The Power Line Interface

This article takes you through the AC line interface of a typical piece of audio equipment–from the wiring in the walls to the power transformer–and provides some practical suggestions for your next project.

BY PETE MILLETT

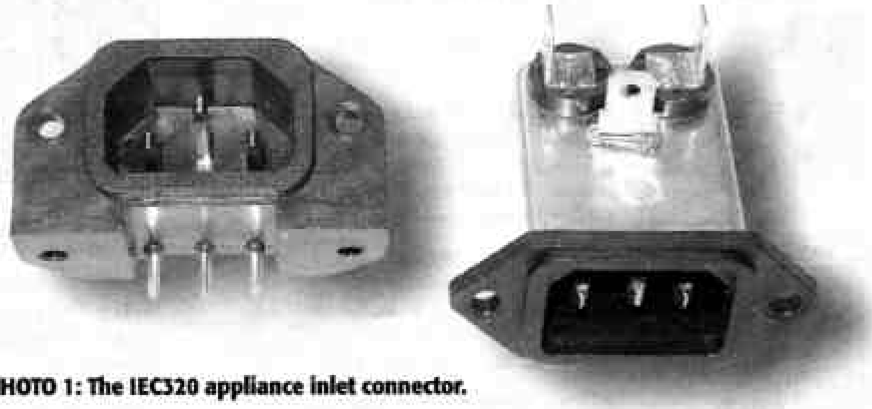

PHOTO 1: The IEC320 appliance inlet connector.

For most designers and builders of audio equipment, the circuitry between the AC wall outlet and the power supply is seldom the subject of much thought. However, there are issues that should be considered in order to provide optimum performance and safety in *anything* you build that plugs into the wall.

IN THE WALL

In the United States, the common AC wiring scheme employs three wires—a black "hot" wire, a white "neutral" wire and a green ground wire. A nominal 115V is present on the hot wire relative to the neutral wire. The neutral wire and the ground wire are connected at the circuit breaker panel.

Not all power connections use the green ground wire, and older buildings are not always wired with it. It is used as a "safety" ground to provide a grounded connection to the chassis of a piece of equipment to protect against electric shock.

On a standard US power cord, the ground wire is connected to the round pin, and the neutral and hot wires are connected to the rectangular blades. Though the plug may be polarized (which means the neutral blade is wider than the hot), there are two-wire power cords and extension cords that can be plugged in either way. Because of this, you can't depend on the neutral wire being grounded.

GROUNDING

Connecting ("bonding") the green-wire ground to the chassis prevents the chassis from becoming energized if the transformer insulation fails or if there's some other short-circuit between a potentially lethal voltage and the chassis. Providing a solid connection between the chassis and ground is one of the most important safety requirements placed upon the AC line circuit.

Unfortunately, this connection can also cause a ground loop with other components in the audio system by allowing power supply currents to flow through the shield of audio interconnect cables. Some solve this problem by disconnecting ("lifting") the green-wire ground from the equipment, but this is risky, especially in tube power amplifiers with very high voltages present.

Equipment that uses a two-wire cord and no ground wire (like most consumer electronic equipment) requires more insulation in power transformers and greater physical spacing between the line circuit and the "safe" secondary circuit. You should avoid this configuration unless you are very confident in your transformer selection and construction practices.

THE POWER CORD

You can wire the power cord directly into equipment, but most high-end audio products use a detachable power cord, which makes construction of your equipment easier and cleaner. There are a variety of cords available, from inexpensive imports to high-end tweakophile cables that cost hundreds of dollars.

From an engineering perspective, the main requirement of a power cord is that it's rated for at least as much current as the line fuse (typically a bit more than the equipment draws—more about that later). Commonly available cords are rated at 10 or 15 amps, which is more than adequate for normal audio equipment use. The sonic characteristics of different power cords is a topic for another time.

AC INLET CONNECTORS

The most commonly used AC inlet connector is a 3-pin IEC connector, technically known as an "IEC320 appliance inlet connector" (*Photo 1*). IEC320 connectors can be found in a multitude of types, some with built-in EMI/RFI filters; some are integrated into "power entry modules" that also contain a fuse holder and/or power switch. Although the IEC320 standard allows for current ratings up to 15A, not all inlets are rated for that high a current, so you need to make sure you use one with at least the same rating as your fuse.

It's a good idea to use an IEC320 connector with a built-in EMI/RFI filter. Although the filters are designed primarily to prevent the conduction of radio-frequency noise *out* of equipment (typically from a switching power supply), they are equally effective at preventing radio-frequency interference from getting *into* your equipment from the power line. Filtered connectors rated at six amps, which are adequate for all but the largest power amplifiers, are readily available at a reasonable price.

ABOUT THE AUTHOR
Pete Millett started playing with tubes as a kid, and has been an electronic design engineer for about 20 years. His experience ranges from consumer electronics to computer hardware and system design. He also runs Wheatfield Audio, a small manufacturer of tube headphone amplifiers. Pete can be contacted by e-mail at pete@headphoneamp.com.

PHOTO 2: Two standard fuse holders.

INTERNAL WIRING

The wire you use to connect the components of the AC input circuit must be large enough to handle the required current, and must have good enough insulation to withstand both the steady-state AC line voltage, as well as any transients that might appear on the line. For most applications, AWG 18 (18 gauge) wire with an insulation rating of at least 600V is used for equipment that draws up to 10A. You can always use larger-sized wire if you wish.

You should pay special attention to the specifications of the ground wire. It must be large enough to handle the entire amount of current for which the building wire is fused in case there is a short-circuit between the line wiring *before the fuse* and the chassis. Since this is usually 15 or 20A, 16AWG wire is a good choice for the ground wire.

FUSES

A properly sized fuse is critical to the safety of any line-operated equipment (*Photo 2*). Placed in series with the incoming power, the primary purpose of a fuse is to prevent a fire if there is a failure that causes the equipment to draw excessive current. Though there is a fuse or circuit breaker in the electrical panel, it is sized only to protect the wiring in the walls—typically 15 or 20A. This amount of current can easily start a fire in a small transformer that has failed insulation.

The fuse can also protect the equipment from further damage if a component fails. For example, if a rectifier tube becomes shorted, the equipment draws excessive current that could eventually result in failure of the power transformer. A properly sized fuse should open before the transformer is damaged.

Though some countries require fuses in both legs of the power line, normally there is only one fuse, which is in the "hot" side of the line—but keep in mind that there is never a guarantee that the "hot" side is really hot. The fuse's current rating is chosen to provide the best possible protection without blowing unnecessarily during turn-on surges and peak power usage. Typically, the value is between 20% and 50% higher than the expected maximum current draw.

To allow for a higher current at turn-on (to charge filter capacitors, and heat cold tube filaments), you can use a slow-blow or time delay fuse. Slow-blow fuses can withstand about two to three times their rated current for one second, but will open quickly in the event of a high-current short circuit. Fuses are commonly available in a couple of different sizes, including the US standard 1¼" × ¼" (AGC or 3AG) size and the smaller European 5mm × 20mm format. Either one is fine for audio equipment use.

Photo 3: An example of an inrush limiter (CL-110).

POWER SWITCHES

The most obvious component in the chain, the power switch, can take many forms—toggle, rocker, rotary, pushbutton, and so on. The switch style you use is up to you. The important things to consider about the power switch are that it's rated for enough current (at least the rating of the fuse) and that it has a high enough voltage rating to live a long life. Unlike low-level switches, power switches usually are stamped with a rating that indicates the voltage and current they are approved for.

Most countries (the US included) require a power switch to switch only one side of the line (again, the "hot" wire) using an SPST (single-pole single-throw) switch. Some countries require the use of 2-pole switches (DPST, double-pole single-throw) to open both sides of the line. This applies no line voltage to your circuit, even if the "hot" and "neutral" wires are reversed—not a bad idea even if it isn't required. You can also use DPDT (double-pole double-throw) switches to switch both sides of the line, as well as to provide some handy tie points for other components (*Fig. 1*).

INRUSH LIMITERS

When power is first applied to a tube circuit, a very high current flows through the input circuit for a short time. This current is caused by a number of different factors, including a building magnetic field in the power transformer, the heating of cold tube filaments, and (especially with solid-state rectifiers) the charging of filter capacitors. Inrush is especially troublesome in higher-powered circuits, where just the inrush caused by the transformer primary can be enough to blow fuses rated for more than twice the steady-state load current.

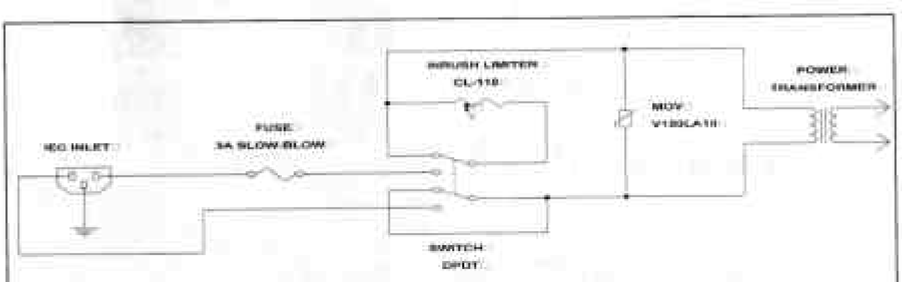

FIGURE 1: Schematic for the AC input circuit for a 15W, Class-A tube power amplifier.

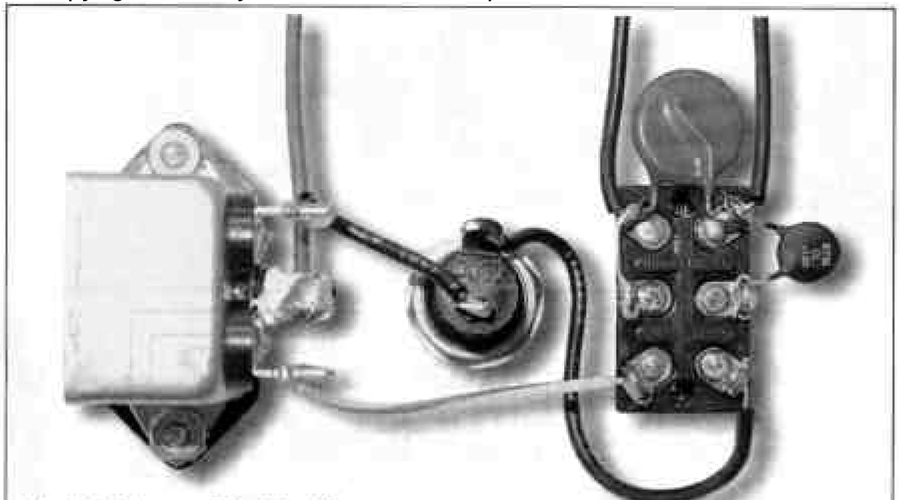

Photo 4: The completed circuit.

Inrush limiters solve this problem (*Photo 3*). They are thermistor devices that are designed to have a relatively high initial resistance, which lowers when current passing through the device heats it. The initial resistance of the inrush limiter prevents this surge current from flowing when the power is first applied. A typical inrush limiter for use with moderate-power tube equipment (CL-110, made by Keystone Carbon) has 10Ω of resistance when cold. This level drops to about 0.3Ω a few seconds after power-up (with a 1A load). This inrush limiter is rated for a maximum continuous current of 3.2A.

TRANSIENT SUPPRESSION

The last component in our circuit (before the power transformer) is a metal-oxide varistor, or MOV (*Photo 3*). The MOV is a device that presents a high resistance up to a specified voltage, where it conducts rather abruptly.

The MOV provides two benefits in the AC input circuit. It provides some protection to the rest of the circuit by clamping any high-voltage spikes—caused by lightning strikes or transient loads—that may appear on the incoming power line. It also suppresses the inductive "kick" caused by the magnetic field in the power transformer collapsing when the power switch is turned off. This voltage spike, if not suppressed, can cause damaging arcing in the power switch.

MOVs are rated for their maximum continuous voltage (also called "standoff" voltage) and their diameter, which relates to the amount of energy they can dissipate. For a 115V power input, a 10mm diameter, 150V part is usually appropriate.

PUTTING IT ALL TOGETHER

Figure 1 is the schematic for the AC input circuit for a 15W, Class-A tube power amplifier, which draws about 50W from the AC line. One side of the line is fused, and a DPDT switch is used to provide mounting points for the inrush limiter and MOV (*Photo 4*). ❖