and **neutral** (white) are intended to carry the load current, typically up to 15 or 20 A in branch circuits
- The "safety" **ground** (green) normally carries no current
- Neutral and **ground** are **bonded** at the main panel

**CODE PROHIBITS NEUTRAL TO GROUND CONNECTIONS ANYWHERE ELSE**

**NEUTRAL BUS**

**N-G BOND LINK**

## The Neutral-Ground Swap




**Load current** now flows in **safety ground** wiring.
Its voltage drop, up to 3 volts, appears as a ground difference voltage to the system – creating truly **severe** noise problems!
The swap is **not** detectable with outlet testers, but a clamp-on ammeter on safety ground will find it!

*AEMC*

## Recommended Instruments

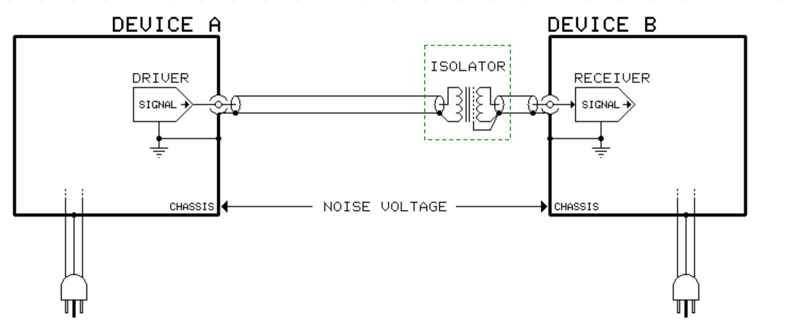
Ideal SureTest® Circuit Analyzer
Model 164 (about $230)

AlphaLab TriField® Meter
*www.trifield.com/EMF_meter.htm*
(about $170)

## **What To Do?** – Equipment

- Buy the "right stuff"
  - Look for mention of AES48 in "specs" or ask if the manufacturer has tested for "pin 1 problems"
  - Test it yourself with the hummer and complain to the manufacturer if it fails!
  - Demand meaningful CMRR specs instead of the usual "no test conditions specified" bullshit
- Pay attention to cables
  - For cables grounded at both ends, avoid cables that use a drain wire
  - For existing cables with drain wires, consider using the Neutrik EMC connector with pin 1 disconnected at the receive end

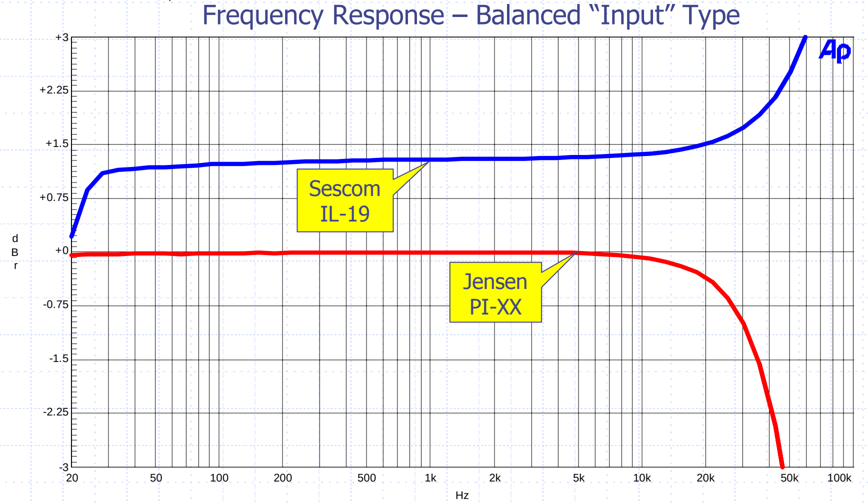
# Ground Isolator for Unbalanced




Signal transfers with **no electrical connection** between driver and receiver – ground loop broken

Jensen Transformers, Inc 06/11/09 15:22:10

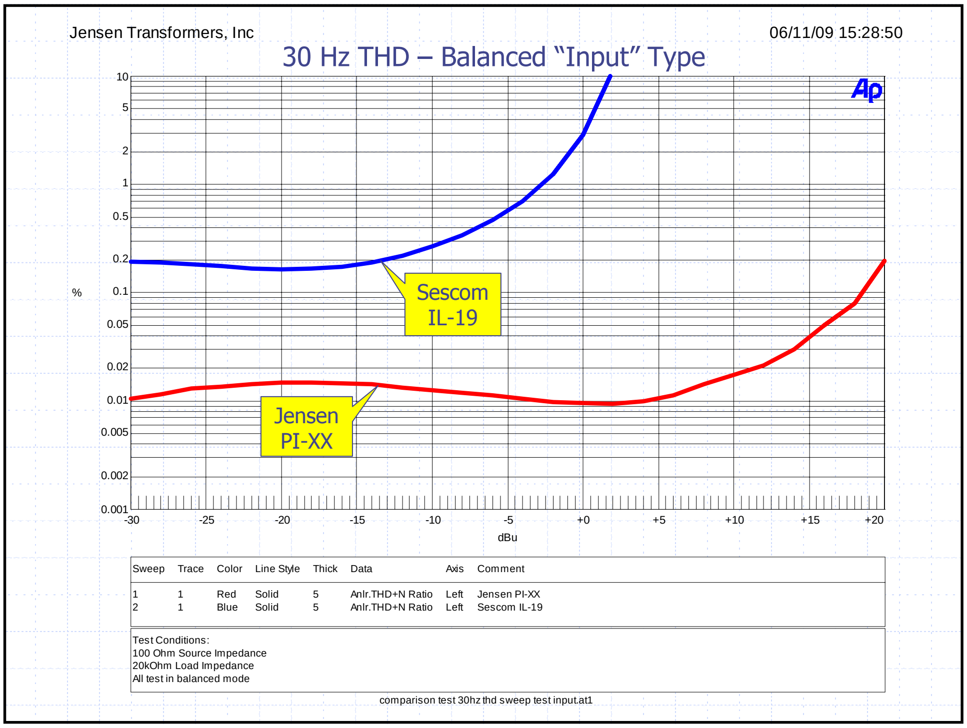
## Frequency Response – Balanced "Input" Type




| Sweep | Trace | Color | Line Style | Thick | Data | Axis | Comment |
|---|---|---|---|---|---|---|---|
| 1 | 1 | Red | Solid | 5 | Anlr.Level A | Left | Jensen PI-XX |
| 2 | 1 | Blue | Solid | 5 | Anlr.Level A | Left | Sescom IL-19 |

Test Conditions:
100 Ohm Source Impedance
20kOhm Load Impedance
All test in balanced mode

comparison test mag sweep test input.at1

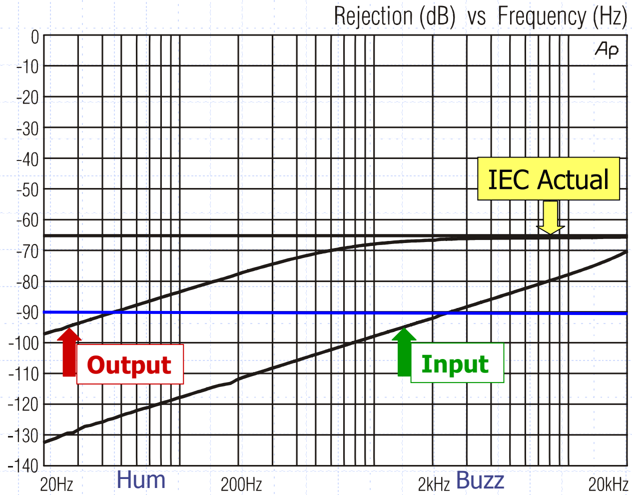



# Ground Isolator for Balanced

- Solves the most common balanced interface problems:
  - **Pin 1 problems**
  - **Poor input CMRR** (real-world)
- DIP switches (on bottom) can reconfigure **shield** connections
- Internal Faraday-shielded **input** transformers boost CMRR, typically by 40 to 60 dB


*Jensen Transformers*

## Boosting Poor CMRR




IEC CMRR Tests of input with **marketing** CMRR of **90 dB**

"Output" and "Input" show effect of adding different types of external transformers

## *Cable Physics from Another Universe?*

- Double-blind tests prove that when audible differences among cables actually exist, they're entirely explainable
- Marketing often hypes transmission line theory as critically important
- Real physics confirms that audio cables only begin to exhibit subtle transmission line effects at **4,000 feet**

**Audio, especially the "high-end," abounds with pseudo-science, anti-science, and mysticism**

## *My Take On Exotic*

- **Exotic cables, even if double shielded, made of 100% pure un-obtainium, and hand woven by virgins, have <u>no</u> significant effect on hum and buzz!**
- Truly high-performance unbalanced audio cables combine very low shield resistance, low capacitance, and reliable connectors
  - I like Belden 8241F (they call it video cable)
  - Very low resistance shield, low capacitance, very flexible, and available in lots of pretty colors!

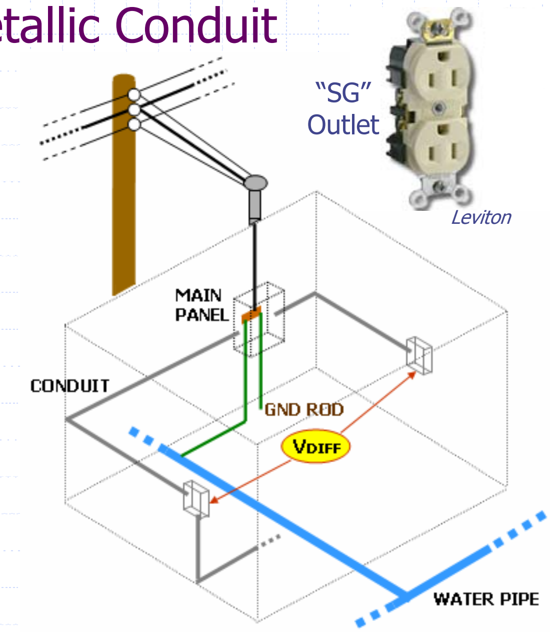

## **What To Do?** – Powering New Installs

- Twist all "line" and "neutral" pairs (not Romex)
  - **Vastly reduces ground voltage differences!**
  - Twist as tightly as practicable for wire size
  - Untwisted safety ground must be in same conduit
- Use separately-derived power transformer
  - Especially if using a 3-phase feeder
  - Locate as close as possible to equipment
  - Faraday shield in transformer prevents noise coupling from primary feeder
  - **"Power White Paper" at Middle Atlantic Products website has great info on this and other power topics**
- Consider "isolated" or "technical" grounding
  - Especially in large commercial buildings
  - Requires user discipline to prevent "violations"

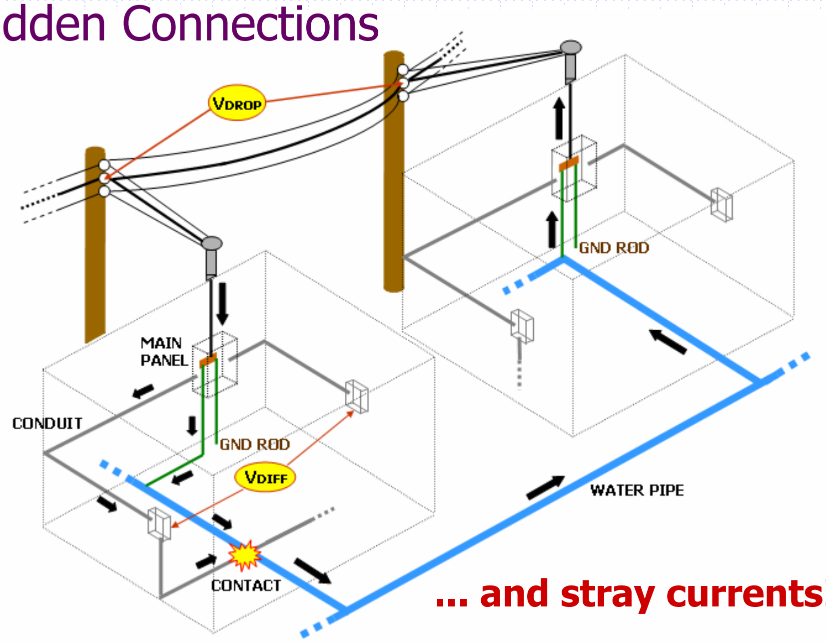
## Building with Metallic Conduit

**VDIFF is magnetically induced into safety ground wires as current flows in other conduit wires. It is this voltage that drives ground loop currents through our signal cables.**

**Normal saddle-ground outlets connect safety ground to conduit when J-box mounted.**

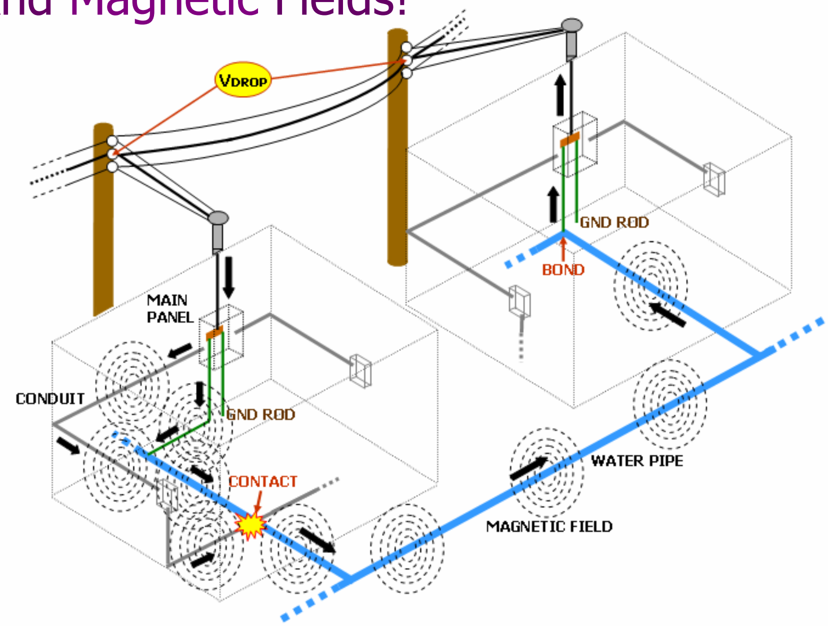



## Hidden Connections




**... and stray currents!**

## And Magnetic Fields!




## "Technical" or "Isolated" Grounding

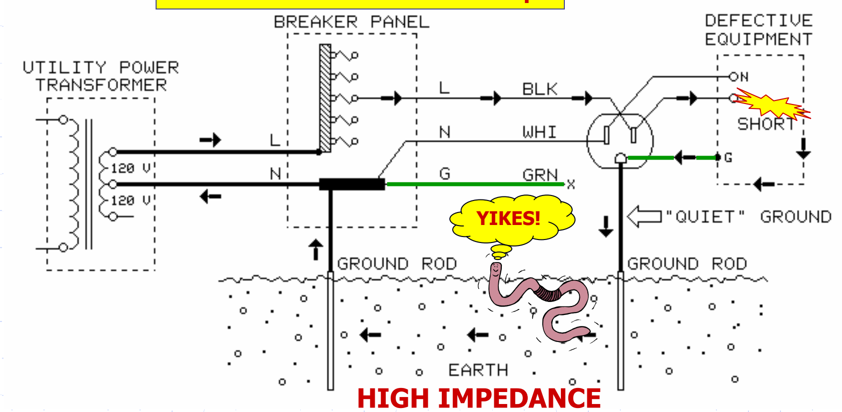
- **Conduit touching ANY separately-grounded metal causes new noise currents in safety ground system**
- Isolated-ground outlets do **not** connect safety ground to their mounting saddle but only to the **green wire**
- IG outlets reduce extraneous, and often intermittent, ground noise problems
- Covered by NEC Article 250-74
- Does **not** apply to premises wired with Romex® and/or plastic J-boxes
  - It's already an isolated ground system!

"IG" Outlet

*Leviton*

## "Quiet" Grounding Scheme

**Circuit Breaker Will NOT Trip!**




This "solution" was offered by a "sales engineer" for a well-known power conditioning company at a CEDIA trade show seminar a few years ago ... some engineer!!

## "Power Conditioning" as a Cure?

"Today's residential systems contractors face un-precedented challenges where high resolution, trouble-free operation is required. From inducing AC **ground loops**, **video hum bars**, static bursts, damage from AC line surges and variable audio and video performance, comprehensive control and conditioning of AC power is no longer an option." *[actual ad copy, emphasis added]*

- Transient voltage "spike" protection (usually MOV clamps)
- Long-term surge, swell, and sag protection (regulation)
- Isolation transformers ("common-mode" noise reduction)
- So-called "balanced" power (leakage current reduction)
- Filters (common and normal mode noise reduction)
- Other "bizarre" (for lack of a better term) noise eliminators

# A $3,000 Power Conditioner

**Nordost "Thor" Specs:**

Internally wired with Nordost Valhalla

Silver Solder used throughout

Polaris-X technology

Number of outlets: 6

Type of outlets: High End Audiophile Grade un-switched outlets.

Standard mains inlet: Audiophile Grade IEC fused

Mains AC voltage: 100-140 VAC

Surge Protection: Full Surge & Spike Protection

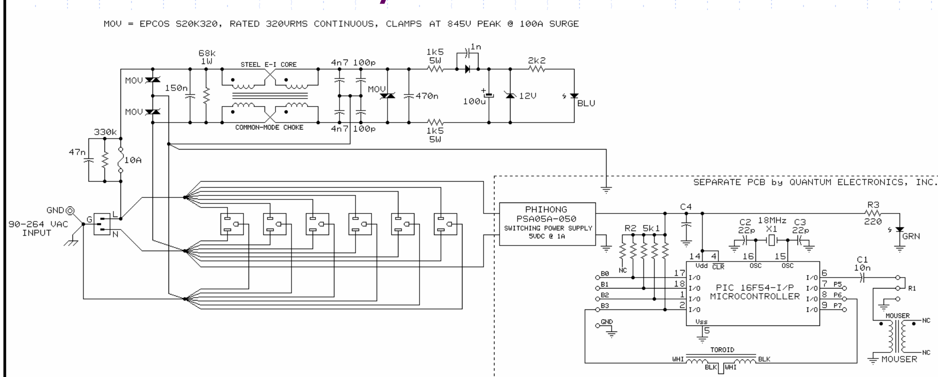
Total maximum current: 18 Amps

Total maximum current: 18 Amps

Dimensions: (W x H x D) 17.4" x 3.34" x 12"

Weight: 13.2 pounds

# What's Actually Inside

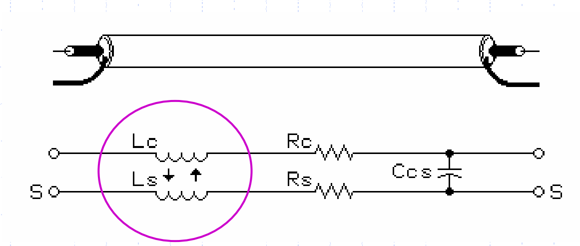



Note that the output of the elaborate filter only powers the blue LED and that the micro-controller circuitry apparently does nothing at all!
**This schematic was generated from an actual production unit.**

## Background Facts ...

- **Ground voltage differences** are **the** driving force behind nearly all audio (and video) noise problems
  - **Generated by magnetic induction in the premises wiring**
  - **Difference approaches zero between equipment powered from closely-spaced AC outlets**
- **Many benefits attributed to "power conditioning" are actually due to their closely-spaced output outlets!**
- The coupling in signal cables that causes hum and buzz becomes negligible beyond about 30 kHz
  - Conditioner filters typically work only at frequencies above 50 kHz
- Power-line "common-mode" (neutral to ground) noise is **zero** at the N-G bond in the main panel

## LP Model of Coaxial Cable



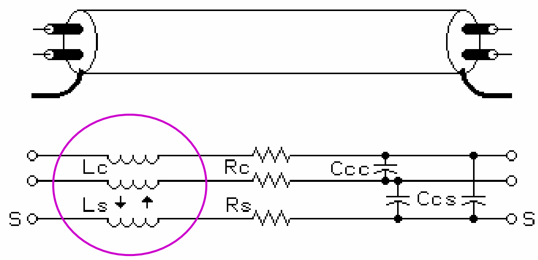

Magnetic Coupling

100% for Coaxial

(60-70% for Unshielded Twisted-Pair)

"LP" = lumped parameter

## LP Model of Shielded Pair Cable




Magnetic Coupling

100% for inner conductors to shield

60-70% between twisted inner conductors

## Power Filters and Isolation Transformers

- Neither can legally interrupt safety ground connection
  - Applies to cord-connected filters and isolation transformers
  - Both add noise to safety ground, often making system noise worse
  - Only a transformer configured as a **separately-derived system** per Code can establish a new N-G bond to improve system noise
    - See Middle Atlantic Products white paper "Integrating Electronic Equipment and Power into Rack Enclosures" for excellent info
- Touted noise reduction specs are unrealistic
  - Measurements made in lab on low-impedance **ground plane**
  - Real-world grounding is via high-impedance **wires** or conduit
- **Filters may be beneficial if installed at N-G bond**
  - All common-mode noise is generated on **load side** of N-G bond

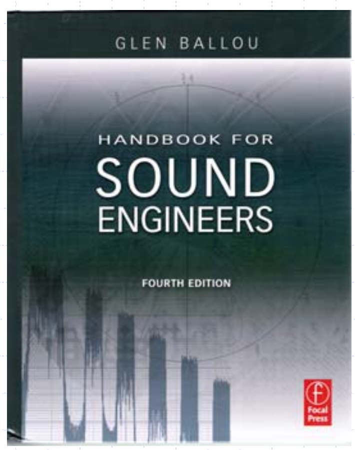
## So-called "Balanced Power"

- Properly called **symmetrical** power
  - Has seductive intuitive appeal
  - **NOT similar to balanced audio lines in any way!**
  - Transformer with 120 V center-tapped secondary
    - **Both line and neutral blades are energized at 60 V**
  - Use **restricted** by Code - ads often imply *endorsement*
    - **Only** for professional use
    - **Cannot** be used with lighting equipment
    - **Must** have GFCI at output
- Only benefit is to reduce leakage currents
  - Leakage currents are a trivial system noise issue
- **Noise reduction generally less than 10 dB**
  - **Likely due to powering system from clustered outlets**

## Thanks for Your Attention!

See the "Handbook for Sound Engineers," Glen Ballou editor, for more on these subjects in three chapters by Whitlock

Think of a question? E-mail me:
whitlock@jensen-transformers.com




*New 4th edition, 2008*