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Switch-mode mains power

The first part of a two-part article explaining how to understand, repair and even modify, an old PC power supply.

FIG 1

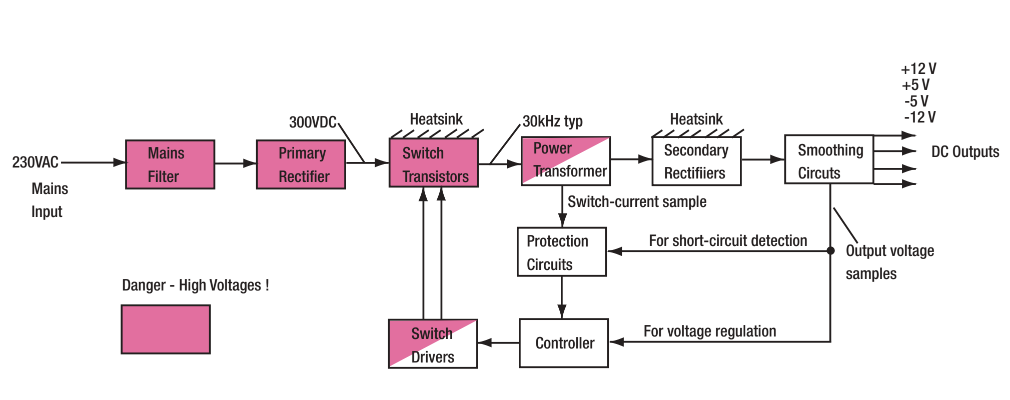


Fig 1
Electronic block diagram of a typical PSU for ATX-style PCs.

Switch-mode mains power supplies are smaller, lighter and often cheaper to manufacture than traditional 'linear' supplies that use a 50Hz mains transformer. But switch-mode supplies are also more complex and less familiar, so this article sets out to explain some of the mysteries. Out of the many different varieties, I will focus on one of the most common – the mains power supplies for ATX-style PCs from around the late 1990s. By then, the circuit design had evolved into predictable patterns, but the more recent complications of remote control and additional output voltages were only just emerging. Also, construction was still based on single-sided PC boards which are easy to work on. Once you have found your way around this particular type of PSU, you will be much better placed to understand the more complex modern variants.

First of all, a few sensible warnings. The insides of these PSUs are **dangerous**! Read the '**DANGER – HIGH VOLTAGE**' panel, and don't go in there unless you have the competence and the equipment to do it safely. Also be sensible about how you spend your time and money. The most frequently-needed repairs are not too difficult; but a shiny new ATX supply only costs about £20, so how much time and trouble is a broken-down box full of dust and dead spiders *really* worth? If it looks like being more than an evening's work, or might cost more than a few pounds to repair, then do yourself a favour: *force* yourself to throw the whole thing away!

This will be a two-part article. The first part will explain what's inside these PSUs, in enough detail to allow an experienced amateur to identify the parts that are most likely to need repair. The second part will move on to consider repairs in more detail, and the potential for conversion to produce a high-current output at 13.8V DC. Switch-mode PSU design is a vast subject, so I can only skim the surface. This article is based upon some very useful web links (see below), and for background I also recommend Marty Brown's *Power Supply Cookbook* which is available from the RSGB Shop.

THE BASICS

Welcome to the world of modern consumer electronics. Your PC PSU comes with no circuit diagram and no user manual, so you have to find your own way around. Some sections of the PSU are very simple, and are easy to repair or modify. Other sections only *look* simple, but in fact are deceptively clever. You will need to learn what you can reasonably work on, and what to leave well alone! Fortunately, the simple sections of the PSU contain most of the components that are likely to fail, and for the moment we can safely ignore the rest. However, some of the modifications described in Part 2 will require us to go into those more complex areas in more detail.

Fig 1 is a block diagram that applies to just about all switch-mode PC PSUs. The basic strategy is:

1. The 230V AC mains input is rectified and smoothed to develop about 300V DC on-load.
2. The power switch transistors chop the DC into an alternating waveform at about 30kHz. This high frequency allows the use of a tiny ferrite-cored power transformer, dramatically reducing the size and weight of the whole unit.
3. Rectify the multiple secondary voltages from this transformer. Thanks to the high frequency, only very small smoothing capacitors and a compact toroidal inductor will be needed.
4. Add the control and protection electronics needed to make everything work reliably. Switch-mode PSUs operate perpetually on the edge of disaster, and are totally dependent on their control circuits. Most of the tricky stuff has been condensed into a single controller IC, and the rest of the support electronics has converged towards an almost standard cookbook design.

The mechanical specification for the ATX format standardises the size of the PSU and the location of its mains input, fan and DC outputs. These standard mechanical requirements combine with the standard electronic block diagram (Fig 1) to make the internal layouts of all ATX PSUs very similar. There is very little choice about the size of the main PC board, or where the heat-sensitive components have to be placed in order to benefit from the cooling airflow from the fan. Although the component layout will vary in detail from one model to the next, you can expect to find almost the same major components in almost the same places. **Fig 2** shows a typical ATX PSU, and identifies the major features from Fig 1; almost all other models will be fairly similar.

THE MAINS SIDE

As Fig 1 shows, the function of the

supplies – part one

FIG 2 © RADCOM 284

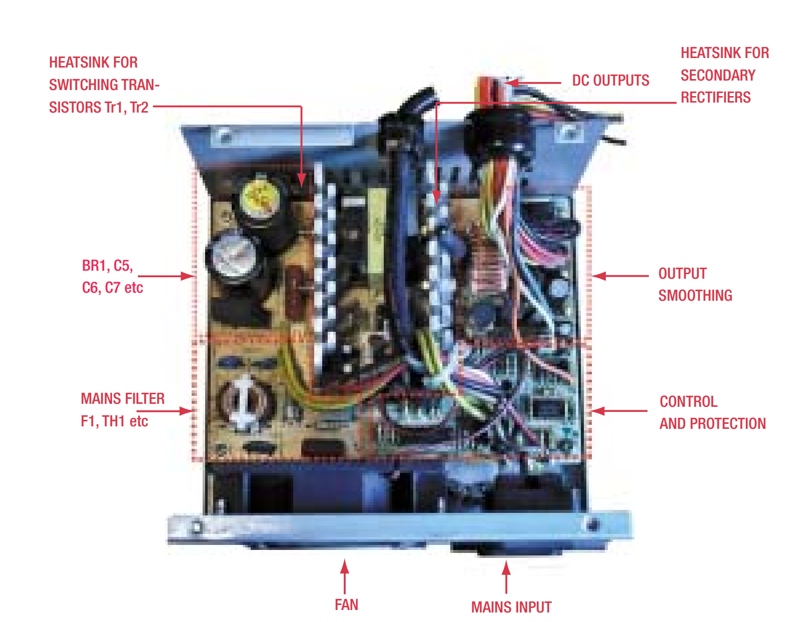


Fig 2
Major areas of a typical ATX PSU.

FIG 3 © RADCOM 286

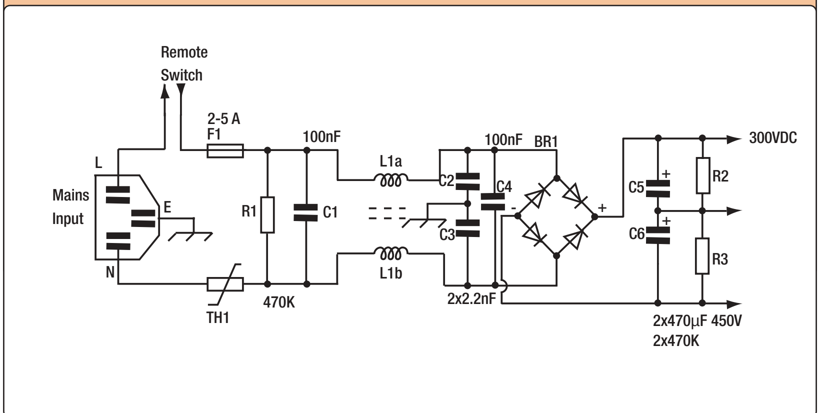


Fig 3
Outline circuit of mains input side. All component values are 'typical' only. All mains-connected components must be rated specifically for this service.

mains side of the PSU is to generate about 300V DC from the 230V mains, chop it at about 30kHz and then deliver it to the transformer. Don't forget that almost all this circuitry is 'live' and lethal - see '**DANGER – HIGH VOLTAGE**'.

Fig 3 is a typical circuit. This example shows the older, simpler type of mains switching; more recent supplies are remotely controlled to power-up 'on demand'. The mains filter is mostly to prevent unwanted switching transients from escaping back from the PSU into the mains. The double-wound filter inductor L1a,b will either be a toroid or it may look like a little rectangular transformer. The PSU case is connected to the mains earth, and the filter capacitors C2 and C3 are typically connected to that same earth by the nearby PCB mounting screw. This is the *only* earth connection on the mains side - everything else is 'live' and must *not* be

DANGER – HIGH VOLTAGE

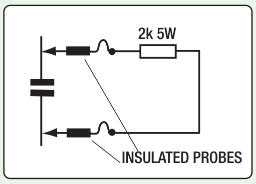
These power supplies can kill you! The label on the box is absolutely right to warn you against removing the cover - because when you do, everything inside is unprotected, and much of it is potentially lethal.

Before you start doing anything, switch off the mains and unplug the PSU from the mains as well. Always put two definite open-circuits between yourself and the mains. Why two? Because, however hard you try, sooner or later you will forget one of them - and the penalty for this should not be death. If the PSU has an on/off switch, that does not count as one of your safety switches!

Having switched off - in two places - then be patient and wait for the high voltages to decay. Be aware that the discharge time constants on the high-voltage capacitors are always very long, and the bleeder resistors could have gone high-resistance or open-circuit. Always discharge these capacitors yourself, using a discharging resistor with insulated probes like the one shown below. Hold the test probes onto the capacitor terminals for a slow count of five, and then confirm successful discharge by shorting across the terminals with a screwdriver.

If the power supply is faulty, use a light bulb connected in series with the mains to limit the current - see 'In Practice' for March and May 1999.

If you absolutely must work on the low-voltage control circuits of a live PSU, add insulation and pieces of cardboard etc to prevent accidental contact with the dangerous parts. Always use insulated test probes, and still never touch any part of the unit directly until you have switched off - in two places, remember - and discharged the high voltages.



Capacitor discharging resistor.

FIG 4 © RADCOM 287

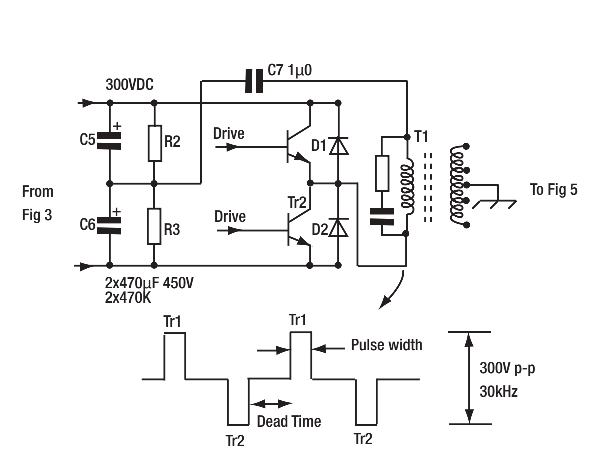
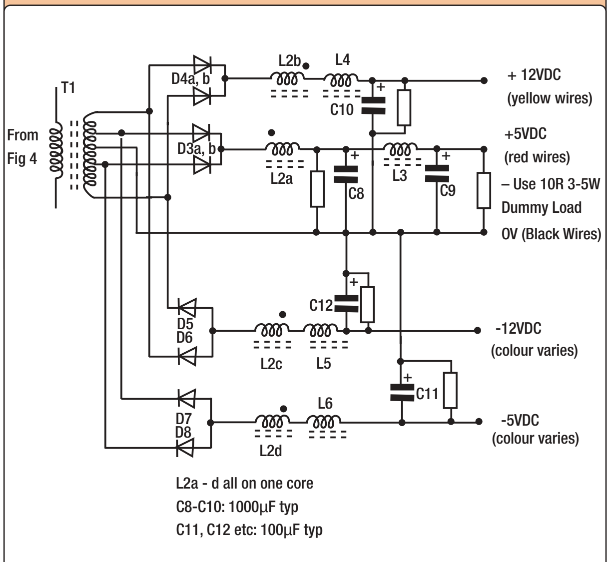


FIG 5 © RADCOM 289



earthed! There will always be a capacitor C1 connected directly across the mains on the input side; capacitor C4 on the output side may not be present, although some boards may have a place for it. A bleeder resistor, R1, may be provided to discharge these capacitors. TH1 is a thermistor surge suppressor and F1 is the mains fuse. All the components described so far are specially rated for direct connection to the mains. If you have to replace them, you *must* use components with those same ratings (selected carefully from a catalogue, or at least salvaged from the same location in a very similar PSU).

BR1 is a packaged bridge rectifier that feeds the two reservoir capacitors, C5 and C6. Two capacitors are used in series, to provide a voltage-doubler option for 115V mains (for 230V operation, you can completely remove the leads to the voltage selector switch) and also as part of the half-bridge switcher - see below. Note that the bleeder resistors, R2 and R3, are a very high value: the time-constant of 470µF x 470kohm is 221 seconds, so it can take several minutes for the voltage to decay to safe levels. C5 and C6 have a very hard life in terms of the voltage stress and the internal heating due to the AC ripple current, and all electrolytic capacitors have a finite rated lifetime which is much shorter at elevated temperatures. To extend the working life of the whole PSU, periodically remove the cover and use a small paintbrush to clean all the accumulated dust out of the case and the fan. This will help enormously to keep all the components cool in operation.

Fig 4
Simplified power switch circuit, showing primary waveform of T1. 300VDC is converted into 300VAC p-p at about 30kHz.

Fig 5
Simplified output rectifiers and smoothing (see Part two).

Electrolytic capacitors are actually *designed* to burst open if they fail short-circuit, either by splitting along the lines scored in the end of the aluminium can, or by popping the insulating cap off the other end. F1 and TH1 will avoid the worst of the violence - which is why you should *never* replace F1 with a slow-blow fuse, or one with a higher current rating. If one of these two smoothing capacitors fails, *always* replace them both with a new pair, selected for the same capacitance and at least equal ratings for voltage and ripple current. If an electrolytic fails short-circuit, the current surge is more than likely to short some of the diodes in BR1, so you'll probably have to replace that too. BR1 can also fail on its own, often due to a large mains spike exceeding the peak inverse voltage limit, and again almost always resulting in a near-short. If you suspect a shorted diode in BR1, look first for a hole in the side of the plastic package - it'll save you the trouble of using an ohm-meter.

Fig 3 showed the bare essentials of the circuit. You may also find surge limiters between BR1 and the smoothing capacitors, and small chokes and/or bypass capacitors for interference suppression. Some PC boards have provision for these, but they're not always installed.

The second reason for using two reservoir capacitors in series is to form part of the half-bridge switching circuit, **Fig 4**. Like C5 and C6, Tr1 and Tr2 are connected in series across the 300VDC supply. The controller IC supplies a train of pulses to switch-on Tr1 and Tr2 alternately at about 30kHz, through a small ferrite-cored driver transformer to provide DC isolation between the controller and the transistors themselves. This switching action connects the lower end of the primary of T1 alternately between two different points: the bottom end of C6, and the top end of C5 which is 300V higher. Meanwhile the upper end of T1's primary is connected via C7 to the mid-point voltage between the two capacitors. This means that the direction of current through the primary is being continually reversed, so 300VDC has been converted into ±150VAC at the switching frequency of about 30kHz. The actual waveform in the T1 primary is quite complex (Fig 4), because the controller varies the pulse width that controls the 'on' times of Tr1 and Tr2, with the aim of keeping the final DC output voltages constant in spite of varying current demands. The greater the current demand, the longer the 'on' times become; in effect, the controller varies the pulse width to let through just enough electrical energy to keep the output voltage constant. The controller also has to keep the durations of the positive and negative half-cycles equal, because any inequality would result in a net DC component appearing across the primary. Important: this kind of power supply *always* needs a load on the output, so that the width of the drive pulses is always inside the range that the controller can handle. When testing a PSU outside of the PC, you *must* use a dummy load of about 10Ω (3 – 5W) on the +5V output.

The switching transistors Tr1 and Tr2 are identical bipolars or MOSFETs. In PSUs of Far Eastern origin, bipolar transistors typically have Japanese-style numbers beginning with 2SC (which may be abbreviated to just C-something on the package itself), while MOSFETs typically have either BUZ- or 3SK-numbers (abbreviated to K-). Bipolars are more common in older, cheaper PSUs as shown in Fig 4. These devices are mounted on the large heatsink nearest to C5/C6, using special silicone insulating washers that do *not* need thermally conducting grease. **Warning: never touch this heatsink**! It is not earthed, and is usually allowed to float to whatever voltage it wishes. Even when the PSU is switched off, this heatsink can be at a dangerous voltage - especially if Tr1's insulating washer has failed.

Like most of the components on the mains side, Tr1 and Tr2 have to work very hard. Keeping the temperature down by periodically cleaning out the dust will greatly reduce the risks of catastrophic failure. An ohm-meter test between emitter and collector of Tr1 or Tr2 should show low resistance in one direction and much higher resistance in the other. If you measure a near-short in both directions, you'll need to replace the transistor and maybe also the protection diode D1 or D2. See later for suggestions about ratings and replacements. ♦

REFERENCES

Power Supply Cookbook by Marty Brown (RSGB Shop). All other references are on the web - see the 'In Practice' website.