Understanding, Finding, and Eliminating Ground Loops

*This report on Bill Whitlock's June 2006 presentation in Washington, DC, serves as the introduction to a series of detailed articles Bill will write for **MMM**, the first of which will appear in the near future. The installments will debunk widespread myths about grounding and electrical noise reduction through straightforward scientific explanations. He will explain the underlying theory, and describe good engineering practices for the manufacture, installation, and interconnection of professional and consumer equipment. Stop humming and learn the words!*

By Fred Geil (AES—DC section Secretary) and David J. Weinberg (AES—DC section Vice Chair and SMPTE—DC section Manager)

A special three-hour seminar co-sponsored by the AES-DC section and with the SMPTE—DC section featured Bill Whitlock, president of Jensen Transformers (www.Jensen-Transformers.com), lecturing on grounding and interface concepts, myths, and problems. Whitlock's experience includes contributing to AES48-2005 and IEC60268-3, standards addressing grounding practices and interfacing—subjects that are closely intertwined. Whitlock's many white papers and schematics are on the Jensen website.

The meeting was chaired by David Weinberg, who recounted his experiences with grounding problems while introducing the guest speaker.

Whitlock declared that grounding and interfacing are widely thought of as "black art," and articles on the subjects are rife with myths. Furthermore, fundamental principles of physics are overlooked, ignored, or forgotten. Manufacturers are often "clueless." Fortunately, Ohm's law is all you need to understand grounding/interfacing.

Safety First. Whitlock stressed that you must never compromise safety in order to troubleshoot or fix ground loop problems, and that there is no reason to do so. He reminded the audience about the role of the green ground wire and safety ground, the National Electric Code, and their importance to the preservation of life. Key to this is the rule that the white (neutral) and green wires inside walls must be tied together *only* at the safety ground point in the breaker panel, and equipment's green wire should never be lifted. Whitlock cautioned that equipment *will* fail, and a missing safety ground can be lethal. Earth ground doesn't figure into this safety issue, it only serves as a relatively lower impedance path in the event of a lightning strike.

Ground Doesn't Mean Zero. Just because there is a metal rod in the ground doesn't mean that it is at 0V AC, although it does provide a reference point. Impedance between any two points in the earth is not zero,

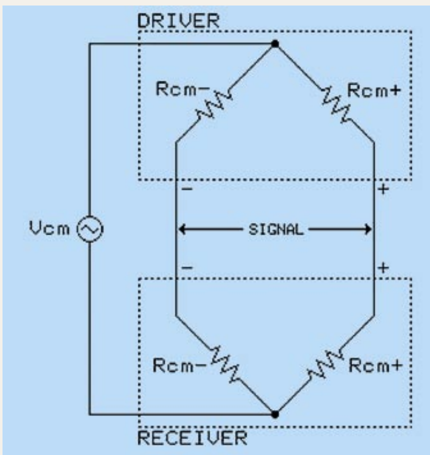

FIGURE 1: A Wheatstone Bridge model.

and there are many electric fields acting on the earth, so there is a voltage difference, and thus a ground current, such as between the cable TV feed ground at the street and the ground in your house. In fact, if there are two earth grounds, in the event of a lightning strike there will be thousands of volts, and hundreds of amps, between them. Thus having more than one earth ground is *less* safe than having only one, and violates the NEC, unless they are solidly bonded together.

As in the earth, there is always resistance in wire (including cable shields), no matter how heavy the gauge, so there will always be measurable AC voltage, and therefore current, between any two ground points.

Hum Troubleshooting. Many ground-loop hum problems arise from having multiple ground points, which can easily be the path along a signal cable shield, through the equipment to one safety ground, through the non-zero impedance to another earth or other ground connection, then back to the other piece of equipment and to the other end of that same signal cable shield.

Temporarily lifting the safety ground, or the ground at one end of a signal cable, and listening might confirm that there are ground currents flowing in signal cables via the signal return wire or shield, and illustrates the inappropriate nature of the RCA connector and feeding unbalanced signals between cabinets, a practice that arose when a convenient interconnection method *within* a TV cabinet became the de facto standard for connections *between* cabinets.

Whitlock lamented that far too much "pro" equipment has unbalanced inputs and outputs, hence the need for frequent hum-elimination troubleshooting. He described two useful tools: the Jensen TA-R1 RCA-RCA test adaptor (two for $12.50) that breaks the signal path yet retains ground connections, and wideband Jensen Iso-Max transformers (available from Old Colony Sound Lab, www.audioXpress.com, or 1-888-924-9465), designed to feed a signal between unbalanced connections while isolating the grounds between them, thus eliminating that ground current.

Noise. Noise gets into equipment because of the RLC of cables plus interface problems, and it cannot be eliminated by anything an electrician can do to the power wiring. A spectrum of typical leakage current will show frequencies into the MHz range. Only a balanced interface can minimize the transfer of this RF noise to the next stage.

Shields. Shields inhibit only electric field coupling, not magnetic. Thus they provide no help if you run a signal cable near a power cable, because the power cable generates magnetic fields, too. An 85%-coverage copper-braid shield is better than a 100% foil shield for most conditions because of the uniformly distributed nature of the current carrying capability, versus the shield wire used with foil shields.

"Exotic cables will *not* stop noise. Expensive cables, even if double or triple shielded, made of 100% unobtainium, and hand woven by virgins, will have no significant effect on hum or buzz. Only the resistance of the grounded conductor can make a difference."

If you must use coax, Belden 8241F—with a low-resistance copper-braid shield—works well for audio and video.

Balanced Works. Whitlock stressed the concept of a balanced interface. Signal symmetry has nothing to do with a balanced connection, which does *not* require equal signal voltages with respect to ground. In fact, the voltage levels on each conductor are irrelevant. The balanced impedances to ground provide the far superior common-mode rejection ratio (CMRR) performance.

The real definition: "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 Ott]

Furthermore, "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].

Impedance matching is only important when transmission-line effects become substantive, which is when the signal wavelengths in the cable are at least 10% of a cycle. In those cases, impedance matching inhibits reflections along the cable that lead to cyclic reinforcement and cancellation, which can cause serious signal loss problems at certain frequencies. For audio, this is not a problem until the cable reaches about 4000´. In fact, the best CMRR is achieved when the source impedances are very low and the receiver impedances relatively high. A Wheatstone Bridge model (***Fig. 1***) aids the understanding of this effect.

This leads to the demonstrable conclusion that sending audio, and for shorter cable lengths even video, over tightly twisted pair, even UTP, will work exceptionally well, but only if the "transmitter" and "receiver" have properly balanced connections.

Whitlock explained why in the real world a good transformer still beats transformerless interfaces in terms of CMRR and ground loop problems. Nevertheless, THAT Corp. has implemented Whitlock's patent #5,568,561 in its 1200, 1203, and 1206 chips that accurately emulate a transformer's benefits. It includes bootstrapped input resistors to achieve very high common-mode input impedances yet preserves the necessary path for first-stage DC bias.

The Pin 1 Problem. When in equipment an XLR connector's pin 1 is tied anywhere except directly to the green wire ground point (such as to signal ground), there is a pin 1 problem, caused by noise current flowing in the signal ground, thus inserting noise into the signal. This should be avoided, especially when trying to realize 24-bit audio performance.

For audio system designers, Whitlock offered several tips:

- Hum might be reduced by plugging the various components into the same outlet strip, in effect tying the grounds together. However, this won't help remove hum from the cable TV feed; a signal isolation transformer might be necessary.
- Typical foil cable shielding is ineffective for magnetically induced noise, but steel conduit can help.
- When troubleshooting hum problems, work stage-by-stage backwards through the system, but first remove any ground-lift devices in the system.
- Avoid unbalanced interfaces whenever possible.
- Tight twisting of wires in a balanced cable improves CMRR.
- Electrolytic capacitors in balanced interface circuits guarantee poor impedance balances, due to their inconsistent characteristics versus frequency between units (wide tolerances).
- When interfacing unbalanced sources to balanced receivers, use a shielded twisted pair with the shield and low (–) signal conductor connected together at the source ground.

The importance and popularity of the topic was obvious, as attendees raised many questions and shared war stories during the discussion/question period afterward. **M³**