The Other Side of the Power Plug

Unless you have a solar powered studio or you're still cutting wax cylinders, you're dependent on electric power and, in most instances, house wiring. While electric power is abundant, inexpensive, and mostly reliable in the US (though I'm not sure that readers in some other countries will concur), stuff happens - stuff whose effect ranges from blowing a take to blowing your stack to blowing up your gear.

There's lots of help in your quest for getting clean power, and lots of confusion, too. In this article, we'll investigate where that power comes from and look at some wiring practices as well as a range of protection devices that you can add to your studio.

The Service Entrance

This is where power comes into your building. Your power company buys electricity from many sources, trading dollars and power according to supply and demand. The national power grid is truly a marvelous thing, stringing power lines carrying tens of thousands of volts from state to state, thousands of volts from city to city, and finally coming down your street at a manageable voltage. Most modern homes and small businesses are wired with two phases of 120 volts each, providing 240 volts between them for heavy appliances and two separate 120 volt buses sharing a common "neutral" wire. In the lexicon of electric power distribution, neutral is like the return in an audio connection, (low in a balanced connection, ground in an unbalanced one). Simply, it's the wire relative to which the 120 volt wires are "hot".

The neutral wire comes into the building from a transformer out at the street. It connects to earth ground at the point (and, according to electrical code, *ONLY* at that single point) where the power enters the building's main distribution (circuit breaker) box. The circuit breaker box contains both a neutral and a ground bus bar, which is literally a metal bar with screws for attaching wires.

Even though those two buses are bonded together at the breaker box ("bonded" means there's both a physical and electrical connection), separate neutral (the electrical return) and ground wires (for safety) wires are run, along with the hot 120V wire, from the distribution box to the wall outlets. Convention in the US is that the hot wire is black, the neutral wire is white, and the ground wire is green. Normally, when power is drawn from the outlet, there will be no current flowing through the ground wire, only through the hot and neutral wires.

Do you live in an old house where the lights dim whenever the refrigerator starts? Can you reasonably expect to operate a studio successfully in that environment? Trouble is brewing there, and it's best to just bite the bullet, call in a qualified electrician, and rewire. While modern project studio equipmet requires a relatively small amount of power, it's really a good idea to have a dedicated circuit fed directly from the breaker box from which all the electronics (but not the lights or air conditioning) is powered. This will assure the cleanest power for your audio gear as well as providing a reliable ground connection. Then and only then should you start dealing with deviations from the norm.

Safety First

Most of our studio equipment, at least units with an internal power supply, is powered through a three wire cable with a standard grounding plug. The flat blades of the plug connect the hot and neutral wires to the device's power supply while the round pin connects the device's chassis to the ground wire of the electrical outlet. The ground wire is there for safety. In the event that the hot wire inadvertently becomes connected to the chassis, the ground wire completes the circuit, carrying the current back to the neutral bus in the circuit breaker box. This is essentially a short circuit which casuses the circuit breaker to trip, disconnecting the hot AC wire from the equipment chassis and any other equipment connected to it through audio cable shields.

But, suppose that ground connection breaks. I'll give you the benefit of the doubt and say the outlet wiring or the power cord is defective, but we *KNOW* about that ground lift adapter that fixed a hum problem. Without the safety ground, if there's leakage between the hot side of the AC line and the case - it doesn't have to be a dead short, it can be through a resistor or capacitor - and if you should happen to touch the chassis while you're standing on the floor in your bare feet, you, instead of the ground wire, will experience what might be the once in a lifetime thrill of becoming the current's path from the chassis back to neutral.

You may have experienced a taste of this on stage when you've had a hand on your guitar which was plugged into an improperly grounded amplifier with a leakage problem, and you touched a mic stand that's grounded through the microphone cable shield. Since you're reading this, you were lucky that there was enough resistance in the cable and in the probably leaky line bypass capacitor in the amplifier to limit the current passing through you. Some were not so lucky and received a fatal shock. **This is why haphazard ground lifting is a very bad idea.**

One defense against both fools and equipment grounding faults is the ground fault interrupter (GFI). Many newer homes are equipped with GFI outlets in bathrooms, kitchens, basements, and garages, places where you have a good chance of being grounded yourself. Local electrical codes often require GFI outlets in specific locations. A GFI senses the current in both the hot and neutral wires and looks for a difference between the two currents. Under normal operation, there's a complete circuit with the current entering on the hot wire and returning on the neutral wire. The same current flows through the hot and neutral wires and the GFI is happy. A direct short between the hot wire and the chassis puts the hot and neutral wires in parallel, causing the neutral current to split between them. This makes the neutral current that the GFI monitors less than hot current by the amount of current that the ground path carries, so the GFI will trip, usually before the circuit breaker trips due to the short since GFIs are very fast-acting. But if the ground path is broken. a short to the chassis develops, and you touch the chassis while you're at least partially grounded, you, rather than the ground wire, will divert some of the return current from the neutral. The GFI detects the difference between neutral and hot currents and, sensing that you're about to get electrocuted, breaks the circuit, usually faster than you can say OUCH!.

While it's not usually required by code to install GFI outlets throughout your studio, it might be a smart idea to put in one or two for "visiting" equipment that may have been butchered by someone else (or is just in poor electrical condition).

Your wall wart doesn't have a grounded plug? Well, the wall wart doesn't have a metal case, either, plus it contains a transformer which isolates the wires going to the equipment from both the building hot and neutral, so it's safe. All wall warts and other external in-line modular power supplies ("line lumps") are safety-tested and certified, which saves the equipment manufacturer the cost of performing that certification himself. That's why they're so common, particularly with low cost gear.

Another safe "groundless" scheme common with portable power tools such as electric drills and weed whackers (but not so much in studio gear) is called "double insulating". A double insulated appliance has a plastic case, so there's nothing conductive to which the hot power lead can short.

Surges, Spikes and Spurious Radiation

A surge is an unusually high voltage for a fairly short time that appears on the power line, seemingly from out of nowhere. A spike is generally a higher voltage than surge, but it's here and gone quicker. Surges can initiate right in your own home or building from large motors switching off, but the most destructive ones are a result of lightning striking a power line. Surges can cause "hard" damage where something is physically destroyed (usually visually charred or melted), or "soft" damage where nothing smokes, but data gets lost or scrambled - your computer might crash, or that killer effect processor patch that you haven't saved yet might get lost.

Surges and spikes that don't have immediately apparent results tend to weaken electrical equipment. In other words, if the first one doesn't get you, the likelihood that the next one will is increased.

Outlet strips are today's extension cords. The multi-outlet strip that you buy in a hardware or computer store nearly always contains a surge suppressor, but chances are you didn't buy it for that purpose, you bought it because you needed to plug in a bunch of things. If it offers your equipment some protection against voltage spikes on your power line, that's great. But are you getting something for (nearly) nothing, or just getting what you paid for, a bunch of outlets?

Surge suppressors are like insurance - nearly everyone needs some, those with a lot to lose or are exposed to high risks need a lot, and you don't know how bad it is until it doesn't protect you. Like an insurance policy, surge suppressors need to be examined now and then to see if they still meet your needs. And like the insurance policy that you forgot to renew and now you're too old, surge suppressors can slip out of your life without telling you.

The garden variety surge suppressing outlet strip employs a component called a metal oxide varistor (MOV) wired across the AC line. The resistance of an MOV is high at normal line voltage so it doesn't draw any current or drop the voltage. When a sufficiently high voltage surge occurs, the MOV's resistance drops, causing it to draw enough current to trip the circuit breaker or blow the fuse in the outlet strip, disconnecting the potentially damaging high line voltage from the equipment. The cheapest surge suppressor outlet strips have a single MOV connected between the hot and neutral leads. This is known as single mode shunt suppression. It protects against surges occurring on the power line, but doesn't help with surges occurring between the line and ground or neutral and ground. Those surges, typically induced by lightning, cause their damage by raising the chassis above ground potential.

The next step up usually carries the enticing label "all mode" or "three mode". This configuration contains three MOV's, one between the line and neutral, one between line and ground, and a third between neutral and ground. This sounds like it covers most of the bases, but under some conditions that arrangement can do more harm than good. Surges occurring on the line or neutral get diverted into the ground lead. In a computer, this can send the surge on to your computer's mother board or out to a printer or modem through data lines, protecting the computer's power supply, but causing damage further downstream.

Power surges occur all the time, and MOVs are designed to take them in stride, at least for a while. But MOVs wear out from this exercise and sometimes burn themselves out in the process of protecting your equipment. Your gear might get saved once, but with a blown MOV, you no longer have protection when the next surge comes along. Unlike your car, which has an odometer to tell you when it's time to change the oil or an idiot light indicating that the alternator has failed, most surge suppressors don't give any indication that they're still working properly. In mid-1996, Underwriters Laboratories (UL) standard 1449 established procedures for endurance testing of surge suppressor devices. If your surge suppressor is UL approved (there's no requirement for UL testing, it's just a good thing), you can at least inquire as to what standards it was tested. This testing is one of the things that sets a $40 surge suppressor apart from a $5 one.

Sometimes a fuse is wired in series with the MOV, with an indicator light connected across the fuse. The theory is that the MOV will shunt the transient, which, if the transient current was sufficient to risk damage to the MOV, will cause the fuse to blow. The voltage across the open fuse will light the indicator, telling you that you're unprotected until you replace the fuse, and it might be a good idea to replace the MOV while you're at it. In practice, though, sometimes the fuse protects the MOV so quickly that the MOV doesn't have a chance to protect what's connected to the outlet strip.

For those willing to pay for extra security, series mode surge suppressors are available from several manufacturers. You'll find them at electrical supply houses rather than computer or hardware stores, though there are now some series mode suppressor boxes sold as audio accessories, primarily for the home theater market. The series mode surge suppressor uses an inductor in series with the line to limit the current resulting from a transient. The inductor acts like a high value resistor at the high frequencies associated with transients, while letting the 60 Hz line frequency pass through unaffected. A shunt capacitor limits the voltage slew rate, further sitting on the transient. These two components form essentially a low pass filter, and additional capacitors switched in by diodes add protection when the voltage rises beyond a certain point.

There are two significant advantages of a series mode suppressor. First, it's not built from components which are prone to self-destruction in the process of doing their job. Second, transients aren't shunted to ground, they're returned back through the neutral wire, so a transient is less likely to cause damage to the next piece of equipment in a chain through interconnected grounds.

Most surge suppressor assemblies also incorporate some degree of RFI/EMI (Radio Frequency/Electromagnetic Interference) filtering. The evils of EMI creeping into signal lines through defective shields is fairly well known, but another route for stray EMI into your equipment is through the power line. A well shielded filter that attenuates frequencies above the line frequency takes care of this. Some are more effective than others, and you pretty much get what you pay for.

Incidentally, most digital electronic equipment (and practically anything that uses a switching power supply) incorporates an EMI filter right at its power connector. The main purpose of this filter, however, isn't to keep EMI out of the unit, it's to keep EMI generated by equipment itself from radiating into space, with the power cord acting as a transmitting antenna.

Power Conditioners

A power conditioner usually combines transient suppression, EMI filtering, and voltage regulation in one box, a kind of cure-all for most of what ails your power. One function we haven't discussed yet is voltage regulation. Throughout the day, the power company makes small changes to the voltage they distribute in order to keep their load stable, or to budget the power that they have available. Generally they keep the line voltage within just a couple of volts of nominal, and changes are made slowly enough so that the adjustment doesn't look like a transient. But stuff happens. Brownouts are short term droops in line voltage that fall out of the power company's normal tolerance, and are also generally beyond the regulating capability of your equipment's internal power supplies (because power supplies are designed around what's considered a normal range of line voltage). While not as common as brownouts, occasionally loads will drop off faster than the power company can regulate the voltage and you get higher than normal line voltage for a while.

A line voltage regulator is designed to handle these problems. The old reliable type is the ferroresonant transformer. A capacitor and an auxiliary winding in the transformer form a resonant circuit at the line frequency. This causes the transformer's core to saturate and limits the maximum secondary voltage. The ferroresonant regulator provides very clean power, free of harmonic distortion or transients, but since it's a resonant device, it depends on the line frequency being accurate. Power companies keep the frequency very stable, so these regulating devices work well when operating from commercial power, but don't take one on tour unless you're sure of the line frequencies where you're going.

A less expensive regulator design uses a tapped transformer with approximately a 1:1 ratio between primary and secondary windings. A controller circuit monitors the line voltage and selects one of three to five taps on the secondary side that raises or lowers the secondary (output) voltage to bring it into tolerance. The output voltage of a tap switching regulator changes in discrete steps, but the switching is very quick, generally within one cycle of the line frequency. Switching occurs at the point where the AC voltage passes through zero to minimize switching transients. If you're skillful at editing audio sample waveforms, you'll recognize this zero-crossing switch principle.

A regulator is a good investment if brownouts are common in your area, and it's a good security blanket when doing remote recording. I was very thankful for mine when I did a remote in a West Virginia bar where the only available outlet was on the same circuit as the beer cooler (as was probably everything else in the place), and the line dropped below 95 volts for about thirty seconds every ten or fifteen minutes when the cooler's refrigerant compressor started. Trust me, in a hillbilly bar, you don't ask them to turn off the beer cooler for the sake of making a recording.

OOPS! Glad I had my UPS!

If your studio (or your life) is based around a computer, an Uninterruptible Power System (UPS) is as important as your keyboard. When the lights go out, the amps and monitors go silent, and you're wondering whether or not to call it a day, a UPS will keep your computer operating long enough to shut it down in an orderly manner. While most hard disk recording systems stream audio data directly to disk, without a proper shutdown, you might be left with a chancy file system repair job before you can recover your project. If you have better things to do with your time than repair your computer's data structure, there's no better investment than a UPS.

The heart of a UPS is an oscillator running at the AC line frequency. A transformer and power amplifier brings the low power oscillator output up to line voltage, supplying enough current to power electrical equipment.

There are two types of UPS - on-line and off-line. An on-line UPS is a full time power maker. The oscillator and power amplifier are always operating, and they're always the source of the output. The oscillator/amplifier is powered by a DC power supply connected to the AC line when there's power present, and by a battery when AC power goes away. Since the battery is always connected across the power supply output, there's never a break during switchover when the AC drops, and the battery keeps fully charged until it's needed.

An off-line UPS works a little differently. The battery, oscillator, and amplifier are still there, but when commercial AC power is available, it goes straight through to the UPS output. AC is also used to charge a battery, but with an off-line UPS, the battery isn't connected to the oscillator/amplifier until it's needed. When AC power is lost, the oscillator starts up under battery power and takes over, providing power until the incoming AC is restored.

Off-line UPS's are substantially cheaper than on-line systems, and they're the ones you'll find at a computer store for a couple of hundred bucks. For efficiency, the oscillator doesn't put out a pure sine wave, but rather a stepped approximation that's good enough to run a computer.

A UPS is rated in terms both of its maximum output capacity in volt-amperes and in the length of time the battery will last, either at the UPS's rated capacity or with what the marketing department (who wants to show you an attractive figure) thinks is a "typical" computer load. You'll want enough capacity to run the computer, monitor, and any externally powered disk drives but there's no compelling reason to buy enough power to run a printer, other peripherals, or your console and monitor system. You really need only enough operating time to close what you're working on and shut down properly. 600-650 VA with about 15 minute capacity is about right for a typical Pentium system and a 17" monitor.

Balanced Power

You're probably familiar with balanced audio connections where the audio signal voltage appears between a pair of wires, neither of which is connected to ground. A shield around the signal wires is connected to the chassis ground and carries no signal current. With an unbalanced connection, the shield, still connected to chassis ground, doubles as the signal return wire. Noise on the ground can contaminate the audio signal.

Balanced power works in a similar manner. Instead of the hot side of the line being 120 volts above ground (by virtue of the neutral-ground connection at the service entrance), a balanced, or symmetrical power source isolates both sides of the line from ground with a transformer, providing 60 volts from either side of the line to neutral. Any noise that your equipment puts into the power line (and consequently feeds to everything else on the same circuit) gets canceled in the same way that common mode noise gets canceled going into a differential (balanced) input.

Balanced power systems are hyped to do everything from curing all your hum problems to make your system sound better. In practice, they fix certain problems caused by degraded or poorly designed equipment, but if there's nothing wrong with your gear, you won't see much if any improvement from one. The case that balanced power deals with best is equipment with some power line leakage to ground. That's a maintenance problem, something that can be fixed once you're aware that the problem exists.

One place where balanced power can be a lifesaver (or client impresser) in the studio is in powering instrument amplifiers, particularly those 1950's classics that people bring in because they love the sound. They can live with the amp's hum and buzz on stage, but they expect that in the studio you can "do something" about it. One thing you can do is provide a small balanced power unit for these problem cases.

Pulling the Plug

There's a lot of hype and scary advertising in the power protection business. The darn thing is that there's some truth in just about everything you read, but you have to balance your risks with your budget. If your studio is the thunderstorm belt, you probably already know that you can't count on power being available all the time, and you may have already lost some gear to lightning-induced surges. But if you live in a relatively benign climate with a reliable power company you can afford to take a little more risk with surge protection and put your money elsewhere. There's a lot of confusion about what equipment provides what kind of protection (and what kind of protection it doesn't provide). I hope this overview helps you to make some intelligent choices.

Star Grounding

Most project studios are originally set up using the closest convenience outlets. Typically there's an outlet or three on each wall, but they may be not all be fed from the same branch circuit, hence their grounds take different paths back to the ground terminal in the main breaker box. A long loop results when devices whose chassis are connected together through cable shields are plugged into outlets on different AC circuits. This acts like a one-turn transformer and can pump significant hum current into the equipment grounds. This is why a "ground lift" sometimes works, but DON'T DO THAT other than as a troubleshooting measure.

In a typical project studio with all the equipment in one room or confined to a small area, and with fairly short audio cable runs (50 feet or less), it's neither difficult nor expensive to set up a completely legal and effective star ground system.

Start by bringing all of the electrical circuits feeding the room (if there's more than one) to a common box in the studio. Alternately, have an electrician run one or two new branch circuits directly to a new breaker box in your studio. This will assure that all circuits powering your studio gear take a single direct path to the main breaker box and hence to the service ground. The ground bus in this new box will become the hub of the ground "star".

You can then run standard 3-wire outlets from the central studio distribution point to convenient places around the studio and control room. For a small installation, you can use conventional outlet strips branching out from a "clean" outlet. This scheme results in the shortest possible ground path, assuring that noise originating from some other ground in the house will connect to your studio gear at a low impedance point (the building ground junction) rather than through the resistance of an unknown length of wire where it can develop enough voltage to get you into trouble.

Cable TV grounds are notorious for carrying noise into the house. Many a studio noise problem has been (temporarily or permanently, usually depending on the family situation) cleaned up merely by disconnecting the cable from the TV set. With a proper direct ground for the studio, you can let the family watch the tube while you play with your tube preamps.

At this point, you may have a fairly effective "star" through the safety ground pins on the power plugs and you need not go further, but in a real star grounded system, each piece of equipment has a heavy wire connected directly between the unit's ground and the central ground point (your new electrical junction box).

Use #12 or heavier wire. You already have several unit-to-unit ground connections through the metal rack rails and cable shields. Since most electrical current takes the path of lowest resistance, using a heavy ground wire between each chassis and the "hub" of the star ground system assures that most of the undesirable noise current flows through this path and not through some unknown path which involves other devices in your studio. No cheating. One ground wire for each chassis.

A Ground Rod? Better not!

A properly implemented “star grounding” scheme, in which all equipment in an installation is bonded to a central ground point, can be effective for minimizing low frequency (but not necessarily RF) common mode noise in the system. If it’s not properly implemented however, in some cases you can make things worse than with the typical haphazard grounding scheme which is often present in studios when equipment is added a piece of a time. If your gear is already connected with three-prong grounded plugs, improperly implementing a secondary grounding system can increase ground loops, resulting in more hum, not less.

One popular misconception about a star grounded system is that each piece of equipment is bonded to a central point using individual ground wires (so far, so good), then connecting this central ground point to its own earth ground, usually a copper rod planted in the earth. (that’s where the misconception lies) While knowing exactly where and what “ground” is seems like a good idea, but there’s a potentially (pun intended) dangerous problem here. The “equipment” ground rod isn’t bonded to the main electrical service ground, but rather, the two grounds are separated by several feet of earth.

A nearby lightning strike can cause significant current to flow through the earth. When current flows along the path between the two ground rods, the voltage dropped across the resistance of the earth results in a potential difference that can raise the chassis of your equipment above real ground potential by hundreds of volts. The result of this voltage surge can be disastrous to the equipment and possibly to anyone who happens to be in contact with it. It can start a fire, and discovery of an independent ground rod that connects to the service ground can invalidate insurance coverage, adding insult to injury. This practice is illegal in every place governed by the National Electrical Code, and certainly a bad idea everywhere else.

One and only one connection between a studio full of equipment and the building ground will make the system safe and compliant with electrical codes. When properly implemented, this single point ground is also sufficient to minimize hum resulting from differences in electrical potential between equipment grounds.