Grounds and Shields

One of the greatest benefits that digital recording systems have brought us is the potential for wider dynamic range than ever before, and at a price affordable today by project studios. But there's a down side. The low level hum and other noise formerly masked by analog tape hiss becomes painfully audible. Even if you select equipment that uses balanced interconnections throughout, with any given mix of equipment, you may find you system noise level some 10 or 20 dB higher than the theoretical limit.

With electrical and electronic pollution creeping into our environment from many common devices which have become part of our everyday life, attention to shielding and grounding is more important than ever. Noise induced from electrical power lines (AC hum) is something we've lived with forever, but until recently, RFI (radio frequency interference), unless you were unlucky enough to build your studio next to a broadcast transmitter or factory, was for the most part down at the inaudible level. Today, this has changed, and we find potent RF generators in the form of switching power supplies, computers, monitors, and the producer's cellular telephone scattered throughout the studio and control room. FCC type certification is one thing - real life audio problems are another. While your computer may be certified not to render your TV set unusable, electromagnetic energy creeping into your audio equipment manifests itself as hiss and crackles that you don't want to preserve in full digital splendor. This month we'll explore some of the approaches to shielding and grounding that have been employed, look at the problems, and some solutions.

Balanced Lines Cures All - Not!

It's a common belief that balanced connections are better than unbalanced at rejecting outside noise, but strangely enough, there's quite a bit of equipment out there with balanced connections which isn't as noise-immune as we'd like. In fact, some unbalanced equipment that performs the same function can turn out to be quieter. This can justifiably cause one to lose faith in scientific theory, as well as faith in your friendly dealer or columnist who advised you to spend the extra bucks for balanced equipment.

What's wrong with this picture? A few things, some of which you can easily fix, some are more difficult, and some you'll just have to live with. You may think your system is properly grounded because all of your power plugs have a ground pin, but you don't know what happens to that green wire once it goes inside the box. There are poorly constructed cables and connectors, both home made and purchased. There's the haphazard scheme of grounding and ungrounding that frequently results when trying to reduce hum and noise in a system. And then there's what audio engineer and consultant Neil Muncy has dubbed "The Pin 1 Problem", which describes how effectively the cable shield connection (Pin 1 on an XLR connector, but it applies to other types of connectors also) carries the shield to the equipment.

What's Ground Anyway?

"Ground" is one of the most common electrical terms. In electrical power systems, it means a direct and electrically sound connection to that dirty brown stuff under the house. Electrical wiring always has one foot firmly planted in the earth to help reduce damage from lightning and other power surges. In electronics, however, the term "ground" has several different meanings, only one of which is a connection to earth. In the practical sense, ground is a very low impedance path for electrical current to return to its source. That source might be the unit's power supply or another unit that feeds it a signal.

Ground doesn't have to be referenced to the earth in order for equipment to work quietly (a portable battery powered recorder is an excellent example). But an inadequate ground connection can make a pretty good antenna, actually making the noise problem worse. In fact, often disconnecting electronics from the power (earth) ground reduces hum. Surely at some time you've plugged in a piece of noisy equipment through a ground lift adapter and found that your immediate problem (the hum) is reduced. This proves that you have a problem, but it doesn't solve it. Lifting power grounds is dangerous and should not be practiced.

In audio equipment, ground is the common electrical signal return point. It's usually the negative (or zero voltage in a bipolar powered unit) power supply terminal, but it's not necessarily the chassis. And this leads us to The Pin 1 Problem, or for short, P1P. (see the Appendix)

Pin 1

Pin 1 is defined as the terminal of any equipment's signal connector to which the cable shield is (or is supposed to be) connected. On an XLR connector, by industry convention, it's actually Pin 1. On a 1/4" or mini-phone connector, it's the sleeve. On an RCA connector, it's the shell. On a terminal strip or multi-pin connector Pin 1 is whatever the manufacturer designates, generally with a "ground" symbol or legend.

What's the problem? For effective shielding, Pin 1 should be connected inside the equipment directly and solidly to the chassis. This makes the shield of a cable going to or from the unit an extension of the box so there's no break in the shielding and no place for RFI to get in. It used to be pretty easy to build like this in the "vintage" days when equipment was hand-wired and constructed on a metal chassis. It's more difficult today with the use of plastic cases and PC board mounted connectors which don't physically attach to the box. In a lot of modern equipment, Pin 1 frequently gets to the unit's ground point through a circuit board trace which may be a longer path than necessary and be of inadequate current carrying capacity. Further, that ground point may or may not be connected to the box.

The problem with this type of construction is that if there's any noise current flowing through the cable shield, it doesn't stop short at the equipment cabinet, but it goes on to the unit's internal signal reference "ground" point, where it pulls that point a little off zero potential and allows the noise to sneak into the device's output.

The indirect path between the shield and the chassis is an electrical path in the form of a loop, the ground loop we've all heard about. Since this is a fairly low resistance path, any current induced in the loop from a nearby magnetic field (a power transformer or a power cord for example) can be fairly substantial. In Muncy's research into P1P, he's found that shield noise current as low as 1 mA has caused hum as loud as 20 dB below nominal output in certain pieces of equipment, and he's measured noise currents as high as 100 mA in what appear to be straightforward installations. Consider a console which with multiple inputs, where the effect becomes cumulative, and noise can build up rapidly.

Noise in an unbalanced system is usually attributed to the lack of common mode rejection offered by balanced wiring, but more likely, it's a result of the Pin 1 Problem. The problem is exacerbated by the fact that the sleeve of PC board mounted 1/4" jacks (a common method of construction today, particularly for bargain priced effects processors) are almost always isolated from the chassis. This is a result of manufacturers' good faith attempts to eliminate ground loops in unbalanced equipment, but assuring an indirect path, if any at all, between the incoming shield and the chassis.

What To Do?

Among all of this gloom and doom, there's some good news. Manufacturers of modern audio equipment are becoming conscious of the problem (the old timers always knew and always built equipment that was ground-clean) and are taking steps to clean up their act with properly grounded connectors and taking care to separate signal and chassis grounds. One thing that the wall warts that we love to hate do for us is isolate the chassis from the AC safety ground. This eliminates the ground loop path through the AC power connection between chassis of two interconnected pieces of equipment, a blessing in disguise.

The best thing you can do is simply to not buy any equipment guilty of the ol' P1P, but how do you know what's "clean"? Perhaps this is something that our reviewers should begin to report. It's fairly easy to test for P1P by inducing a current into the equipment ground and see if it appears on the output, but there's not an established standard for how much leakage is acceptable.

One-End-Only Shielding

If much of the noise we're trying to eliminate comes in via the cable shield, then why not simply disconnect it? Indeed that's one of the time honored methods of de-noising a

system. The principle of one-end-only (OEO) shield connections, sometimes called telescoping grounds, has been with us for years. Wiring in this manner was easy to do when engineers built their studios from stem to stern, but using custom-built cables makes it difficult to accommodate “visiting” equipment or setting up portable systems. Never the less, this is a tried-and-true system that works most of the time on equipment that is built with less than an ideal ground configuration. Nearly all equipment from the first generation of home studios which typically used RCA phono jacks can benefit from OEO wiring.

Today, however, most personal studios are wired with store-bought cables. These, universally, are built with shields connected on both ends, making OEO wiring impossible unless you want to take them apart and modify them. That’s not unheard of. At least you only have to work on one end of the cable rather than both. And, yes, I did inquire into the feasibility of the cable manufacturers building shield-OEO cables. Although companies such as Conquest, Gepco, and Whirlwind, who manufacture cables to order, would be happy to build them with any shield configuration you specify, it’s not likely to happen with the mass-market cable folks such as Hosa. The sad truth is that it would make even more products for the dealers to stock, many users wouldn’t know what they were buying, and most dealers wouldn’t know what to sell.

Interestingly, the fact that knocking a hole in the shielding (by disconnecting a cable shield) and having the system noise figure improve tells us that the ground problem is more serious than the RFI problem. Even with aluminum and plastic case construction, it seems that manufacturers are doing a pretty good job of keeping their equipment relatively immune to stray electromagnetic radiation.

Be Systematic

There are two approaches to OEO grounding. One sounds more fun than scientific, but may actually be more effective in the long run. The other is systematic and boring but generally leads to satisfactory results and is the one to use when building (or rebuilding) an installation from the bottom up.

The fun way is simply this. Start with your system fully interconnected with cables that have shields connected at both ends. Turn it on, crank it up, and listen to the hum and noise. Now, pick a cable, choose an end, and cut the shield. If the hum gets louder, reconnect it. If it gets quieter, leave it disconnected. Then do it again, and repeat the process until either:

(a) the hum is down to an acceptable level

(b) something stops working because you’ve lifted shields at both ends of the cable and have broken a signal return path

(c) you get electrocuted (just kidding! – but DO be careful)

If you're using store-bought cables and you can't disconnect the shield without cutting and re-terminating the cable, build yourself a shield-breaking adapter - a short cable between a plug and an in-line jack, wired with the shield disconnected. If you're using a mix of balanced and unbalanced cables, make your adapter out of two-circuit (TRS) parts.

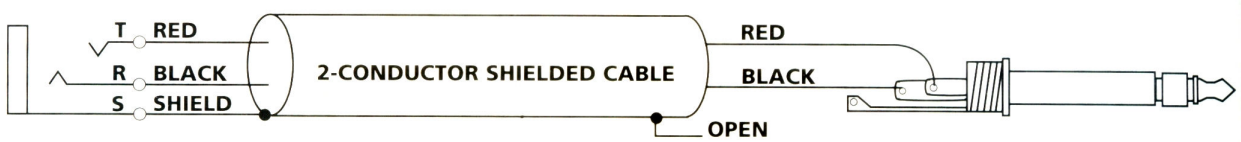

Fig. 1 - A shield-breaking adapter

The systematic approach is based on the executive decision (and conventional wisdom) to connect the shield on the source end of each cable (the end connected to an output) and leave it disconnected on the destination end (the end that goes to an input). This may not be the optimum configuration since you might have a device that has worse Pin 1 problems on its output than the device you're connecting it to has on its input, but by being consistent, you at least assure that you aren't leaving an ungrounded shield or allowing the signal to find a less direct return path.

Home Brewing

If you're going to build you own cables, it's a good idea to make all of them from two conductor shielded cable even if they're being used to connect unbalanced equipment. For one thing, you'll have the wire ready when you change out a piece of unbalanced gear for a balanced replacement. For another, it gives you a better way to interconnect balanced and unbalanced equipment.

When constructing cables to go between two balanced connections, the connections are obvious. The shield goes to Pin 1 (or the sleeve of a phone plug) on the source end, and is either connected or not on the destination end depending on whether you have a P1P to solve. With two XLR's or two phone plugs on the ends of a cable, of course connect Pin 2 to Pin 2, Pin 3 to Pin 3 or tip to tip, sleeve to sleeve to maintain correct signal polarity. When connecting an XLR to a balanced phone plug, common practice today is for Pin 2 and Tip to be "hot" (and therefore carries the signal), but check your manual for a clue. I've encountered vintage gear that uses XLR connectors with the signal on Pin 3 and Pin 2 unused.

When connecting two conductor shielded cable to unbalanced connectors, things are a little more complex. You'll of course use one conductor for the hot lead (the Tip of the phone plug), but the tricky part is to wire the second conductor to the ground (Sleeve of the phone plug). Now, if you leave the shield disconnected on one end of an unbalanced cable, you still have an electrical connection for the signal return that's

going along a predictable path (the wire) rather than relying on a mechanical ground connection through the rack or power cord.

There are more possibilities for interconnection schemes. One of my favorite references is Rane's Application Note 110, available on line at http://www.rane.com/note110.html Figure 2 is a good starting approach.

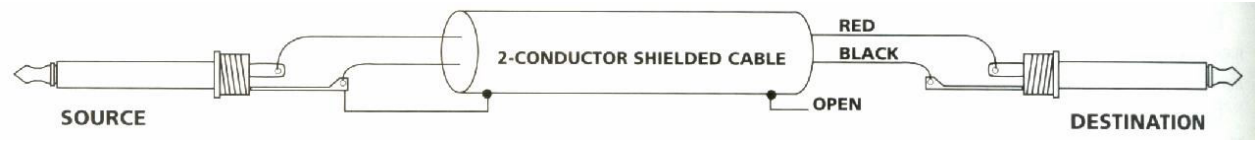

Fig. 2 - Wiring Unbalanced Connectors (One-end-only grounding)

Buzz Off!

Eliminating electrical noise in a studio is one of the biggest challenges, particularly in a system that evolves over time as your production needs, gear lust, and budget changes. There are many techniques that I haven't discussed here (balanced AC power is a hot item these days), and we've not even touched on the problem of the poorly shielded electric guitars and other instruments. If you want to read more about testing your own gear (and much more about this subject), the current best reference is the Journal of the Audio Engineering Society, Volume 43, June 1995. It's devoted entirely to the topic. A trip to http://www.aes.org/publications/journal_issues.cfm and fifteen bucks will get you a copy.

Sometimes, there's just not much you can do without modifying a piece of gear to right a manufacturer's wrong, but that's part of what engineering is about.

Appendix:

The Pin 1 Problem

Whether it's actually Pin 1 on an XLR connector or the sleeve or barrel on a 1/4" or RCA connector, we use "Pin 1" as a shorthand term for the terminal on an input or output signal connector to which the cable shield is connected. For the shield to be fully effective, two things must occur. First, Pin 1 must have a direct, low resistance path to the equipment's chassis so the cable shield acts as an extension of the box, effectively blocking electromagnetic interference from entering the unit. This wasn't too difficult in the days when vintage gear was contemporary since connectors were mounted directly to the metal chassis and wiring was point-to-point, but with today's all-on-one-board type of construction, often the route from Pin 1 to the chassis is through a circuit board trace that takes a roundabout route and has greater electrical resistance than a piece of wire. The indirect path taken by the ground is in the form of a loop - the famous "ground loop."

The problem resulting from an indirect path to ground is that if there's any noise current flowing through the cable shield (which can occur any time the cable is within an electromagnetic field, something that's almost unavoidable today) the noise doesn't stop short right at the point where the cable enters the unit's box. Instead, it meanders it's merry way through the not so direct path to ground, causing the voltage at the presumed ground point to be at some potential other than zero. Since the ground point is the reference for signal levels, when the reference changes, the potential difference between the desired signal and the reference point will change, resulting in the noise appearing at the output.

How bad can this be? Well, according to engineering consultant Neal Muncy, in some designs he's encountered, a noise current as little as 1 mA in the shield can result in noise levels as great as 20 dB below nominal level at the output, and a power transformer or wall wart can induce currents as great as 100 mA in a nearby cable. This noise is inherent in the design or construction of the equipment. It won't go away if you change to balanced wiring (if that's an option) or star grounding.

The good news is that most modern manufacturers are aware of this issue and are taking steps to design their equipment to minimize Pin 1 problems. If you see 1/4" jacks that are bolted directly to the metal chassis, this is a good sign. With older semi-pro or poorly designed "vintage" gear, however, sometimes your only alternatives are to live with the problem or modify the equipment.