

## **Grounding and Shielding for your DIY Audio Projects**

I get numerous questions and requests for assistance about how to "get rid of hum". Thus was the genesis of this text. The following information is not designed to be a definitive treaty on grounding and shielding in DIY audio equipment. It is more of a practical nature, and for sure, there are other ways of doing the things I mention. From a formal perspective, there have been numerous texts written on all this for those of you with insomnia. These however, work for me and are a collection of things I have discovered and learned that you can apply to many DIY projects. First a bit of background. While I have been involved in one form or another of electronics for about 50 years there were always some holes in my knowledge. Grounding and shielding was something I took for granted. Everything connects to the chassis, right? Wrong. It was not until I got serious about designing circuits instead of building ones someone else designed, that I came face to face with the error of my thinking. My first high gain tube audio project was a marvelous hum generator. Since then, I have both studied and learned by trial and error a few things that work.

First and probably the most important thing I learned is that all *grounds should not go directly to the chassis*. This seems contrary to logic. A little side trip into electricity and conductors is appropriate now. Any conductor has some finite resistance and anytime some current is passed through it a voltage will be correspondingly created. Actually the voltage is first, but in this case we want to concentrate on the current. In a typical piece of audio equipment (most everything else as well) there are usually three distinct ground circuits. The first is obvious, the signal ground, the second is the power supply ground and third and often ignored is the case or chassis ground. Each has a particular function and all interact. The signal ground's usual and primary function is to provide a return path for the audio. Likewise the power supply ground is the return path for the power used by the circuitry. The case ground I will cover a bit later. Remembering that anytime current flows through a conductor it will cause a voltage, let us see what happens if you mix the signal and power grounds. Each will generate a proportional corresponding voltage. So for an example: the conductor is a piece of wire that has a 1 ohm resistance, the signal voltage (and thus its return) has one millivolt (mV) of amplitude and the power supply is causing a flow of 100 milliamperes (mA) through the wire. The contribution to the voltages on the conductor is then, 1 mV for the signal and 0.1 Ampere times 1 ohm equals 100 mV for the power - see [Ohm's Law](#) for equations. Since it is really unlikely that the power is perfectly clean DC it will contaminate the signal with hum and noise. Even a 1% noise level in the DC will result in a noise voltage equal to the signal voltage. I grant that this is a gross simplification, but it does illustrate the situation. *So my rule number one is to absolutely avoid having any ground conductor handling both signal and power.* So how do you do this? I find that a sort of modular arrangement is best. This does not mean that the physical components can't be on the same board though. What it does mean is that the power supply is wired independently from the active signal portion. Eventually these grounds need to connect, but I will get to that later.

As I mentioned earlier there is a third "ground", the case or chassis. Here there can be two distinct issues. As part of many electrical codes all exposed metal parts of AC mains electrically powered equipment must be either connected to the "earth" ground or doubly insulated from any electrical connections. This is to protect the user in case there is an internal failure. Any potentially dangerous voltages will be "grounded" to the earth. I find it is rather difficult to double insulate DIY projects and still have the circuitry be effectively shielded (more on that in a bit). So I use three wire connections all the time. The "earth" ground from the AC mains is directly connected to the chassis at the entry point. As a note of interest I also use the standard IEC connectors that are found on nearly all personal computers to connect to the AC mains. This makes it easy to move equipment around and you don't have the AC cord

permanently affixed to the equipment. In addition to protecting the user from shock hazards, the case now acts as an EMI shield. Any external EMI is diverted to the earth ground via the power cord.

So if you have followed everything so far, we have three separate grounds; the signal return, the power supply return, and the chassis. *I find that all must interconnect at a single place* to avoid having any conductor contaminated with something from one of the others. I suppose that putting a signal on a power conductor would not be likely to cause the power supply any problems, but the reverse results in serious issues.

At this point things can get a bit problematic. Where should the connections be made and how to connect them. I have found that the best place for a central ground to be is at the signal input ground. This will be where the connections to other external equipment is made. In a typical audio component there will be left and right channel inputs. Each channel will be via a shielded cable from the source (CD, FM, etc.). At the input jacks I have found that you *can* connect the two input signal ground returns together (not to the chassis) using isolated jacks *provided* you don't run shielded cable with both ends connected together internally to the unit. This part is often hard to envision, but *you don't want multiple ground paths for the signal*. This is likely to cause a ground loop, more about that later. A common error is to connect the signal grounds together at the input jacks *and* then run shielded cable inside the unit to something like a volume control *and* connect the shields together there. The shields then act as conductors and not solely as shields. *Use only one end of the shield inside equipment*. If needed, run a separate ground wire to the volume control or wherever the signal is going. It will be the ground reference for the signal and the shields will be only shields. This can greatly improve the signal to noise in a piece of equipment.

We still have three separate grounds. At the input jack ground I connect a single wire from the power supply ground. I like to use something with low impedance to do this, often silver wire. Also at the input jack ground I attach a single wire from the active circuitry ground also with a low impedance wire. In this arrangement, neither ground is contaminated with voltages from the other. An obvious question now is that if you provide power to something in the active portion of the circuit, won't the current end up in the signal ground. The short answer is yes. It is also unavoidable and generally rather small in magnitude and normally does not cause problems. An exception is in power output stages. The large amount of current involved can cause noise in the signal ground so I ground them separately to the input jack ground. Could you run separate ground wires from each place in the active circuitry that puts current into the ground path? Certainly, and it would be a type of "star" ground system. I generally find it unnecessary. I can achieve signal to noise ratios of -90 dBV in high gain circuits without going to that method.

So at this point we have the signal and power grounds connected. Next is the chassis. There are a number of ways that we can accomplish this connection. *The key thought is to maintain the shock protection while using it as an EMI shield*. Sometimes it can connect directly to the ground at the input jacks. This was a fairly common practice in the earlier days of electronic equipment. These were also in many cases what I would consider lower fidelity equipment and things that did not benefit from three wire AC mains. I don't recommend this as there is the possibility of introducing the EMI noise from the chassis and AC mains earth ground into the signal path. Most methods of making the connection involve resistors, capacitors or rectifiers. I suspect all will work. *My preference is for a parallel combination of a metal film resistor of about 120 ohms (1/2 Watt is fine) and a type X2 capacitor in the range of 0.1 to 0.22uF. Type X2 capacitors are rated for use with AC mains circuits. I have seen ceramics and polys used there but since they are not usually AC mains rated I strongly recommend against them. The capacitor and resistor provide sufficient isolation between the chassis and circuitry to allow the chassis to be an effective EMI shield but not induce the EMI into the active circuitry.*

At this point all three grounds are joined. We have avoided mixing power and signal in ground returns within the equipment and established the chassis as a combination shock protective device and EMI shield.

Unfortunately we are not quite done yet. I mentioned the concept of a ground loop earlier. This is a particularly insidious problem that can easily ruin a good project. In very general terms it is formed whenever there are multiple signal ground paths to the same termination. It can be internal or external to the piece of equipment. The most frequent result is a hum that either won't go away or happens only when something is connected to the piece of equipment. I need now to provide a few brief words about hum. If the hum is at the same frequency as the AC mains (either 50 or 60 Hz typically) then it is likely from interconnections external to the equipment or poor shielding internal to the equipment. If the hum is at twice the mains frequency then it nearly always is because of inadequate power supply filtering. Ground loops are usually at the mains frequency. So if you encounter one, then you must search for the alternate ground paths that relate to the signal chain. If it is external (occurs only when the equipment is attached to an external item), then check for things like phonograph grounding at the phonograph end. As an example I have seen is when one terminal of a cartridge connected to the ground in the tone arm (OK and fairly common) and a separate ground from the same tone arm (not OK) is provided for connection to the amplifier chassis ground (this is not to be confused to the situation when there is a separate ground wire from the phonograph chassis that has no connection to the ground in the cartridge). Since both the signal ground and tonearm ground are connected at the phonograph they will form a ground loop (between the shields and ground wire) when connected to the amplifier. The solution in such cases is to separate the grounds at the phonograph. An internal example was mentioned earlier when both ends of internal shielded cables are joined in two different places (at the input jacks and volume control). The irony of the situation and part of the insidious nature of ground loops is that they can on occasion be benign and not cause hum. They can later show up when a new piece of equipment is attached to the system. In all cases however, they have the same fundamental cause, alternate paths for the signal return.

By now I have probably confused some of you. To simplify things here are what I consider the basics.

- All grounds do not go directly to the chassis.
- Absolutely avoid having any ground conductor handling both signal and power returns.
- Avoid multiple ground paths for the signal (ground loops).
- Use only one end of the shield inside equipment.
- Do not connect the chassis directly to the signal or power supply grounds. Isolate it with a type X2 capacitor and parallel resistor.
- All grounds must eventually interconnect at a single place. Use a central ground connection for all three common types of grounds. I prefer this to be at the input jack location.

As mentioned at the start this was not written to be an all encompassing text on grounding and shielding, just a collection of practical things I have found to work. If you follow the above concepts and good building principles your projects should be hum free. Discussion about grounding and shielding is welcome in the [Grounding Techniques thread](#).

## About the Author

Bruce Heran is the VP for Design and Support of [Oddwatt Audio](#). He has been involved in the field of electronics in one form or another for nearly 50 years. Bruce is a strong supporter of DIY audio projects

and generally specializes in vacuum tube designs for Hi-Fi. One of his main goals is to educate and encourage newcomers in the building of affordable high performance audio equipment. For more DIY audio building tips and techniques from Bruce see these articles:

- [Design and Construction of Vacuum Tube Amplifiers](#) - [External Link]
- [Vacuum Tube \(Valve\) Amplifier \*\*Wiring Color Code\*\*](#) - [External Link]
- [The Care and Feeding of LM317 and LR8 Integrated Circuit Regulators, Particularly in Valve Circuits](#)