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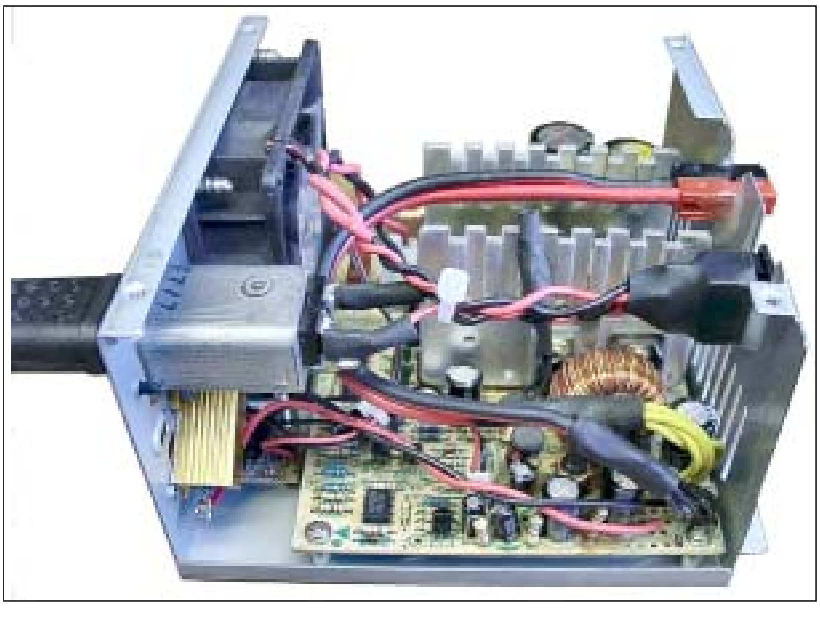
Switch-mode mains power supplies – part two

In the concluding part of his two-part article, G3SEK takes up the story on the secondary side of the main power transformer.

Everything on the low-voltage side of T1 (Fig 5 in Part 1) is referenced to mains earth – but probably only through the PC board mounting screws. Also, beware of high voltages very close by! There is mains on the back of the IEC socket, and mains and high DC voltages on the PC board, never more than a finger's-length away.

Typically, T1 has a single secondary winding that delivers something like 12-5-0-5-12VAC, and the centre-tap is connected to the common 0V rail. At the high switching frequency, very few turns per volt are required, so the winding resistance is very low and the ferrite transformer core can be very compact. Multiple paralleled wires help reduce losses due to the skin effect, and are also easier to wind on to the bobbin. A packaged double-diode, D3a,b, rectifies the 5V supply at up to 20A. A smaller double-diode, D4a,b, delivers +12VDC, typically at up to 8A. Both of these diode packages are mounted on the second large heatsink, which is usually connected to the case and to mains earth. Further diode rectifiers produce the low-current -5V and -12V DC outputs, along with a low-current +12V operating supply for the controller. All of these diodes are high-speed Schottky rectifiers, and if any fail, they must be replaced by similar types. Ordinary rectifier diodes simply won't work - they cannot keep up with these high switching frequencies.

The output smoothing circuits are basically choke-input filters, although an unusual feature is that all the major output choke windings share the same toroidal core. L2a is the winding for the +5V output, and in a PC it will carry by far the largest current, so the other windings, L2b – L1d, are wound in the opposite sense to reduce the net magnetisation of the core. L3 – L6 and their associated capacitors provide further filtering. The high switching frequency means that none of the inductors needs to be large, and the smoothing capacitors can be very small, both physically and in terms of capacitance (compared with what you'd need to remove 100Hz ripple). However, these are electrolytic capacitors, so they do have a finite working lifetime and may eventually fail.



A practical modification for +13.8V DC output.

VOLTAGE REGULATION

Switch-mode power supplies are totally reliant on their control circuits to keep them from disaster – including disaster to the expensive equipment downstream. However, the control circuits are well developed and quite reliable. Most PC supplies of the age that I'm describing are based on the industry-standard TL494 controller, so look for the 16-pin DIL IC package (equivalents of the TL494 include the uPC494, IR3MO2, MB3759 and KA7500; the SG3524 is similar but has a different pinout). This IC stabilises the output voltage by driving the switch transistors Tr1 and Tr2 at just the right pulse width, and it also looks after the tricky startup and fault situations. Close to the TL494, you will often see an LM393 dual-comparator (or equivalent) in an 8-pin DIL package, and this is part of the fault protection.

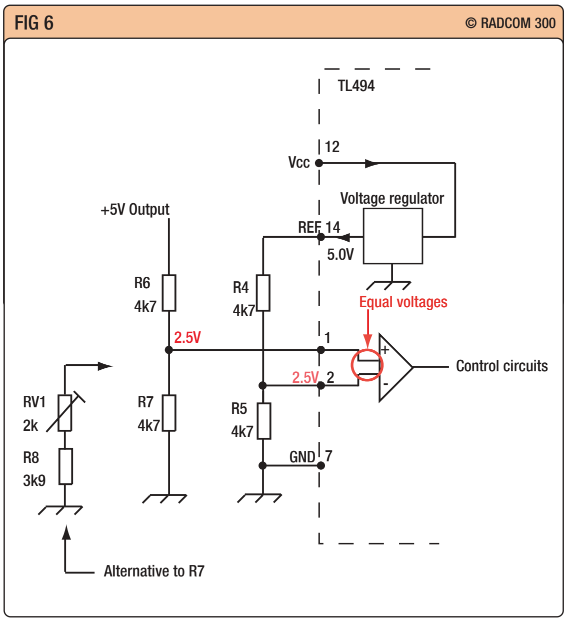
Although a PC supply has at least four different output rails, their voltages are not equally stabilised. The +5V output has the best stabilisation, because that rail is delivering the highest current, and it also has the greatest need for an accurate voltage. All the other output voltages are determined mainly by the transformer turns ratio, although the +12V output is also somewhat stabilised as described below. All of these outputs are derived by rectifying the same pulse-width-modulated waveform, so this means that the output voltages and currents will interact in quite a complex way.

To understand these interactions, we need to know how the TL494 stabilises the +5V output. As shown in **Fig 6**, the TL494 requires an unregulated supply of about +12V on pin 12, and an internal voltage regulator produces a +5.0V output at pin 14. This forms a local supply rail for various other functions of the TL494, one of which is to provide the reference voltage for the output voltage controller. This is based on a simple op-amp, exactly as you would find in a conventional 'linear' (non-switching) voltage stabiliser. The reference input (pin 2) is held at a constant voltage, derived from pin 14 through the voltage divider R4-R5. These two resistors are usually equal, so the reference voltage at pin 2 is +2.5V. The other input of the op-amp (pin 1) receives a divided-down sample of the regulated output voltage from R6-R7. As you probably know, an op-amp in a feedback circuit will always try to keep the voltages at its inverting and non-inverting inputs exactly equal. In this case, the TL494 achieves that goal by varying the width of the pulses that Tr1 and Tr2 deliver into T1, in such a way that the sample of the output voltage finally arriving back at pin 1 is exactly equal to the +2.5V reference voltage at pin 2.

In Fig 6, we have made R6 and R7 equal in value, so that the output voltage will be regulated to exactly twice +2.5V, ie +5.0V. If you want a different output voltage, simply adjust the ratio R6:R7 so that when this new output voltage is divided down, the voltages at pin 1 and pin 2 will still be equal. Most PC supplies include a small trimpot RV1 (shown as an alternative in Fig 6) so that the regulated output voltage can be adjusted up or down a little.

The +12V rail is usually regulated along with the +5V rail by sampling from both rails at once, as shown in **Fig 7**. Once again, the controller does whatever is necessary to maintain +2.5V at pin 1 – but this means that the two regulated outputs will interact. Neither is as well regulated as it would be on its own, and an increased current demand on one output will cause an unwanted *increase* in voltage on the other. Meanwhile the -5V and -12V outputs are at the mercy of changes on either one of the positive rails... but, fortunately, the PC can tolerate this. Marty Brown's *Power Supply Cookbook* (referenced last month) explains how the relative voltage stabilisation of the +5V and +12V rails is controlled by the ratio of the currents flowing through R9 and R10; the resistor delivering the greater current has the greater degree of control. In PC power supplies, the +5V rail requires the better stabilisation, so the current ratio between R9 and R10 is typically about 70:30%. Marty Brown also explains exactly how to calculate the resistor values - it's nothing more than Ohm's law.

In addition to the monitoring for voltage stabilisation, all four output rails are monitored for over- and under-voltage faults. There is also a little ferrite transformer that monitors the primary current of T1, to protect against the whole power supply being significantly overloaded. The 'Power Good' line is a shutdown input from the PC, but the PSU will run with this input disconnected. All of these protection functions are typically carried out by the LM393 comparator, a few discrete transistors and a handful of resistors, diodes and Zener diodes. The specific circuit details vary (which has serious implications if you want to modify the PSU for 13.8V DC output) but all fault signals eventually find their way to pin 4 of the TL494. This input overrides the normal voltage regulation loop, and can reduce the width of the drive pulses to Tr1 and Tr2 to a tickover. That will reduce all the output voltages, so a fault on any rail can cause the 12V DC fan to slow down or even stop. In extreme cases the supply will latch into a permanent shutdown state, which can only be reset by switching off the mains.



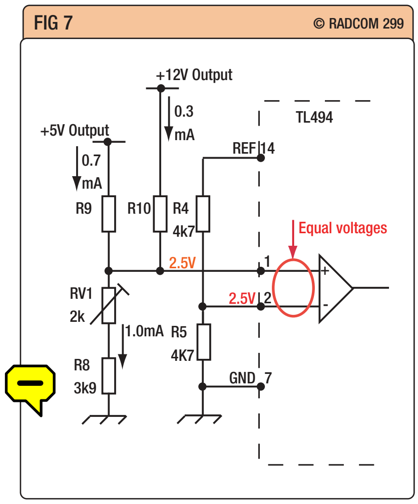


Fig 5: See Part 1, last month.

Fig 6: Voltage stabilisation using the TL494 or equivalent.

Fig 7: Stabilisation of both the +5V and the +12V rail.

SPARES AND REPAIRS

I have already pointed out that some of the components in these PSUs are unusual, and many of them are safety-critical. Don't expect to be able to replace them from your junk-box of normal electronic components - it can be dangerous to try.

By all means try to find a circuit diagram on the web; but the manufacturers of PC PSUs are very self-effacing, and often don't mention either their name or a model number on the label. Your next-best friend will be a stack of component catalogues, to identify the failed parts. Another alternative is to search for information on the web, using the part number and 'data' as keywords. It isn't always essential to find an exact replacement, but it takes some judgement and experience to identify a so-called 'equivalent' that will prove suitable in every important respect. And as I warned in Part 1, please try to retain some perspective about repairing these old PSUs. When brand-new replacement PSUs are so cheap, there is no point in spending more than a few pounds on repairs.

Fortunately, the components that are most likely to fail are also the easiest to identify. Part 1 explained that the most highly stressed components are mostly on the mains input side: BR1, C5, C6, Tr1 and Tr2. The diodes D1 – D4 also lead quite a hard life. Failure in the low-voltage and controller areas are relatively much less likely - which is just as well, because these circuits are much more difficult to troubleshoot. Remember that the PSU is a closed-loop control system, so if any part of it fails, you will see abnormal voltage and current indications *everywhere*. **Danger: Deep Hole!** If you jump to the wrong conclusion about where the fault is, you can easily create even worse problems by disturbing circuits that are actually perfectly OK. Until you have reasoned out exactly where the fault has to be, leave that soldering iron alone.

MODIFICATIONS

Despite these dire warnings about failures and repairs, PC power supplies are really very reliable. When the rest of the PC has reached the end of its useful life, you are quite likely to have a working PSU left over. It then becomes tempting to modify the PSU for other uses, especially to provide +13.8V DC to power your station.

The photograph shows some basic mechanical mods to the PSU that was pictured last month. Any respectable mod is going to need a mains switch, mains filter, 12-13.8V DC output connector and a permanent dummy load on the +5V output. On the PC board itself, the options range from minor changes to a near-total rebuild of the output side... but the detailed variations between different models of PSUs take such mods beyond the scope of a magazine article. I have created a follow-up page that provides further information, and has links to other useful sites:
www.ifwtech.co.uk/g3sek/smps

Beyond that point, you will have to make your own way, and I hope this article has given you a useful start. But even if you never do more than open the PSU to clear the dust out, you now know much more about what goes on inside.♦