In Practice

High voltage PSUs and staying alive!

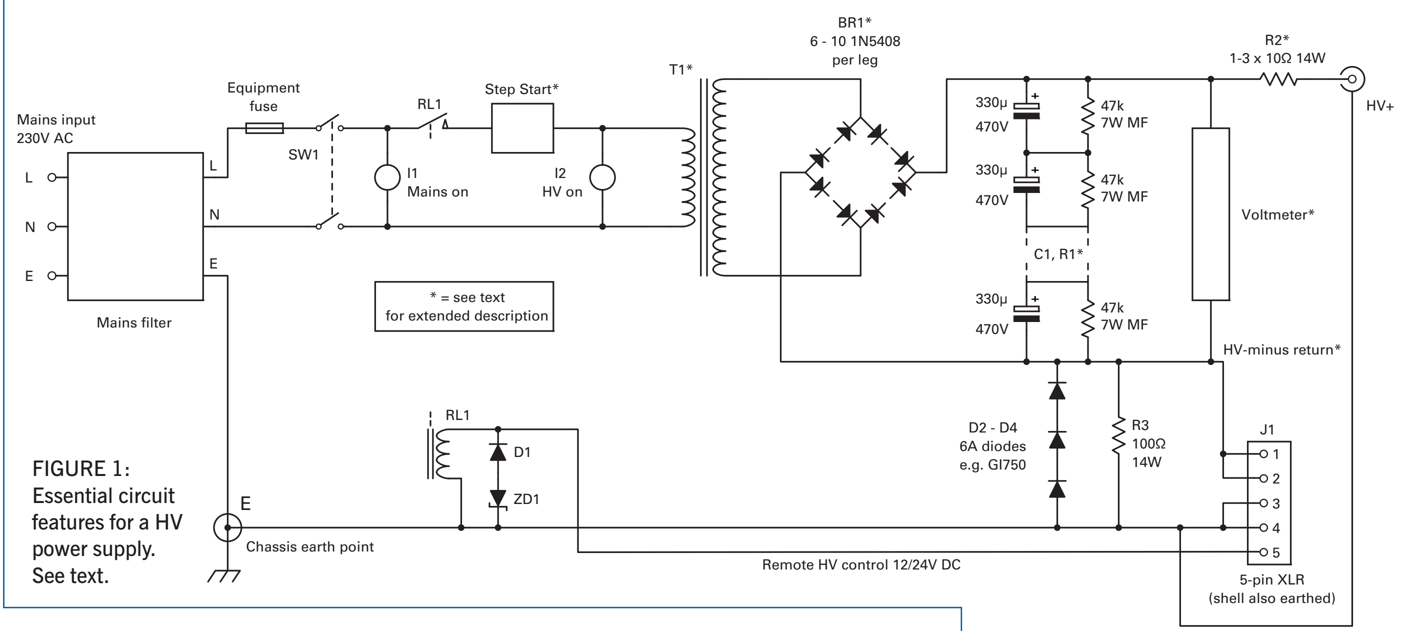

FIGURE 1: Essential circuit features for a HV power supply. See text.

Q: I want to build my first high voltage power supply for a valve power amplifier. The HV PSU will sit on the floor and the PA will be on the table. Any ideas, please?

A: Welcome to the world of 'big iron'. A power supply for a legal-limit valve amplifier is a serious project in more ways than one. It will typically need to deliver about 1kW of DC power, at 2000-3000V depending on the characteristics of the valve(s) in use. If this is your first project at such a large scale, there's a lot you'll need to know.

The very first thing to know is: **if you let it, a HV PSU will kill you – so don't let it do that.** No two home-built HV PSUs are the same, because they always rely heavily on surplus components, particularly transformers and chassis/cabinet metalwork. I can lay out some basic principles and circuit ideas, but it's your responsibility to build them into a safely functioning PSU.

This is yet another topic where small details make a big difference – between safety and danger, and to the reliability of the finished product. With so many detailed suggestions to pass on, I will once again run the story over two months' columns rather than leave out anything you would need to know.

SAFETY. Safety is paramount in HV supplies and valve power amplifiers – if you touch the HV, you're dead **[1]**. Even so, there is no doubt that high voltages can be handled safely by amateurs, for thousands of us are doing it routinely. The November 2008 column about small mains PSUs pointed out the need to follow good engineering practice, taking a leaf out of the professionals' book wherever relevant. Those recommendations still apply at this larger scale, but 2–3kV is much more dangerous than 230V AC. You need to *think carefully* about every possibility that could lead to accidental contact with HV and then *do something* to prevent it from happening.

It isn't difficult to build a HV PSU and get it working, but I've seen too many examples that could become lethal if even one small thing were to go wrong… and it's always due to sheer thoughtlessness. To help focus the mind, here are two safety principles that have proved successful against a wide range of lethal industrial hazards and they run as a thread through the rest of this article **[2]**.

- Defence in Depth: make sure that several different things would all have to go wrong before any lethal hazard can appear. This article shows many examples.
- Do not rely on 'being careful' all the time, for sooner or later you'll drop your guard and make a mistake… or maybe kill someone else, who didn't know your PSU was a death trap. Wherever human error can be lethal, we need to build our safeguards into the hardware instead.

Both of those principles dictate that, in normal use, the PSU *must* be enclosed in an earthed metal cabinet. The risks are much greater when you have to work on the PSU, so Rule 1 should be: don't work on a live PSU. If you think you need to, just stop and think harder – there is almost always a safer alternative. Rule 2: before touching any components that have been live, *always* short-circuit them to earth. But rules give no protection against a moment's carelessness or bad judgement, so back up your good intentions with physical safeguards such as internal plastic covers.

CIRCUIT IDEAS. **Figure 1** shows the essential circuit features of a free-standing HV PSU, designed to sit underneath the table and be controlled from a power amplifier on the desktop. Most of the features will also apply if the PSU is integrated with the PA into a single desktop case. This article will step through Figure 1 and point out what's important. Next month's continuation will also describe the metering circuits for anode and grid currents that interface with the connection marked 'HV-minus return'.

Many of the ideas are based on the chapter on HV power supplies by John Nelson, GW4FRX, in The *VHF/UHF DX Book* **[3]**, updated by further experience and information gathered over the intervening 15 years. As you will see, safety and Defence in Depth are built in at every stage. Some parts have also been covered in previous columns, many of which are archived in the 'Best of In Practice' web pages [3].

MAINS INPUT. This part of Figure 1 looks very similar to the circuit diagram recommended in November 2008 for small mains PSUs. The mains filter, equipment fuse and double-pole mains switch are essentially the same, only bigger and with higher current ratings. The MAINS ON indicator I1 is particularly important because this PSU has remote-controlled switching through relay RL1. Even when RL1 has switched the HV off, I1 warns that live mains is still present within the PSU.

RL1 is a critical component, for even under conditions of heavy current overload it must be able to switch off the mains supply to the HV transformer primary. This is no place for a relay at the limits of its current rating. To be sure that the contacts will *always* open on demand and won't ever weld together, RL1 should have a contact rating of 30A or more [3]. For this application I still favour electromechanical relays over solid-state relays because I like to see and hear the contacts operate. A second mains indicator I2 warns when mains power is switched though to the transformer, so HV will also be present. Note that RL1 is powered remotely from the amplifier, not from within the PSU, so that a short-circuit in the interconnection cannot possibly turn the HV on spontaneously (again, Defence in Depth). The coil voltage of RL1 should be 12V or 24V DC, and the purpose of D1 and ZD1 is to collapse the magnetic field so that the relay can switch off as quickly as possible. D1 can be a 1N4007 and ZD1 should be a 5W Zener diode with a voltage rating about equal to the RL1 coil voltage (note the polarity of these two diodes).

A PSU of this size will always need a 'step start' circuit between RL1 and the HV transformer primary. This circuit contains a large resistor in series with the mains supply to limits the initial surge of current into the transformer primary at switch-on. The initial surge only lasts for a few AC cycles, and then the resistor can be automatically switched out of circuit, so the supply steps up into normal operation. The December 1998 column **[4]** gave several circuit options for a step start, so I won't repeat those here. Another big incentive for a step start is that the main equipment fuse F1 no longer has to handle a large current surge. That lets you use a faster-acting fuse with a lower current rating, which will give much better protection to the PSU, the expensive transmitting valve(s) and other amplifier components. A PSU of the size we're discussing will run quite happily with a fast-acting mains fuse rated at 15A or even 10A (either of which will blow before the 13A fuse in the mains plug). A circuit breaker avoids having to replace blown fuses, but it must be the fast thermal-magnetic type because conventional thermally operated breakers are relatively slow. This month's web links include a nice example of a combined double-pole mains switch and thermal-magnetic breaker [3].

The front panel mains indicators I1 and I2 would typically be neon bulbs with a built-in series resistor for 230V. These components are not outstandingly reliable, so make sure they are not your sole defence against touching anything live. And even while you're concentrating on the kilovolts, don't forget the risks from 230V AC. As with even the smallest mains PSU, the entire mains input side must be insulated so that no accidental contact is possible.

HV TRANSFORMER. In every way, this is the 'core' component of your PSU – the largest, heaviest and probably most expensive single item. Many HV transformers are acquired surplus and are being used in ways for which they were never designed, so don't fall into the trap of building an entire PSU around a transformer that isn't going to perform well. You can now avoid most of those nasty surprises by using M0KGK's *PSU Designer* program to predict the PSU's performance. All you need to know are the secondary voltage (from the transformer nameplate) and the resistances of the primary and secondary windings. It may take an evening to learn how to use *PSU Designer* for the very first time, but that will be time well spent – it can save you weeks of wasted effort. The 'Best of In Practice' web page includes downloadable files linked to the August 2001 column [4] and, a link to download the program [3].

A word about measuring the secondary and primary resistances. The high voltage secondary winding will have several thousand turns with a total resistance of some tens of ohms, which will be quite easy to measure on the lowest resistance range of your multimeter. The primary will have fewer turns of much heavier wire, so it will measure almost zero ohms; but you can't assume it equals zero. Both PSU Designer and the earlier chart-based methods for estimating PSU performance require a value of 'effective winding resistance' which is:

secondary resistance
+ [primary resistance x (turns ratio)^2]

The step-up turns ratio of a HV transformer is somewhere around 10, so the (turns ratio)^2 term will magnify the effect of the primary resistance by a factor of 100 or more. You may find that the contributions of the primary and secondary windings are making almost equal contributions to the total effective winding resistance, so it's important to have an accurate resistance measurement for both windings. A good technique for measuring very low resistance is to connect an external DC supply that has adjustable current limiting, and push a measured amount of current through the primary winding. Then you can use a voltmeter to measure the voltage drop and finally calculate the resistance using Ohm's Law. Warning: before attempting to do this, you *must* short-circuit the secondary winding to prevent a dangerous pulse of voltage when you switch off the DC current.

Low resistance in both primary and secondary windings is important because you want to achieve the best possible voltage regulation – in other words, the smallest possible 'sag' in the HV output as the anode current increases. There are three different operating conditions to be considered.

1. The amplifier and PSU will spend most of their operating life in the receive condition, with the valve biased to cutoff and the PSU completely off-load. The output voltage is at its very highest, so what matters in this condition is the stress on the reservoir capacitors and associated components (see next month).
2. When you switch to transmit, but don't apply any RF drive, the valve will be biased to draw typically 100 – 200mA of 'standing current'. The Americans call this 'Zero Signal Anode Current' or ZSAC. The anode voltage will be lower than condition 1, but that drop in voltage is not particularly important.
3. When you apply RF drive, the anode current will rise and the voltage delivered by the PSU will fall, until at maximum RF drive you reach condition 3: maximum anode current and minimum anode voltage.

The important aspect of voltage regulation is the difference between conditions 2 and 3. If the anode voltage sags too much as the RF drive increases, the gain of the valve will decrease and the peaks of RF output will be compressed. On SSB this may lead to quite severe intermodulation distortion. A good design target would be about 10% drop in anode voltage between zero and maximum RF drive; as much as 20% could be acceptable, but beyond that you should start to be concerned. You may also need to make some allowance for voltage drop in the mains supply itself. If the voltage regulation of your HV PSU is marginal when powered from the home-station mains, the amplifier may be in serious trouble when connected to a poorly regulated generator supply.

Next month we'll look at the rectifier, electrolytic capacitors and all the other components in Figure 1.

NOTES AND REFERENCES

[1] Or if not actually dead, you'll certainly have used up a lifetime's allowance of good luck.

[2] These principles of 'no single failure' and 'engineered safeguards' appear across the entire spectrum of publications by the UK Health and Safety Executive [3].

[3] For more information, follow this month's links from the 'In Practice' website, www.ifwtech.co.uk/G3SEK.

[4] Members can download these earlier 'In Practice' columns from the RadCom Plus site, www.rsgb.org/membersonly/publications/radcomplus/index.php.