In Practice

High voltage power supplies, Part 3 – connecting the details

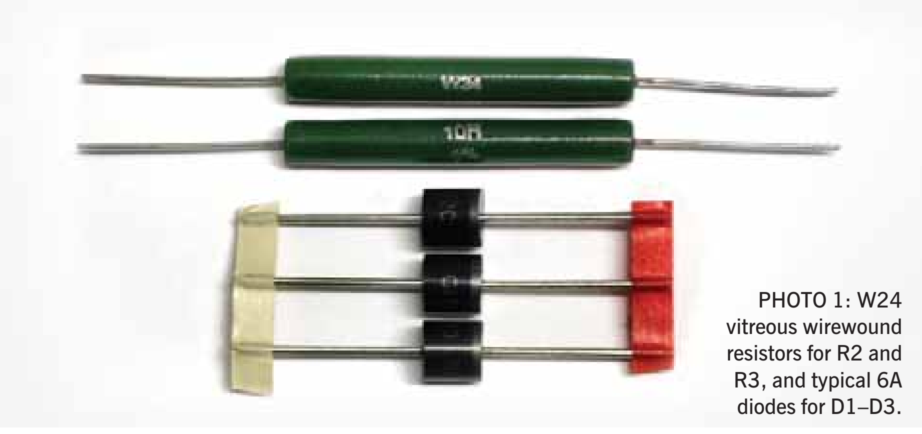

PHOTO 1: W24 vitreous wirewound resistors for R2 and R3, and typical 6A diodes for D1–D3.

QUICK RECAP. This is the final part of our detailed tour of a typical HV power supply. We are still using the circuit diagram that appeared as **Figure 1** in the January column **[1]**.

SURGE LIMITING RESISTOR. All high voltage components are operating under stress, especially when high RF voltages and currents are involved, so occasional flashovers (arcing) and short circuit failures are part of the normal course of events. But contrary to amateur folklore, faults in HV circuits don't have to end in disaster. Minor flashovers are often self-clearing and, with a few basic precautions, your amplifier can be back on the air very quickly. Your design aims should be:

1. No need to remove the covers unless there has been a major component failure; and
2. No 'collateral damage' to unrelated components.

What happens in a high voltage flashover or short-circuit? First, it will trigger an immediate pulse of stored energy from the reservoir capacitor. Then the PSU will bravely attempt to deliver a massive current for as long as it can… until something finally breaks the circuit. The key to survival is R2, a beefy resistor in series with the HV+ output. As the first component downstream of the reservoir capacitor, R2 can protect all the other expensive components by absorbing most of the energy surge itself, until a fuse or circuit breaker can shut down the PSU without further damage.

Why can't we simply use a HV fuse? There are many practical reasons, but it's mostly because a fuse provides no current limiting until *after* it has blown – and at these power levels, even the fastest fuse may be too late to prevent damage. In contrast, a resistor will instantaneously limit the surge of current to a known maximum value, which the rest of the amplifier can then be designed to survive. With a surge limiting resistor in the HV+ line, you don't need the HV fuse as well. The main fuse or circuit breaker can be located in the 230V AC primary circuit, where it will safely shut down the entire PSU and is easy to replace or reset without removing the covers **[2]**. But please remember that this protection scheme won't work unless you include *both* the HV surge resistor and the fast-acting mains fuse or circuit breaker. Neither will do on its own.

R2 is no ordinary resistor, for it has to survive a very large pulse loading. Several kilovolts will suddenly appear across the resistor in the first few moments of the current surge and this current must obviously be forced to flow *through* the resistor. Many common types of resistor would flash over from end to end, so R2 will need to be a large, long-bodied resistor with its connecting leads at opposite ends. The peak surge current is also limited in part by the internal resistance and inductance of the reservoir capacitors, in series with R2, so a resistor of 20 – 30Ω should provide adequate protection for amateur-sized amplifiers [1]. The power rating of R2 is not determined by any of these surge conditions, but by the need to handle routine levels of anode current in normal operation. A quick I^2R calculation shows that the power rating should be at least 20 – 30W, so R2 will need to be a fairly substantial component with a good supply of cooling air.

An economical solution to this demanding set of requirements is a string of two or three 10Ω 14W vitreous wirewound resistors, eg the familiar green Welwyn W24 type shown in **Photo 1**, which are readily available in the UK [1]. These resistors can handle short-term surges well in excess of their normal ratings and have been found to survive repeated HV short-circuit tests. A larger amplifier could use a series-parallel network of the same 10Ω resistors to achieve the necessary total power rating. You could also use a single large vitreous enamel wirewound resistor, although those have to be ordered from outside the UK. The surge resistor can save your valves and many other expensive components, so this is no place for false economies. In particular, *do not* use cheap cement-coated resistors or metal-clad resistors, both of which have poor surge performance.

The final test for HV short-circuit protection is brutally simple: would you dare to short the HV *deliberately*?

HV CONNECTORS. That question is realistic and important, because the HV+ connection between a power supply and a separate amplifier is quite vulnerable to damage. The best form of protection is a coaxial HV cable with a securely earthed shield, so that most kinds of damage will provoke a deliberate short-circuit. If your PSU can withstand that

PHOTO 2: Purpose designed coaxial HV connectors: MHV (left) and the far superior SHV (right).

PHOTO 3: Five-pin XLR connectors.

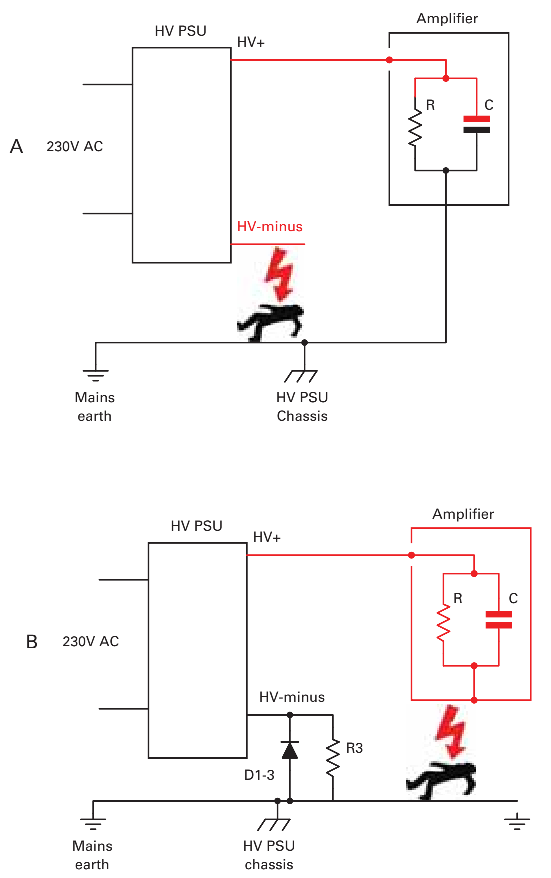

FIGURE 3: (a) Broken HV-minus connection creates shock hazard inside HV PSU. (b) Broken chassis/earth return creates shock hazard from amplifier metalwork.

test and shut down safely, all will be well. There are many published examples of remote PSUs using single-wire HV connections, but many of these are only one step away from a whole range of lethal situations; in modern terms, they have no Defence in Depth. So do use coaxial HV connectors and always use a purpose designed type such as SHV or MHV (**Photo 2**) or the older British PET series. Never use any type of RF connector for HV – it's a booby-trap that could easily kill someone. SHV connectors are much the best for HV because the centre conductors on both sides are deeply recessed and can never make contact without also having a good earth connection. Also SHV connectors cannot possibly be mated with any other series of connectors (a major design fault of the MHV socket, which can be mated with a BNC plug). SHV connectors are very expensive to buy new **[3]**, but can sometimes be found in scrap nucleonic equipment… and how much is your life worth, anyway?

Purpose designed HV connectors are generally made for RG58-type cable, which is more than adequate for the currents and voltages involved. It is obviously vital to connect the shield of the HV cable to mains earth in the PSU, so do not rely on chance connections through the front panel and other metalwork. Run a totally independent earth bonding wire directly from the flange of the HV connector to the point where the mains earth connection enters the unit (marked 'E' in January's Figure 1).

HV-MINUS RETURN. As Figure 1 shows, the negative end of the capacitor stack is not connected directly to chassis, but to a separate HV-minus return rail. This facility allows safe metering of the anode current without needing to connect a meter in the HV+ line **[4]**. An independent HV-minus connection also allows correct metering of the anode and grid currents in a grounded-grid amplifier.

The 'clamping' diodes D1 – D3 are important safety components. They have no function in normal operation, because they are shunted by the amplifier's anode/grid current meters. If the voltage drop across the metering circuits is designed to be less than the threshold voltage at which D1 – D3 would begin to conduct, these diodes will have no effect on meter readings. But in HV fault situations D1 – D3 will provide a reliable return path for the surge current, and will protect the meters by 'clamping' the HV-minus rail close to chassis/earth potential. The peak current is limited by R2 in the HV+ line, and D1 – D3 can then be rated to survive this surge; the diodes shown in Photo 1 are rated at 6A RMS and 400A surge **[5]**. Resistor R3 is connected in parallel with D1 – D3 as a backup, and for true independence R3 should have its own separate connections to the HV-minus rail and the chassis. The recommended value of 100Ω is low enough to prevent hazardous voltages developing across R3 under any circumstances, but high enough to have no significant effect on the accuracy of external metering. The high power rating of R3 is purely for physical reliability; its normal power dissipation will be almost zero.

Figure 3 shows two faults in the HV return circuit that must be prevented. In Figure 3a, D1 – D3 and R3 have all somehow disappeared, so the HV supply has no negative return inside the PSU. It can then float away to some indeterminate high voltage, creating a hazard in a part of the wiring that you'd normally assume to be 'mostly harmless'. Figure 3b is even worse because the amplifier has no chassis/earth connections to the HV PSU – most likely because you simply forgot to plug them in. In that situation, the HV bypass capacitors and/or bleed resistors within the amplifier will charge its chassis metalwork up to HV+ potential. And then the HV circuit will attempt to complete itself through the nearest earthed object… most probably you.

To avoid those risks, the chassis and HV-minus interconnections demand the same level of integrity as the HV+. A multi-way connector will be required, and for this role I like the 5-pin XLR series (**Photo 3**). These are high-quality latching connectors with very adequate current ratings, and are readily available from several manufacturers [1]. The reason for using a 5-pin connector is that triode amplifiers require two separate return connections capable of carrying high current, one for the HV-minus and another for chassis/earth. Each connection is duplicated, using a substantial multi-way cable and two pins in the connector. As shown in Figure 1, the fifth pin is connected to the relay RL1 in the HV transformer primary. By using an additional core in the same multi-way cable, the 5-pin connector creates a safety interlock to ensure that the HV cannot be switched on unless the HV-minus and chassis/earth connections are also in place.

Together, all those precautions will give good Defence in Depth against any of the faults shown in Figure 3. Even so, you might still wish to add a dedicated earth bonding strap between the PSU and the amplifier – in comparable workplace situations, many authorities would demand this as a matter of policy.

IT'S ALL IN THE DETAILS. Almost every single component in a high voltage power supply requires detailed attention. If you have only been accustomed to low-voltage circuits, you'll be exploring new territory where your old comfortable assumptions could be lethal… or at the very least, could produce columns of expensive smoke. I hope this mini-series has identified the details that you need to think about. Choose your components carefully, use your very best workmanship in construction, and be especially careful when testing and trouble-shooting. Always take time to think, and those details will add up to a safe and reliable high voltage PSU.

NOTES AND REFERENCES

[1] Figure 1 was in the January column, Figure 2 in February and Figure 3 appears in this issue. Links and supporting material for this series will be maintained on the 'In Practice' website.

[2] HV fuses are specially designed for use in HV DC circuits; ordinary mains fuses may arc internally for several seconds and may even explode. Also be aware that a HV fuse does not shut the whole PSU down.

[3] For instance see http://tinyurl.com/inpr-shv

[4] It is dangerous to measure anode current in the HV+ line because ordinary meters do not have sufficient insulation to the metal panel or to the front-panel zero adjustment. For further information on metering in grounded-grid amplifiers, follow the web links.

[5] The continuous current rating of D1 – D3 isn't actually relevant, because they carry no current in normal operation. The peak inverse voltage is also irrelevant because these diodes never experience reverse voltage (which means there is also no need for reverse-connected diodes in parallel with D1–D3).