The Myth and Mystery of Analog Signal Interfaces

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Bill Whitlock started his pro-audio career at console-maker Quad-Eight in 1972, where he conceived and designed Compumix® console automation. In 1981 he joined Capitol Records as manager of electronic development engineering. In 1989, he replaced the late Deane Jensen as president of Jensen Transformers and began his research into signal interfaces and system grounding. He sold Jensen in 2014.

He’s become an industry guru on AC power, grounding, and signal interfaces through his writing and seminars at trade shows and universities, including MIT in 2007. Long active in AES standards work, he chaired the group that wrote AES48, initiated a revised CMRR test in IEC standard 60268-3 in 2000, and is a member of UL’s Technical Advisory Committee on pro audio. His landmark paper on balanced interfaces is in the best-selling June 1995 AES Journal. He’s adjunct faculty for both InfoComm Academy and CEDIA University. NSCA students voted him Technical Instructor of the Year in 2009 and 2010. His writing includes numerous magazine columns and articles, chapters for Glen Ballou’s Handbook for Sound Engineers, and dozens of application notes for Jensen Transformers.

His five patents include the InGenius® balanced line receiver by THAT Corporation and the ExactPower® waveform-correcting AC voltage regulator. He’s a Life Fellow of the AES and a Life Senior Member of the IEEE. He now offers his expertise as Whitlock Consulting in Ventura, CA.
MYTH AND MISINFORMATION

• Do cables really “pick up” noise from the air like a radio?
• Equipment manufacturers often don’t know ground loops from FROOT LOOPS ... and it’s often what’s NOT on their spec sheet that complicates noise and other problems!
• Basic rules of physics are routinely overlooked, ignored, or forgotten
• Overheard at a cocktail party:
  “What do you do for a living?”
  “I design and install sound systems.”
  “What's so hard about that ... you just plug the stuff together, right?”
When all equipment in a system is powered by a single utility connection, the only “grounds” that matters are those beyond the N-G bond at the main breaker panel.
NORMAL CURRENT IN BRANCH CIRCUIT

* For clarity, meter and other “phase” not shown
AC POWER – THE 3-WIRE SYSTEM

- NEC “Code” requires 120-volt AC premises power distribution to use a 3-wire system (since about 1960)
- **LINE** (black) and **NEUTRAL** (white) are intended to carry **LOAD** current, typically up to 15 A or 20 A continuously in branch circuits
- The “safety” **GROUND** normally carries no current
- **NEUTRAL** and **GROUND** are **bonded ONLY** at the main “service disconnect” panel

**NEC PROHIBITS NEUTRAL TO GROUND CONNECTIONS ANYWHERE ELSE**
PHYSICS POLICE RULE!

Courtesy of Coilcraft
FARADAY’S LAW OF MAGNETIC INDUCTION

Fluctuating field surrounds every wire carrying AC CURRENT

Field induces an AC VOLTAGE in any nearby conductor (transformer principle)
THE “CONDUIT TRANSFORMER”

Formed by proximity of randomly-positioned wires inside electrical conduit!
THE “CONDUIT TRANSFORMER”

- This effect creates the driving force for 99% of ground loops!
- Load current in line and neutral produces opposing magnetic fields since instantaneous current flow is in opposite directions
- Imperfect cancellation *magnetically induces* voltage over the length of the nearby safety ground conductor
  - Strongly affected by geometry and proximity of wires
  - Highest voltages with randomly positioned wires in conduit
  - Lower voltages with uniform geometry of Romex®
- Voltage is directly proportional to load current, wire length, and rate of change in current or $\Delta I/\Delta t$
  - Mechanism favors high-frequency harmonics of 60 Hz or “buzz” sound
  - For constant current in L and N, induced voltage rises at 6 dB/octave
Current in L and N are equal but flow in opposite directions

Safety Ground Wire “Sees” Zero Magnetic Field at Exact Midpoint

(cross-section view)

Instantaneous L and N currents are flowing into page and out of page
TEST RESULTS

Induced Voltage vs Frequency
6 A rms Test Current, 20 foot Sample Length
DIMMERS ARE HIGH-FREQUENCY NOISEMAKERS!

- Phase-control light dimmers
- Fluorescent lamps
- Electronic power supplies
- Arcing switches, relays, or motors
- Outdoor power-line corona discharge
- AM radio power line pickup

In the frequency domain, this rise-time creates very strong harmonics up to 70 kHz.
AC POWER AND GROUNDING – THE “AGRESSOR”

• AC power is the electrical framework on which electronic systems are overlaid
• The National Electrical Code, a.k.a. “Code,” defines wiring rules and practices designed to prevent fire and loss of life.
  – Enforced nation-wide by the “authority having jurisdiction” or “AHJ”
  – NOT designed to reduce noise problems in electronic systems!
  – Code is NOT optional – violators can be, and often are, prosecuted!
• To deal with system noise issues, we must understand how a Code-compliant system works – and what the unintended “side effects” are
THE FACTS OF LIFE

• SMALL VOLTAGE DIFFERENCES WILL **ALWAYS** EXIST BETWEEN ANY TWO PIECES OF *GROUNDED* EQUIPMENT

• SMALL LEAKAGE CURRENTS WILL **ALWAYS** FLOW IN SIGNAL CABLES OF *UN-GROUND*ED EQUIPMENT
GROUND – WHAT DOES IT MEAN?

• Known as “Earth” outside the USA
• In Utility Power Context: an actual electrical connection to SOIL
• In Electronics Context: a common return path for various circuits, whether or not actually connected to soil
• A FANTASY invented by engineers to simplify their work
  – The “uni-potential” fantasy assumes all ground symbols on drawings are at exactly the same voltage
  – Truth: Real conductors have resistance, causing small voltage drops
  – Truth: Ground circuits usually serve, either intentionally or accidentally, more than one purpose
• Meaning of “ground” has become vague, ambiguous, and often fanciful
GROUND – MAGICAL THINKING

• Eliminate ground voltage difference or GVD by “shorting it out” with massive wires and/or bus-bars
• Reduce noise experimentally by finding a “better” or “quieter” ground
• Skillfully route noise to an *earth* ground, where it disappears forever!
  – The late Neil Muncy called this “the sump theory of grounding”
• Is an *earth* ground for electronic systems really necessary? Think about aircraft electronics ...
GROUND – **MYTH vs FACT**

- **MYTH:** Earth ground is the absolute zero-volt reference
  - Fact: Many unintentional currents flow in soil and create voltage drops just as in any other resistance – soil is a poor electrical conductor

- **MYTH:** Ground wires have zero impedance
  - Fact: Wires have impedance and can’t make multiple points in a system identical “zero-volt” references

- **MYTH:** Noise exists on a single wire or at a single point
  - Fact: A voltage can exist only between two points
  - All voltages are relative or differential
    - Notice that voltmeters have two probes ...
  - Always ask “with respect to what?”
EARTH GROUND IS FOR **LIGHTNING**

- Power lines are frequent targets of lightning
- Before Code required grounding of power lines, they often guided lightning strikes directly into buildings!
- Power distribution lines are grounded at intervals
- Ground rod impedance is low enough to control lightning
- **NEC requires protection of EVERY LINE that penetrates a building**
GROUNDING FOR LIFE SAFETY

• Exposed conductive parts (including signal connectors) can become “energized” at 120 volts if the equipment develops certain internal defects

• **Insulation** is used in power transformers, switches, motors and other internal parts to keep electricity where it belongs

• Insulation can and does fail, effectively connecting “live” power to exposed metal – this is called a **FAULT**

• Without equipment safety grounding or “protective earthing,” people can be seriously shocked or electrocuted!
FAULT CURRENT TRIPS CIRCUIT BREAKER

• Grounding wire in a power cord connects equipment’s exposed metal to safety ground via 3-prong plug
• Outlet safety ground returns via green wire or metallic conduit to neutral at main panel
• Low-impedance connection causes high fault current, which trips breaker quickly!
  – Typical fault currents range from 150 A to over 1,000 A
• SAFETY GROUNDING MUST RETURN THE FAULT CURRENT TO NEUTRAL – THE EARTH GROUND CONNECTION IS IRRELEVANT!
Fault currents range from 150 A to 1,000 A
Trip times range from under 10 ms to 2.5 s
EARTH GROUND ROD IS **USELESS** FOR FAULT CURRENTS

Circuit Breaker Will NOT Trip!
“GROUND LOOP” LINKS AGGRESSOR TO VICTIM

AGGRESSOR

VICTIM

Ground Voltage Difference

Safety Ground Wiring

Signal Cable
GROUND VOLTAGE DIFFERENCES = “GVD”

- Hum is rarely caused by “improper” grounding, whatever that means ...
- Properly installed, fully NEC-compliant AC power wiring NORMALLY creates small voltage differences between outlet safety grounds
- Generally, these voltage differences:
  - Are lowest, usually only a few mV, between nearby outlets on the same branch circuit
  - Are highest, often over 1 V, between far apart outlets or those on a different branch circuit
  - If over 3 V, indicates a serious and life-threatening wiring error that should be investigated immediately!
NOISE

• In its broadest definition, noise is any undesired signal.
• Analog signals accumulate noise as they flow through system equipment and cables.
• Once noise is mixed with the signal, it's essentially impossible to remove it without altering or degrading the original signal.
• Therefore, noise must be prevented along the entire signal path.
• Signal interfaces are generally the dominant danger zone.
• However, audio equipment itself can have “designed-in” problems that cause noise problems when used in real-world systems – rather than the “ideal” environment of a lab test bench.
SIGNAL INTERFACES – THE “VICTIM”

• An interface consists of a device output (line driver), the interconnecting cable (line), and a device input (line receiver)

• **TWO** conductors are always required to complete a signal circuit

• **Balanced** versus **Unbalanced** status depends **ONLY** on the **IMPEDANCES**, *with respect to ground*, of these two conductors!
  – For unbalanced interfaces, one impedance is 0 Ω or “grounded” while the other is significantly higher – generally 50 Ω or more
  – For balanced interfaces, impedances are “nominally” **EQUAL**
  – Since driver, line, and receiver are connected in parallel, each must have equal impedances to ground – it’s a sub-system!
UNBALANCED vs BALANCED

Unbalanced

Balanced

Grounded
UNBALANCED INTERFACES

- **INHERENTLY SUSCEPTIBLE** to noise coupling!
- It’s ironic that they *still* dominate consumer audio after nearly 100 years, while the dynamic range of readily-available program material has steadily increased – the era of AM radio and scratchy 78 RPM records is long gone!
Two currents, power-line leakage and signal, flow in the same impedance “R,” which allows them to couple!
ABOUT 2-PRONG PLUGS

• UL listing demands extraordinary/expensive measures:
  – Insulation “creepage” distances must be large
  – One-shot thermal cutoffs must be embedded in transformers and motors to prevent overheating and subsequent insulation failure
  – Equipment must remain safe (limited leakage current) in spite of component failure, overload, and mechanical abuse

• Chassis voltage with respect to ground, or “float” voltage, can measure up to 120 V, but the available current is harmlessly low
  – High-impedance voltmeters indicate voltages that may frighten those who don’t understand!
PARASITIC CAPACITANCES AND LEAKAGE CURRENT

- Exist in all real equipment connected to AC power due to
  - Transformer inter-winding capacitance (not shown in schematics)
  - Internal EMI filter capacitors
- Capacitances cause **LEAKAGE CURRENT** to flow from power line to chassis in real-world equipment
  - UL established safety limits for “listed” equipment
    - 3.5 mA for devices with 3-prong plugs
    - 5 mA for devices with 3-prong plugs and a special warning label
    - 0.75 mA for devices with 2-prong plugs
LEAKAGE CURRENT IN “INVISIBLE” GROUND LOOP

Both devices have 2-prong AC plugs

< 0.75 mA
AC POWER ISN’T PURE 50/60 Hz

• Many loads, especially “brute force” electronic power supplies, draw current in pulses only at the peaks of the voltage during each cycle
  – “Power Factor Corrected” or PFC power supplies suppress this problem
• 120 VAC waveform distortion is typically 2% to 6% THD
• High-frequency harmonic voltage is caused by rapid current changes
  – Typical low-cost light dimmers have a current rise-time of about 5 \( \mu \)s, producing strong harmonics to beyond 70 kHz!
  – The conduit transformer favors those harmonics, coupling voltages that increase with frequency (+6 dB/octave) into safety ground wiring
TYPICAL LEAKAGE CURRENT SPECTRUM
EXAMPLE OF CABLE NOISE DUE TO LEAKAGE CURRENT

- A 25-foot audio cable (foil shield, #26 AWG drain wire) is found to have an end-to-end shield resistance of 1.0 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 $E = I \times R = 316 \, \mu A \times 1 \, \Omega = 316 \, \mu V$
- Consumer signal reference level = $-10 \, \text{dBV} = 316 \, \text{mV}$
- Therefore, SNR (signal to noise ratio) = $20 \times \log \left( \frac{316 \, \text{mV}}{316 \, \mu \text{V}} \right) = 60 \, \text{dB}$
  - **20 dB worse than a CD player!** (15 dB “headroom” assumed)
- The same length of **Belden #8241F** cable, with its shield resistance of only 0.065 Ω, increases SNR to 84 dB, an **improvement of 24 dB**!
IT GETS MUCH WORSE IN A GROUNDED SYSTEM!

• Ugly truth: unbalanced interfaces simply can’t deliver on “plug-and-play”
  – Only the smallest of systems, in the most benign imaginable electrical environments, could possibly live up to a “high performance” promise
  – Listening at maximum volume, with signal source muted, should result in only a faint hiss

• If unbalanced interfaces exist between two GROUNDED points in a system, hum and buzz can easily become louder than the signal!
  – Ground voltage differences between outlets is effectively applied across the ends of the audio cables, where they directly add to the signal
  – Other “alien” ground connections, such as CATV or DBS, can create very high ground voltage differences
"GROUND LOOP" LINKS AGGRESSOR TO VICTIM

Signal Cable

VICTIM

AGGRESSOR

Safety Ground Wiring

Ground Voltage Difference
GROUND VOLTAGE DIFFERENCE ADDS DIRECTLY!

Just a few millivolts here can be noise disaster!
HOW MUCH NOISE IS TOO MUCH?

• Our ears perceive 10 dB reductions as “half as loud” and 2 or 3 dB reductions as “just noticeable”

• **Dynamic range** is the ratio, generally expressed in dB, of maximum undistorted signal to residual “noise floor” levels

• In **audio**, a dynamic range up to **120 dB** may be needed in high-performance systems in typical listening environments (*1980 Louis Fielder paper*)

• Audio hum or buzz, “stationary” noise, is much more noticeable and irritating than the hiss, “random” noise, inherent in all electronics
  – Excess random noise is a gain structure issue (not discussed here)
THE BALANCED INTERFACE

• Inherently immune to noise coupling – that’s why it’s “professional”
• Telephone companies popularized it in 1890s and still use it today
• Its true nature has been WIDELY MISUNDERSTOOD for decades!

“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.”

This **WRONG** explanation from the internet, like many others in print, doesn’t even mention **THE** single defining property of a balanced interface!

*I presented my paper “Balanced Lines in Audio – Fact, Fiction, and Transformers” 25 years ago, hoping to debunk this myth, whose consequences have tarnished the reputation of balanced interfaces in general!*
“A balanced circuit is a two-conductor circuit in which both conductors and all circuits connected to them have the same impedance with respect to ground and to all other conductors. The purpose of balancing is to make the noise pickup equal in both conductors, in which case it will be a common-mode signal which can be made to cancel out in the load.”

*Henry W. Ott, Distinguished Member of the Technical Staff, AT&T Bell Labs*

“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.”

*IEC Standard 60268-3 (2000)*
Audio signal between HI and LO is “differential-mode” or DM.
Noise appears on both HI and LO at receiver as “common-mode” or CM.
COMMON-MODE REJECTION RATIO or CMRR

• **Ideal** receiver would respond only to **DM** and not respond at all to **CM**

• **Real** receivers, whether using amplifiers (“active”) or a transformer, will have some small response to **CM** (i.e., limited rejection)

• **Common Mode Rejection Ratio**, or **CMRR** is the ratio of **DM** (signal) gain to **CM** (noise) gain, most commonly expressed in **dB**
  
  – Is a **ratio** not a signal level – and **not** expressed as dBU, dBV, or dBm

  – Is a **positive** number for any useful receiver

  – A larger number means better noise rejection
BALANCED INTERFACE = WHEATSTONE BRIDGE

- Driver/receiver CM impedances form bridge
- Unless precisely “balanced,” the bridge converts $V_{cm}$ to signal, reducing rejection
- “Balance” requires precision ratio matching of the + and – “arms” of the bridge
  - Variations have worst effect when all four impedances are equal and least effect when upper and lower pairs are widely different
  - If lower pair (receiver CM input) impedances are made extremely high, good balance (high CMRR) is maintained even with wide variations in upper pair (driver output) impedances
“REAL” vs “MARKETING” CMRR SPECS

• In real-world equipment, driver output impedances are determined by typical ±5% tolerance resistors and ±20% tolerance (or worse) capacitors
  – Typical output impedance **imbalances** are about **±10 Ω (at 60 Hz)**

• In real-world “electronically-balanced” line receivers, CM input impedances typically range from 10 kΩ to 50 kΩ
  – This makes their **real-world** noise rejection (CMRR) *exquisitely* sensitive to driver output imbalance
  – CMRR of the popular SSM-2141 balanced input IC drops by **25 dB**, from 90 dB to 65 dB) with only a **1 Ω** imbalance at the driver output

• Actual CMRR then becomes unpredictable in the assembled system, although the receiving equipment input has a high advertised CMRR!
Transformers were the norm in audio gear for decades and their noise rejection was taken for granted. But in the early 70s, a “transformer-less” movement started. We were told that a solid-state “differential amplifier” was better in every way (and far cheaper). I knew from my own experience this was not true! After my first 4 years at Jensen, I finally figured out why:

- An input transformer’s CM input impedances are typically 10 MΩ to 50 MΩ, about 1,000 times that of the electronic “diff-amp”
  - A good transformer’s real-world noise rejection (CMRR) is essentially unaffected by driver output imbalances
  - The CMRR of a Jensen JT-11P-1 input transformer drops only 7 dB (from 107 dB to 100 dB) with a 600 Ω imbalance in the driver output

- This means actual noise rejection (CMRR) remains very high and essentially unaffected by source imbalances, even with completely unbalanced sources!
CMRR vs Input CM and Source Imbalance Impedances

- Typical Active Balanced Inputs
- InGenius® IC
- Good Input Transformer

Input Z_{cm} (per leg)
- Z_{cm} = 5 \, \text{k}\Omega
- Z_{cm} = 50 \, \text{k}\Omega
- Z_{cm} = 10 \, \text{M}\Omega
- Z_{cm} = 50 \, \text{M}\Omega
NEW TEST TO “MAKE IT REAL”

• A CMRR (noise rejection) test that uses a shorted input or a laboratory trimmed source produces data that’s meaningless in the real world!

• Traditional CMRR tests completely ignored effects of “real” signal sources
  – In 1999, the IEC recognized that results of their test didn’t reflect real-world experience and asked for comments
  – I proposed the new test, which was adopted and published August 2000 in *IEC Standard 60268-3, Sound System Equipment - Part 3: Amplifiers*
  – Audio Precision, much to their credit, has also incorporated the new IEC test in several audio analyzers
AUDIO PRECISION MODEL APX525

First Commercial Analyzer to Incorporate the New IEC Test
TESTS FOR CMRR – OLD vs NEW

**IEC Normal-Mode Test**
Establishes 0 dB reference

**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 DO I REALLY NEED?

- Professional reference signal level is +4 dBu = 1.23 V
- A “hostile” 1.23 V ground voltage difference (common-mode voltage) might exist in a system
- In this case only, SNR (signal-to-noise ratio) = Interface CMRR
- Total dynamic range = SNR + “headroom”
- If headroom is 15 dB, CMRR of 80 dB would result in 95 dB of total dynamic range, which is comparable to an audio CD
  - A “less hostile” 123 mV ground voltage difference would increase dynamic range by 20 dB
- 80 dB of “real-world” (IEC test) CMRR is generally acceptable, but 50 dB is rarely enough for commercial sound systems
THE “PIN 1 PROBLEM” – IT’S DESIGNED-IN

• Common-impedance coupling that occurs inside equipment, turning its shield connections into very-low-impedance signal inputs!
• Dubbed the “pin 1 problem” (XLR pin 1 = shield) by the late Neil Muncy in his 1994 AES paper
• This defect has been inadvertently designed into an alarming number of products ... and, sadly, it continues
• It allows shield current (ground-loop current) to flow in wires or PCB traces shared by internal amplifier circuitry
• This problem can exist at I/O ports, whether analog or digital, in ANY piece of equipment
Shield current flows in equipment’s internal signal reference “ground”

Power-supply leakage current flows in signal reference ground in two of the boxes. This design flaw results in so-called “sensitive” or “power-line prima-donna” equipment.
GOOD DESIGNS AVOID “PIN 1 PROBLEM”

Shield currents must flow back to safety ground – giving them their own separate path completely avoids the problem!
DEALING WITH MAGNETIC FIELDS AND CABLES

• Coaxial cables are essentially immune to AC magnetic coupling
• Balanced cables may have slightly mismatched voltages induced into the two signal conductors, the difference becomes noise added to the signal
  – TWISTING improves matching by averaging physical distances of each wire to the external field source (same is true for electric fields)
• Effective magnetic shielding for 60 Hz fields requires enclosing conductors in steel conduit or enclosures made of special magnetic alloys
• The most effective treatments are
  – increase the distance between magnetic field source and victim
  – reduce open loop area between circuit conductors (twisting) in both source and victim
BASICS – FARADAY’S LAW OF MAGNETIC INDUCTION

Fluctuating field surrounds every wire carrying AC CURRENT

Field induces an AC VOLTAGE in any nearby conductor (transformer principle)
MAGNETIC FIELDS AND POWER CORDS

Far from cord, magnetic field cancellation is nearly complete

At distance of 10 times the conductor spacing, magnetic field is about 1% of close-in value
HIGH-FREQUENCY CABLE BEHAVIOR

• At audio frequencies, $R_s$ is responsible for common-impedance coupling
• Impedance of shield rises above 4 kHz (typical) due to its inductance $L_s$
• At 10 times this frequency (40 kHz typical), essentially all voltage across $L_s$ is magnetically induced into $L_c$, cancelling most noise at receive end
• **Shielded** cables inherently cancel CM noise above $\approx$ 40 kHz
  – Weigh this against claims made for power-line filters …
  – This does NOT apply to UNshielded CAT-5 types!
TRANSMISSION LINES AND TERMINATION

• Transmission line effects become significant when the cable’s physical length becomes about 10% of an electrical wavelength at the highest frequency
  – A wavelength is the distance traveled by the signal during one cycle
  – The “propagation velocity” or “\( \eta \)” of signals in cable is about 0.7 to 0.9 times the speed of light
  – Characteristic impedance is the impedance of an infinite length of cable
  – Signals will reflect from end-to-end in the cable, causing various problems, unless terminated in its characteristic impedance at each end
• Video, RF, and data cables over a few inches long need terminations
• For analog audio cables, termination is very rarely required!
  – 10% of a wavelength at 20 kHz in typical cable (\( \eta = 0.7 \)) is 3,442 feet ... if an audio cable is longer than this, you might consider terminating it
PHYSICS vs SNAKE OIL

• Exotic cables, even if triple-shielded, made of 100% pure UNOBTAINIUM, and hand woven by virgins, will have **no** significant effect on hum and buzz!

• Truly high-performance unbalanced audio cables combine **very low shield resistance**, low capacitance, and reliable connectors

• Belden 8241F (they call it video cable) combines very low shield resistance, low capacitance, high flexibility, and availability in pretty colors!
PHYSICS FROM AN ALTERNATE UNIVERSE?

- Double-blind tests prove that if audible differences among cables actually do exist, they’re entirely explainable.
- Marketing hype often invokes transmission line theory and implies that nano-second response is important.
- Real physics reminds us that audio cables only begin to exhibit subtle transmission line effects when some 3,500 feet long.

“High-end" audio is awash in pseudo-science, anti-science, and mysticism.
CABLES AND “POWER CONDITIONERS”

• Ground voltage difference or GVD is the force behind most noise issues
  – Created by magnetic induction in premises AC wiring
  – A power isolation transformer or “balanced power” has no effect on GVD created by the “conduit transformer”
  – GVD is near zero between closely-spaced AC outlets

• Many benefits attributed to a “POWER CONDITIONER” are actually due to the tight clustering of output outlets!

• The coupling mechanism in signal cables that causes hum and buzz operates below about 40 kHz, where typical power-line filters have little effect

• Power-line “common-mode” (neutral to ground) noise is, by definition, zero at the N-G bond (main power panel) and does not enter from outside
UNBALANCED TO BALANCED TRANSITIONS

• Also called “Consumer to Pro” conversion
• Signal reference levels are different
  – Consumer ref = −7.8 dBu = −10 dBV = 0.316 V rms
  – Professional ref = +4 dBu = +1.8 dBV = 1.228 V rms
  – Requires voltage gain of about 4 X, or 12 dB
    • 0 dBu = 0.775 V rms
    • 0 dBV = 1.000 V rms
    • 0 dBV = +2.2 dBu
• Why not use a 1:4 step-up transformer do I hear you ask?
"CONSUMER TO PRO" LEVEL CONVERTER?

- Uses a 1:4 step-up transformer for 12 dB gain
  - 1:4 transformer reflects \((1:4)^2\) or a 1:16 impedance ratio (it’s physics)
  - With a 10 kΩ to 40 kΩ pro input, the consumer output must drive a 625 Ω to 2.5 kΩ load. IEC standards specify load on consumer outputs be 10 kΩ minimum!

- The overload degrades gain, headroom, distortion, and frequency response.

- Actual gain is only 3 to 8 dB, not 12 dB
  - 12 dB of gain “reach” is usually available in a system
USE A SIMPLE “TRANSITION CABLE” INSTEAD

• Mode transition and noise rejection are the issues, not gain
• “Adapters” and most “adapter cables” throw away the noise reduction benefit of the balanced input
  – An RCA to XLR adapter at a balanced input reduces the entire interface to a noise-prone unbalanced one!
• A 3-conductor (shielded twisted-pair) hookup takes advantage of noise rejection available at the balanced input
  – If the balanced input uses a quality input transformer or the InGenius® IC, noise rejection can be 80 dB or more!
  – Even with “garden variety” balanced inputs, noise rejection will generally be about 30 dB
2 CONDUCTORS ... OR 3?

Unbalanced cable + ADAPTER = 0 dB rejection

Balanced (STP) cable = typically $\geq 30$ dB rejection
BALANCED TO UNBALANCED TRANSITIONS

• Also called “Pro to Consumer” or “+4 to −10” converter

• **Signal level difference is a legitimate concern**
  – Consumer inputs are easily over-driven by pro levels, requires 12 dB loss
  – If pro output level is reduced, metering and S/N are degraded
  – Resistor “pad” can be used but provides no isolation

• **Design variations among balanced output stages makes it risky business!**
  – Some misbehave or are damaged if either output line is grounded
  – But some must have one line grounded, but where?
    • Grounding at driver reduces the entire interface to unbalanced
    • Grounding at receiver, enabling noise rejection, may cause high-frequency instability in some “servo-balanced” outputs
BALANCED OUTPUT STAGE TYPES

**SYMMETRICAL VOLTAGE**
ONE OUTPUT **CANNOT** BE GROUNDED!

**ELECTRONICALLY-BALANCED**
ONE OUTPUT **SHOULD** BE GROUNDED

**TRANSFORMER FLOATING**
ONE OUTPUT **MUST** BE GROUNDED!
THE MANUFACTURER PROBABLY WON’T TELL YOU
Experimenting can be both frustrating and dangerous to equipment!
THE ONLY METHOD THAT ALWAYS WORKS

- Transformer isolation works with **any** output type
- 4:1 step-down transformer reduces signal 12 dB
- Superior noise rejection
ANALOG SIGNAL INTERFACES AND STANDARDS

• The Audio Engineering Society has a number of standards committees that work to make the results of assembling even the most complex audio systems predictable.

• Some manufacturers are ignorant of existing standards and do things their own way, often making their equipment incompatible with other gear. System performance may be unacceptable or simply not work at all!

• Critical specifications and/or test conditions are sometimes conspicuously absent from specifications and user manuals

• Installers and users of equipment sometimes find that system performance is poor for no obvious reason. For example, an unbalanced input might have an input impedance of 2 kΩ instead of meeting the accepted IEC standard of 22 kΩ minimum. Low end frequency response would likely suffer.
Thanks for Your Attention!

Questions?