1 Understanding Problems

When interfacing equipment in the real world, problems arise. This is because of the lack of standardization for audio interfacing. To avoid problems, it is important to decide on a grounding and shielding plan and follow it consistently. The Project Patch system is based on a grounding philosophy which has been developed over years of experience. For a successful installation it is important that you understand the principles behind this philosophy. This section provides that information.

1.1 Noise

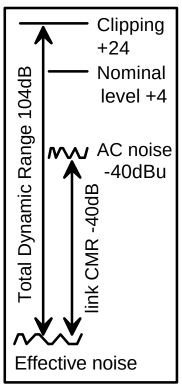
Noise developed in interconnection is "acceptable" only if it is low enough to be indiscernible beneath the equipment's internal noise level. It typically consists primarily of the 60 hz powerline frequency and it's harmonics, along with SCR dimmer noise, florescent ballast noise, and other non-musical signals which abound on the power and AC ground system.

This Noise exists in our environment as radiated magnetic fields, resulting in voltage potentials between equipment. It is the object of good system design practice both to:

- Reduce the amount of noise present in the electrical system and thus on the audio ground
- Increase the ability of the audio system to reject the noise so that it dosn't become audible

A. Quantifying Noise

"Dynamic Range" is the total range from audio clipping ("Headroom") to the noise floor. Most professional audio systems provide at least +22 dBu at clipping, therefore to achieve "16 bit resolution" (96 dB dynamic range) you need -74 dBu or better noise floor. For 20 bits of resolution you need to lower the noise floor to -98 dBu. This is extremely difficult.



Dynamic range is the range from clipping to the effective noise floor, which is the arithmetic sum of AC ground noise and CMR.

Depending on the quality and attention to detail in the power and ground system, it is common to see AC ground noise in the range of 10-100 millivolts (0.010-0.1 V). This translates to an audio level of approximately -20 to -40 dBu. With reasonable quality balancing we can expect common mode rejection of 50 db or better. This give us a noise floor of at least -70 to -90 dBu, a very reasonable number. However you can see that if the CMR is inadequate or the AC ground noise level is too high, noise floor is compromised.

The problems are aggravated when we add a mixer. Hum and buzz are generally in phase accross all of the inputs. When in-phase inputs are summed the level rises by 6dB for every doubling. For example, say you have a ground noise of -40dBu between the mixer and the tape machine. If you fade one channel up you have -40dBu on the output. Mix together 2 channels at unity gain and you have -34 dBu on the output. Four channels and you have -28. Eight channels and you have -22. Sixteen gives you -16 and thirty-two leaves you only -10! So your -40 has been eroded by a full 30 dB by mixing 32 channels. (Side note -- tape noise or electronic hiss only rises 3dB per doubling because it is incoherent) In this example, if you want your buss noise to be down at -70 where it belongs, then you need common mode rejection of better than 60dB between the console and tape machine. From this example, you can see that -40 dBu (10mV) is a reasonable maximum limit for AC noise voltage. However, the lower the better.

B. Measuring noise

Another problem arises when we want to measure the noise present at the AC grounds. It would be awfully convenient to be able to say to our electrical contractor "provide a ground voltage less than 1mV from any ground in the control room to any other". However, he must run wires (test probes) to make a test. The wires themselves will pickup hum fields from stray electromagnetic fields. The routing of these wires will affect the measurement greatly -- making it seem impossible to get an accurate and consistent reading.

Installed audio cables also pick up these fields, sometimes adding to the problem and sometimes subtracting. What we really care about is that there is a low noise voltage as measured through the audio wiring itself, which takes into account the physical path the audio follows. Unfortunately, this means that the ground noise tests cannot be made before all of the audio equipment and wiring is in place.

The only meaningful measurement is to disconnect equipment cables where they come into the console, and measure the voltage from the shield of the cable to the console ground. This is the voltage that your console / equipment I/O circuity must reject.

1.2 Ground

The first and foremost function of the ground conductor is safety. Ground conductors serve as a path for the "fault current" to follow in the case of a short. This fault current trips the circuit interrupter (breaker), preventing electrocution and fire.

Here's how it works. According to the electrical code, the incoming power neutral conductor is connected to ground at the service entrance. All of the mechanical devices such as breaker box chassis, conduit, and "U-grounds" are also grounded to this point. If for any reason the HOT conductor comes into contact with a box or length of conduit, a short circuit is formed and fault current flows. If the conduit wasn't connected to ground, nothing would happen except you could receive a shock if you touched the conduit.

If you disconnect the third wire ground from an item of equipment in your studio, you have defeated this safety mechanism. The only connection the unit has to ground may be through a signal wire, or there may not be any connection at all -- as in a guitar amp. If the connection is through signal wire, then the entire fault current will pass through that wire. Since the conductor size in the typical signal wire is much smaller than power wiring, it may not be low enough resistance to trip the circuit breaker. It could pull enough current however to heat up the wire to the point it bursts into flames! The bottom line is, a buzzing system could make you crazy... but an ungrounded system could make you dead. Don't use power line ground lifters!

For audio purposes, "ground" has a completely different role. It is the zero voltage reference for all audio signals. A "good ground" is one which keeps all audio equipment at the same electrical potential; ie: minimum voltage between all chassis.

1.3 How Grounds become Noisy

Noise voltages (Potential difference between the chassis of two or more devices) are developed by induction and conduction.

A. Induction

AC currents traveling in conductors generate magnetic fields which will induce noise currents in any conductor they cross. AC ground conductors, due to the fact that they must run in close proximity to the current carrying conductors, pick up a great deal of this noise. This is unfortunate as it is these same ground conductors which we must rely upon to provide our audio reference.

A common method to avoid this problem in past years was to provide a completely separate ground wire, run independent of the power wiring, and disconnect the AC ground. This system violates electrical codes and should not be adopted in new installations.

B. Conduction

Under ideal circumstances there should be no current flowing in the AC ground conductor. Reality is often different. Ground current is created by leakage in equipment power supplies, often from input noise filters. Wires have a certain amount of resistance, and the current passing through them is reflected as noise potential at the chassis as I x R (Current times Resistance).

It is standard commercial practice to use the metallic conduit as the safety ground conductor. However, the conduit is often inadvertantly connected at several points along the path to building steel members, water pipes, framing, etc. These often have voltages present on them due to induction from large current consumers such as elevators, air conditioners, etc. When that voltage is shorted out against a branch circuit, noise current flows in the conduit.

1.4 Keeping the ground quiet

For those installations where it is possible to install new electrical wiring, there are several recommendations which can be made to improve the ground noise. This is only a summary of techniques. There are many other considerations which cannot be addressed in this space. Electrical work should be undertaken only by a qualified electrical contractor.

- Use a separate "Technical power" system with "isolated ground" wiring and receptacles to avoid conducted noise currents
- Use larger ground wire (size up one gauge) to reduce voltage resulting from noise currents
- Twist hot and neutral conductors together in conduit to reduce induction
- Keep the branch circuit lengths short. Locate technical distribution panel near control room.

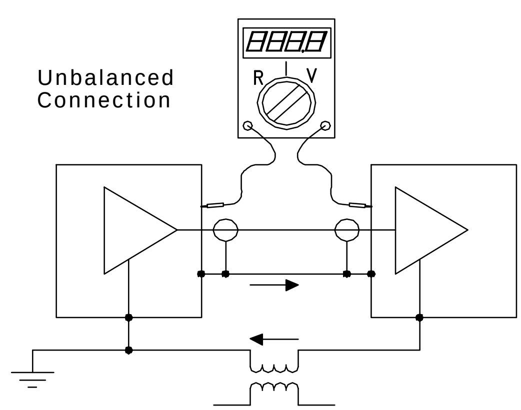
1.5 Audio System Noise Sensitivity and Rejection

Now that we have seen how and why noise exists, we can discuss how audio systems pick it up and how they can be rendered insensitive to it.

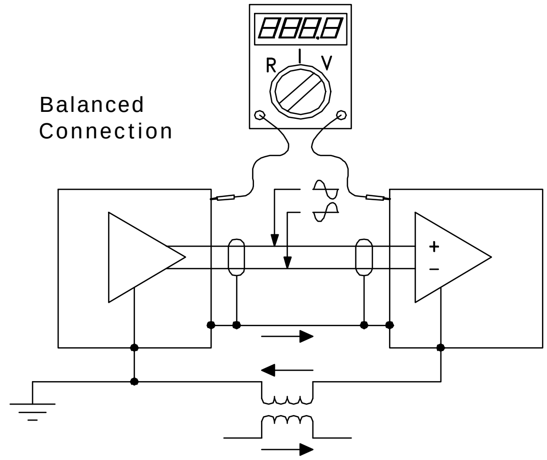
A. Unbalanced Circuits

In the example shown, two devices are connected in an unbalanced configuration: the signal is impressed on a single conductor referred to ground. The meter in the drawing would be metering the voltage induced by the transformer between the two chassis. The transformer represents the inductive coupling of powerline noise into the ground conductor between the two units.

The signal at the output of the second device would equal the signal at the output of the first device plus the noise voltage as shown on the meter; they would sum arithmetically. The unbalanced connection provides no rejection of noise.



B. Balanced Circuits

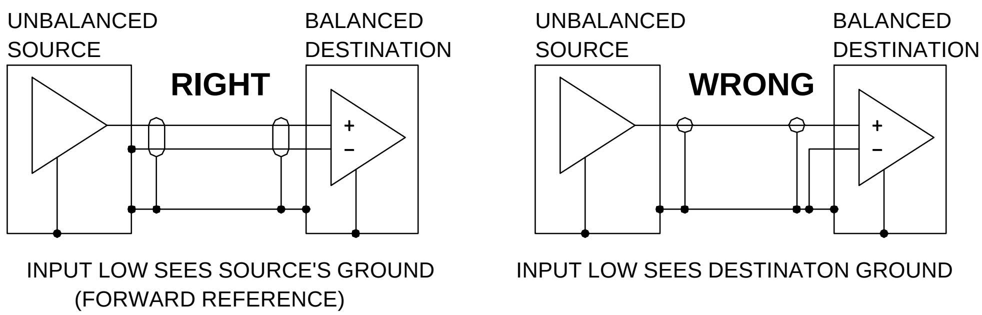


The only way to reject noise is to use a balanced connection. This is where the source is fitted with a balanced driver and the destination is fitted with a balanced receiver. The balanced driver impresses the audio on two conductors (the "High and the Low", or the "Hot and Cold") in equal and opposite (out-of-phase) amounts. The balanced receiver is sensitive only to this *differential* signal and ignores ("rejects") the noise, which is impressed equally and in phase (common-mode). This is the Common Mode Rejection. With well balanced send and receive amplifiers, noise rejection of better than 60 dB is routinely acheived.

C. Hybrid Connections

Because of the cornocopia of equipment we are faced with every day in the studio, hybrid connections are common: unbalanced outputs feeding balanced inputs, balanced outputs feeding unbalanced inputs. Unless every item of equipment in your studio has balanced I/O, chances are you will throw a patch one day which will cause a hybrid connection.

If wired properly, a hybird connection becomes what's known as a "forward reference" connection. That means that the balanced low side references to the ground of the unbalanced device. This gives a degree of rejection of the common mode voltage between the units. Since the source is not balanced, there is no rejection of electromagnetically induced voltages in the wiring. Under the best circumstances you can expect 20-30 dB of common mode voltage rejection from this configuration -- but only if the wiring is done properly.



I. Unbalanced -to- balanced

This configuration is usually quite reliable and will offer 20-30 dB of noise rejection if wired as forward reference.

II. Balanced -to- unbalanced

Depending on the type and quality of the balanced output circuit, a hybrid connection to an unbalanced input can work almost as well as a unbalanced to balanced connection. However, balanced outputs are not all the same. Most modern equipment has a "cross-coupled" output balancing amp which senses current flow in both sides and works to keep them equal. If you unbalance such a device by plugging it into an unbalanced input, it's "hot" side rises by 6dB in compensation and the "low" side (the one shorted out) is effectively off, or a reference.

Older equipment and some inexpensive equipment create a balanced output simply by using an inverter with no cross coupling or sensing. When you short out the low side of these circuits they may misbehave. For example, they can oscillate and overheat. This oscillation may not be audible but it often results in audible distortion in the "hot" side. Also, the low side can drive excessive amounts of signal current into the ground of the next device. This can cause crosstalk due to the "pin 1 problem" (next).

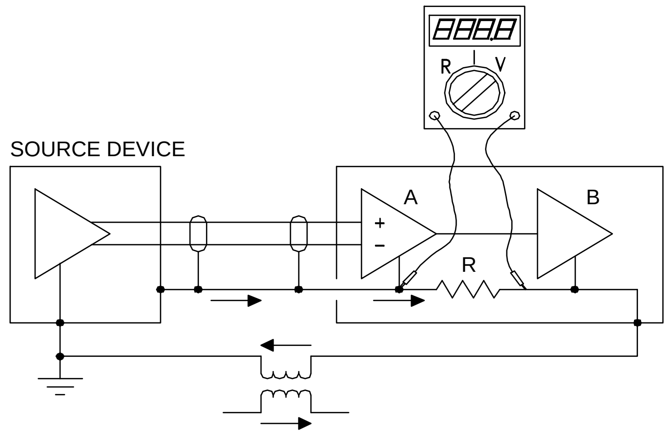
D. The Pin 1 problem

The "pin 1 problem" is an extremely common but misleading anomaly. Basically it is this: certain equipment is sensitive to currents being injected into the signal ground terminal at the inputs or outputs (pin 1 on an XLR). If a current is injected into the shield terminal on such equipment, it is appears as audio in the signal outputs.

I. Understanding the Pin 1 Problem

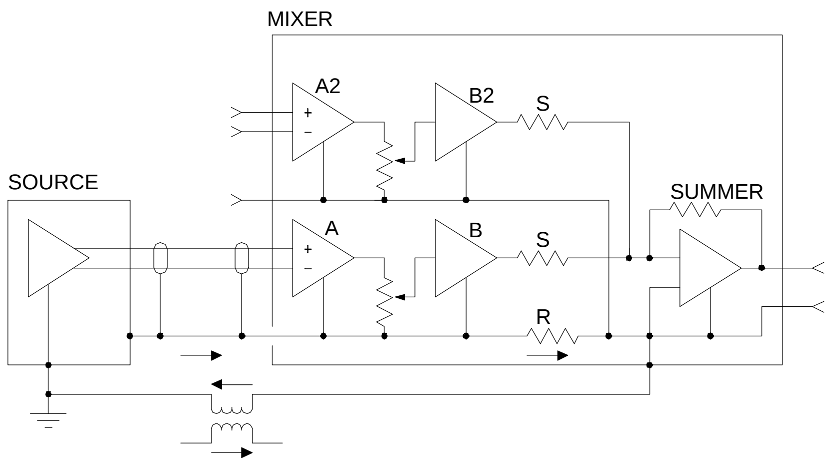
The reason this happens is the internal geometry of the circuitry. Modern electronic production techniques make use of printed circuit board mounting of all components, including the input and output jacks. Sometimes the shield terminal ("pin 1") is connected via circuit board traces, following the circuit common path through the board, inter-board interconnects, motherboard, etc., before it is connected to chassis ground. The problem happens when a noise current is introduced into this wiring. All wiring has resistance, including thin circuit board traces.

Referring to the illustration, the resistor R represents the resistance of these PC traces. Noise current flowing into the input shield is passing through resistor R, causing a voltage which may be measured by the meter. Since the resistor is the ground reference of stage A, the output of stage A is elevated by the IR voltage across R. The input to stage A is clean -- but the signal is corrupted afterwords.



The pin 1 problem can be even more confusing than this. In the next example, the internal detection occurs in the summing stage of a mixer. Currents injected into an input shield are detected by trace resistance R. Even if the input fader is down the buss noise is elevated. This can be extremely confusing if you think that you have "isolated" an input by turning down it's fader!

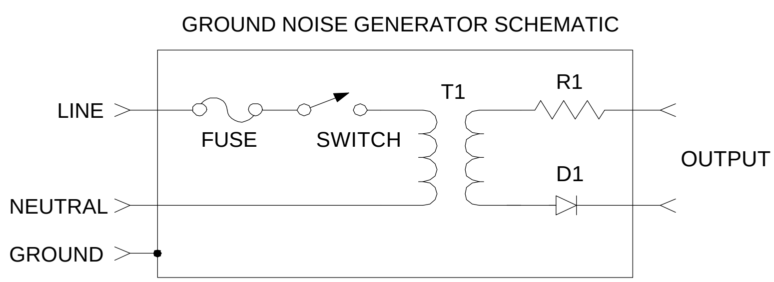
There is also a "reverse" pin 1 problem which has been documented in certain equipment. Due to proximity of ground traces or wiring to the power transformer inside the box, the equipment itself is capable of inducing noise voltages between input and output jacks.



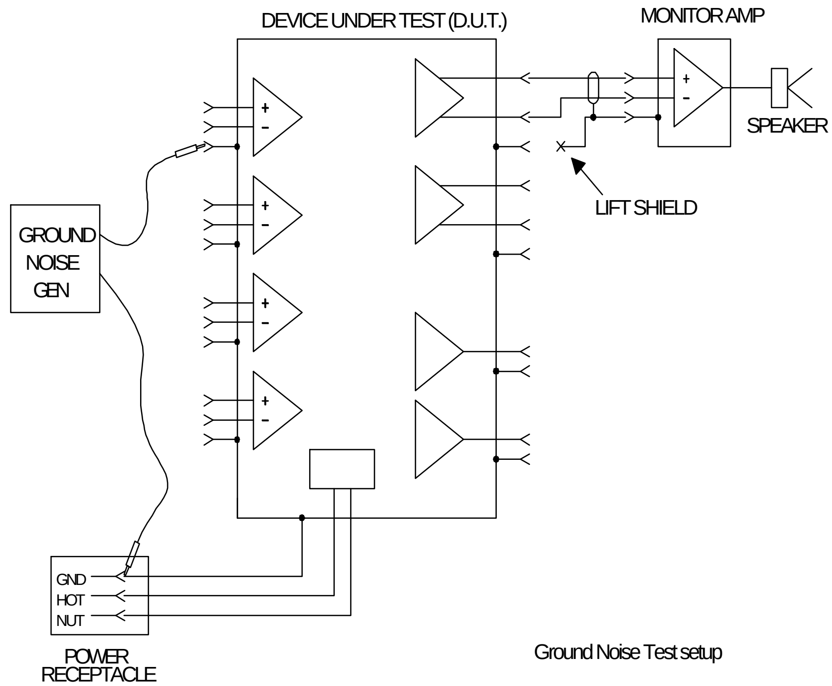
II. Testing for the Pin 1 Problem

The pin 1 problem can be identified by a simple test, requiring only a device to inject current into a ground pin, as shown above. A low voltage transformer is coupled with a current limiting resistor to drive approximately 100 mA into a short circuit. A diode is added to chop the waveform in half, giving it plenty of upper harmonics for audibility.

T1: 12VAC 1A 50-60hz
R1: 120Ω 2W
D1: 1N4001
Fuse: 1/8A
Values are approximate and not critical. Output current should be around 1/10 amp.



To use the tester, you need to isolate each device you want to test by disconnecting it from the rest of the system everywhere except the monitor output. Take care to wire the monitor output so that there is no ground loop there. Monitor the output with headphones or loudspeakers. Start at a low listening volume and then raise it to listen carefully to each test. Hook up one of the probes to the AC ground the device under test is plugged into. Move the other probe to the input and output connectors, probing the ground pins (Pin 1 on an XLR, sleeve on a 1/4" jack). You should hear no additional noise when you probe. You should be able to turn the monitor volume up high enough to hear the self noise of the device and still not hear the injected current. If a buzz appears when you probe any terminal, the gear has the pin 1 problem.



Ground Noise Test setup

If you find a piece of equipment with a pin 1 problem, you might consider modifying it by re-routing the shield terminals directly to the chassis internally. Take care though -- you may be voiding a warranty by doing this!

III. Avoiding the Pin 1 Problem

The Pin 1 problem is very common and for this reason we make all of our stock Project Patch cables with shield disconnected at one end to break the ground loop and eliminate circulating currents into pin 1.

The one caveat to this system is that since we do not connect shield, it is necessary to have a ground to the equipment. Much consumer equipment is "double insulated" and falls under a different classification from commercial sound equipment, therefore it can be manufactured without grounded power cords. If this type of equipment is in your facility you will need to either:

- Build a custom cable with shield tied at the patch bay
- Provide a ground to the equipment. This can be a clip-on ground or a lug under a chassis screw. Be aware, however, that some consumer equipment is not grounded to it's own chassis! You may find a difference between grounding the chassis and grounding the shell of the output connector.

2 Troubleshooting

2.1 Crosstalk

Crosstalk in audio systems is usually caused by one of two phenomena: capacitive coupling into high impedance circuits, or signal current circulating in the ground.

Capacitive coupling is depending on the line impedance of the line you are coupling into. In modern systems, the source impedance governs the line impedance and is usually below 100 ohms. If an input is unterminated, it will exhibit a high impedance and will probably pickup low levels of noise and signal crosstalk. For example, if you put a patch cord into a line input and leave it hanging, that line input is not being sourced by a low impedance. Turn up the gain on that channel and you will probably hear high frequency components from adjacent channels. This is normal and there is nothing you can do for it except to not do it: Turn off all unused inputs!

The pin 1 problem causes mysterious noises for both signal crosstalk and hum/buzz.

2.2 No Signal

If you have no signal or it is low, channels reversed, etc., check the orientation and alignment of the connectors at the rear of the project patch bay. The white channel numbers on the connectors need to be facing up, and the connectors must be properly aligned on the pins. See section 3.3.

2.3 Hum and Buzz

There is no weapon against system noise better than an understanding of the problem. Read the Ground Rules section if you have noise in your system. If you are still having problems try this chart.

First, follow the universal rule of troubleshooting: ISOLATE THE PROBLEM. Have faith that there is a reason for your problems. There is no magic, no smoke and mirrors, no mystery to "grounding". Audio systems can be consistently quiet. But it is easy to get confused and follow a wrong path of reasoning which, once accepted as "fact", causes the truth to be hidden.

To isolate the problem, first turn down all of the input faders on the console. Make sure that all echo returns are down also. Turn up the monitor fader and listen. This is the buss noise of your console. If it has a hum and buzz component, this is the problem of the console. If there is, try one more thing. Unplug all lines (or dead patch) to and from the console. If the buzz goes away... you still have a console problem! Most likely it is a "pin one" problem relating to an unbalanced input or output... one of the cables you removed was injecting current into the console ground. Now you can plug in the cables one by one until you locate the problem.

If you have isolated a buzz to a particular interconnection, take a look at what you have. Is the interconnect Balanced to Balanced? Unbalanced to Unbalanced? If it is anything but Balanced to Balanced you will have to make efforts to reduce the noise voltages between the units. Take a look at the path the ground is taking. Perhaps you can reduce the relative voltages by improving the power wiring. Or you might have to try swamping out the voltages. If all else fails you should add balancing amplifiers or transformers. Under no circumstances should you defeat the safety grounding devices in a quest for low noise.

When you find a problem, isolate it and cure it before going on to more interconnects. Try to avoid the comedy of errors. As the system gets more complicated, understanding the mechanism by which the system is picking up noise becomes progressively more difficult.

2.4 Common Misconceptions

- "The Shield dumps noise to ground"

"Ground" is not a sump where current goes never to be seen again. Ground is merely another one of the electrical conductors in the system and works to return current to it's source. Remember that there can be no current flow without a closed circuit.

- "I need a Separate Audio Ground"

No you don't! The most important function of an audio ground is to keep all equipment at the same potential. Installing a "separate" ground (Stake) invariably causes new currents to flow, defeating this purpose. What you need is a single ground, not multiples. Remember, it is the relative voltage beteen equipment that counts, not the "absolute" voltage from earth.

- "My studio buzzes -- I need better wire"

The wire is almost never the problem -- unless you are using zip cord to wire the microphones. Most buzz comes from poor AC power grounding, unbalanced signal paths, and "the pin 1 problem"

2.5 What to DO?

We have outlined the many ways in which audio can get noisy. The bottom line is that you want your studio to be quiet, and you don't want to have to get an engineering degree to get it that way. Here are a few simplified rules:

- Choose equipment with balanced I/O
- Wire the entire studio with balanced wiring even if some gear is unbalanced
- Put in a technical power system with isolated ground outlets and TEST the system before energising.
- Use balancing boxes ("+4/ -10" boxes) in line with consumer tape machines
- Use cheap transformers in line with unbalanced Time Code I/O
- Use DCE's Synth Driver on your Midi gear
- Put some undedicated audio transformers at patch so that when you encounter a buzzy patch you can patch in a transformer and quiet it down.
- The larger the facility, the worse the problem. Many small studios work just fine until they grow a machine room -- then everything falls apart. Don't expect to "get away" with the same old way as you grow.