Grounds, Shields, Hums and Buzzes

One of the greatest benefits that modern audio equipment has brought us is the potential for wider dynamic range than ever before.

There's a downside, though. Low-level hum and other noises formerly masked by analog tape hiss become audible when working with a really quiet recording medium. Even if you use balanced interconnections throughout your system, with any given mix of equipment, you may find your system noise level is10 to 20 dB higher than the theoretical limit. Where's it coming from?

Electromagnetic Interference

With electrical and electronic pollution creeping into our environment from devices that 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, EMI (ElectroMagnetic Interference) was usually down at the inaudible level, unless you were unlucky enough to build your studio next to a broadcast transmitter or factory.

Today, this has changed, and we find potent EMI generators in the form of switching power supplies, computers, monitors, and cellular telephones scattered throughout the studio and control room. FCC type approval is one thing - real life audio problems are another. While your computer may be certified not to scramble the picture on your TV set, electromagnetic energy creeping into your audio equipment manifests itself as hisses, crackles, and buzzes that you don't want to preserve in full digital splendor.

Do Balanced Lines Cure All?

It's a common belief that balanced connections are better than unbalanced when it comes to rejecting outside noise, but strangely enough, there's quite a bit of equipment that, even when using balanced connections, 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, magazine columnist, or web site writer who advised you to spend the extra bucks for balanced equipment.

What's wrong with this picture? A few things. Some you can easily fix, some are more difficult, and some you'll probably 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 ground wire once it goes inside the box (on either end – the unit or the power outlet). There are poorly constructed cables and connectors, both homemade and purchased. There's the haphazard scheme of ground-lifting that frequently results when trying to reduce hum and noise in a system. And then there's what has been dubbed "The Pin 1 Problem." This occurs when unwanted signals are introduced into audio equipment through cable shields, which, due to design or construction deficiencies, inadvertently become radio antennas. Mackie is very much aware of this issue and has taken care to design our mixers with good, solid internal grounding. We can't supply all of your studio equipment, however.

What's Ground?

"Ground" is one of the most common (pun intended) electrical terms. In electrical power systems, it means a direct and electrically sound connection to that dirty brown stuff under the house.

Commercial electrical wiring always has one foot firmly planted in the earth to help reduce equipment damage resulting from lightning strikes 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 noiselessly. A portable battery powered recorder is an excellent example, and airplanes have plenty of electronics and aren't connected to the earth. But an improper ground wire can make a pretty good antenna, actually contributing to the noise problem.

In fact, sometimes disconnecting electronics from the power ground reduces hum. Most of us have at some time plugged a noisy piece of equipment in

through a ground lift adapter and found that the immediate problem (the hum) was reduced. This proves that you have a problem, but it doesn't solve it. Lifting the power safety ground is dangerous and should not be practiced.

Pin 1

Pin 1 is the name we give to the terminal of any 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" phone plug, 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.

The Pin 1 Problem

For effective shielding, Pin 1 should be connected solidly to the unit's chassis. When connecting two units with a shielded cable, the shield running between the units becomes an extension of each unit's box. With a continuous, unbroken shield, there's no place for RFI to get in.

Mackie builds all of our mixers on a steel chassis with connectors attached directly to the metal, but you may find some gear in your collection that uses circuit-board mounted connectors and even plastic cases, creating a devious route from the cable shield to the unit's electronic ground. Further, that ground point may or may not even be connected to the box.

The problem with this type of construction is that any noise current flowing through the cable shield doesn't stop short as soon as it enters the cabinet. Rather, it goes to the unit's internal signal reference or "ground" point, pulling that supposedly zero voltage reference off zero by the amount of the noise voltage. Since the unit's output is referenced to its internal ground voltage, the output will have the noise added to the signal —just what we want to avoid.

Ground Loops

An indirect electrical route between the shield and the chassis is a path that forms a loop, the famous 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 AC power cord for example) can be fairly substantial. Noise current as low as 1 milliampere in the shield has been known to cause hum as loud as 20 dB below nominal output in certain pieces of equipment, and noise currents as high as 100 milliamps have been measured in what appear to be straightforward installations.

Is Unbalanced So Bad?

Noise in an unbalanced system is usually attributed to the lack of common mode rejection offered by balanced inputs, 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) is almost always isolated from the chassis. This is often the result of a manufacturer's attempt to eliminate ground loops in the unbalanced equipment, but it also guarantees an indirect path, if one at all, between the incoming shield and the chassis, and that's not good.

What To Do?

Amidst all of this gloom and doom, there's some good news. Modern audio equipment manufacturers are beginning to understand grounding and shielding issues and are cleaning up their act. (Check out the jacks mounted directly to the steel chassis of your Mackie mixer.)

It's best simply not to buy any equipment that has a Pin 1 problem, but how do you know what's "Pin 1 clean"? It's fairly easy to test for Pin 1 problems by inducing a current onto the equipment's ground and see if it appears on the output, but there's no established standard for how much leakage is acceptable. Such problems are rarely reported in product reviews unless the reviewer has a nasty situation, which he usually blames on temporary connections.

One-End-Only Shielding

If much of the noise we're trying to eliminate is a result of noise current flowing through the cable shield, then why not simply disconnect it so it doesn't get to a unit's ground point? 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 the use of custom-built cables with shields on one end and not on the other makes it difficult to accommodate "visiting" equipment or setting up portable

systems. Nevertheless, this is a tried-and-true principle that can often improve the noise performance of equipment that is built with less than an ideal ground configuration. Nearly all equipment dating from the first generation of home studios (which were typically interconnected with RCA phono cables) can benefit from OEO wiring.

Today, however, many studios are wired with store-bought cables that are all built with their shields connected on both ends. This makes OEO wiring impossible unless you take the cables apart and modify them.

Since disconnecting a cable shield (which actually creates a leak in the shielding) can in some cases reduce system noise, we can logically conclude that in those cases, the ground problem is more serious than the EMI 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.

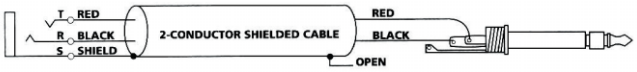
Be Systematic

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 everything in your system connected together using cables that have the shield connection intact at both ends. Turn everything on, crank up the monitor volume, 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:

- the hum is reduced to an acceptable level (it'll never go away entirely).
- something stops working because you've lifted shields at both ends of the cable and broken the signal return path.
- you get electrocuted (just kidding!).

If you're using store-bought cables with molded-on connectors, you don't want to cut off one end and rebuild it without the shield unless you know it'll help. Building a ground-breaking adapter and plugging it in-line with a cable at either end will let you experiment without unnecessarily destroying your cables. A plug, a jack, a piece of cable, and a few minutes with a soldering iron and you're ready to go on a ground loop hunt. If you're using a mixture of balanced and unbalanced cables, build your adapter using a two-conductor jack and plug and two-conductor cable as in the illustration. It'll work for either balanced or unbalanced connections.



The systematic approach requires that every cable have its shield connected at the source end (the end that's plugged into an output) and disconnected at the destination end.

This may not always be the optimum configuration since Pin 1 problems can occur on both inputs and outputs. You might have a piece of equipment that has a worse problem on its output than the unit to which you're connecting it has on its input, but by being consistent, you at least assure that every shield is broken at only one point.

AC Power and Grounding

If all the world's electrical equipment ran on DC (direct current) as Thomas Edison proposed when he first wired New Jersey, we wouldn't have many of the hum and noise problems we encounter in our sound systems today. There are many very practical reasons why we adopted alternating current as a standard for power distribution, but we got some problems in return.

Probably the greatest source of hum in an audio system is unwanted voltages related to the AC power lines creeping in where we don't want them. This is mostly a result of normal voltage differences that exist between the chassis of two interconnected pieces of equipment. Those differences are a result of different electromagnetic fields such as nearby power wiring, internal or external power transformers (wall warts), and electromagnetic hash conducted into the chassis through the power line. When there's a voltage difference between the two ends of a cable shield, current can flow through the shield and into our gear. Our goal is to reduce these stray paths as much as possible, and to swamp out whatever gets by despite our efforts at shielding.

Dedicated Power

The ideal studio or PA installation has a dedicated power feed from the main circuit breaker box, with no other electrical equipment tied to it that isn't part of your audio installation. This isn't difficult if you're building a studio from the ground up or are setting up a studio in a private house, but practically impos-

sible if your studio is in an apartment or college dorm.

The advantages of a separate power feed for your studio are two-fold. First, a direct feed will present the lowest possible impedance to ground for stray noise sources. Your power line won't meander throughout the house acting as an antenna, picking up stray electromagnetic interference from the television set or cordless phone on its way back to the main electrical ground point.

Second, you can be sure (assuming the job was done properly by a qualified electrician) that the new power feed will have its neutral and ground wires tied together at one and only one point – that point where the power feed is grounded when it comes into the building. Sometimes the neutral wire (which is supposed to be at ground potential) can inadvertently get grounded somewhere along its route between the main breaker box and your studio. This creates a ground loop in the neutral wire and assures that you'll be putting some line frequency hum on the chassis of your equipment.

Star Grounding

An excellent defense against ground-related hum problems is to provide a separate, low-impedance insulated ground wire (14 gauge minimum) for each piece of equipment, connecting its chassis (ideally very close to the internal Pin 1 ground point) to a central ground point in the studio. All the ground wires radiate out from this common ground point like rays of light radiating from a star, hence the name "star grounding."

A good place to tie your ground wires is a copper plate or bar (you can buy one at a electrical supply house). The ground plate should be connected to the AC power ground at the point where the power feed comes into the studio. This sounds like an extreme measure but it's not expensive or difficult to do, and it really can prevent a lot of trouble farther on down the road. Don't cheat. Ground everything with its own wire.

It might occur to you to provide your own ground for the studio by driving a copper stake into the earth and running a wire from it up to your central ground point. DON'T DO IT!! A nearby lightning strike (it doesn't even have to be a direct hit) can induce a substantial potential difference between two points on the earth, and that potential difference between your well-planted ground rod and the AC power ground for the building will ZAP your gear. Guaranteed. It might also burn down your house. And to top it off, you might find that your fire insurance won't cover the loss since this, according to the National Electrical Code, is strictly not Kosher.

Built-in Grounds

Almost everything (including your Mackie mixer) that isn't powered by an external transformer has a three-wire power cord with one of those wires connected to the equipment chassis. It seems like this would suffice for a star ground if you plugged everything into the same outlet.

It does in concept, but not in practice. First off, the ground wire is there for safety, not electronic interference reduction. It's usually lighter than the 14 gauge wire that we recommend for your signal ground path, and it's designed to hold up only long enough for a fuse or circuit breaker to blow if there's a certain type of electrical failure in the equipment. In this service, it doesn't matter if there's a couple of volts dropped across the ground wire while it's doing its job, but we want to keep voltage drop in the ground to well below microphone levels.

Second, our studios tend to have a lot of equipment plugged in. Let's face it – we're gear sluts. And what's the most convenient way to accommodate a lot of AC plugs? An outlet strip. Outlet strips tend to get daisy-chained, increasing the length of the indirect ground wire, and pretty soon you no longer have a star ground.

The direct run of 14 gauge wire from each piece of equipment to the ground point will provide a substantially lower-impedance ground path than the safety ground through the power plug, so it will carry away the noise you don't want.

Rack Mounting

Rack mounting gear is pretty common. Since equipment is attached to the metal rack rails with metal screws, all the metal cases in a rack are connected together electrically – sort of. There's usually paint on the rack mounting ears (that you hate to scratch) that partially insulates the screws and the rails from the chassis, reducing the effectiveness of a low impedance chassis-to-chassis connection through the rack rails. It's still important to individually star-ground each piece of rack mounted equipment in order to eliminate inadvertent AC voltage differences between rack mounted chassis.

Sometimes people try to isolate rack-mounted gear by using wooden racks or rails, or plastic screws and plastic insulating bushings. This is good in theory but pretty chancy in practice. Unless you take great care when installing the units, adjacent panels can touch, blowing your attempt at isolation.

Buzz Off!

Eliminating electrical noise in a studio is one of your biggest challenges, particularly when the studio evolves over time as your production techniques and gear list change constantly. What happens all too often is you'll bring home a piece of gear this month, and another next month, and then one day you'll crank up the monitor volume and realize that you have a hum problem that's bigger than you realized and you won't know what caused it. Checking for problems with each change in the studio will keep them from compounding.

In fact, although your patience will probably get the best of you before you're done, a very good procedure to follow when you first assemble your studio or sound system is to power up the amplifier and speakers first, connect them to the mixer, and check for hum as you plug in each cable. If connecting something causes hum, fix the problem before making the next connection. This is really more efficient than taking a fully wired system apart one cable at a time until you find the guilty one.

Notes