VK Powermate 25

Here is the highest power 13.8V DC supply we have described to date. Featuring a 25 amp continuous current rating, with a peak capacity of 35 amps, it it capable of running transmitters and amplifiers in the 100-150W class. It is fully protected with both foldback current limiting and an over-voltage crowbar circuit.

by MARK CHEESEMAN

The need for a reliable source of DC power in any amateur shack has been around for as long as amateurs have been transmitting radio waves into the ether. When vacuum tubes were universally used in transmitter finals, this supply needed to produce anything up to a few thousand volts, depending on output power, with current ratings of typically much less than one amp. This formed the plate supply to the output 'bottles', and in the case of integrated transceivers, was incorporated into the rig itself.

The advent of cheap semiconductors for RF amplification resulted in radically different power supply requirements. Instead of the potentially lethal voltage required by valve finals, solid-state output devices require a much lower voltage DC supply, with a corresponding increase in current requirements. While some transceivers did (and still do) incorporate this DC supply into the main cabinet, it is more common these days to make the DC supply an external entity.

The advantages of this are pretty apparent. The rig can be built into a more compact enclosure, and the heat dissipation is also greatly reduced. By choosing a supply voltage of 13.8V, and taking advantage of the smaller enclosure made possible by the omission of the internal power supply, the rig could be used 'mobile', even in today's smaller Japanese cars.

Another advantage which may not be immediately obvious is that with an external supply, the one power source can be used to power several rigs simultaneously, on the assumption that generally only one is being used to transmit at any one time – the receive current drain being much less than that on transmit.

Design aspects

There are several ways in which the AC mains may be converted into the required DC potential. One technique is to use a switching power supply, of the kind commonly used as computer power supplies. While such supplies are very efficient, they tend to have a rather noisy output, requiring a fair amount of filtering to reduce the noise to acceptable levels for powering sensitive receivers, such as those encountered in amateur communications.

The other significant problem, which rears its ugly head all too often in projects designed to be constructed by readers of *EA*, is that of parts availability. Switching power supplies require the use of special high-frequency transformers, which are difficult (read expensive) to source in small quantities.

One variation on the switching supply is the switching regulator. This makes use of a conventional transformer, rectifier and filter, and uses switching techniques to convert the unregulated DC supply to the desired voltage. This still has the problem of output noise, and the more one tries to reduce this noise, the more the efficiency tends to suffer.

This brings us back to the tried-and-true linear series regulator configuration, as used in many power supply projects which we have published over the years. While their efficiency is nothing to write home about, linear regulators do have a very clean output, so as not to swamp that weak QRP signal from the other side of the globe.

Electronics Australia's most popular 13.8V power supply has no doubt been the VK Powermate, first described in May 1978, and updated twice, most re-

cently in October 1988. It provided a steady 13.8V at up to 5A, or more if two output transistors were used.

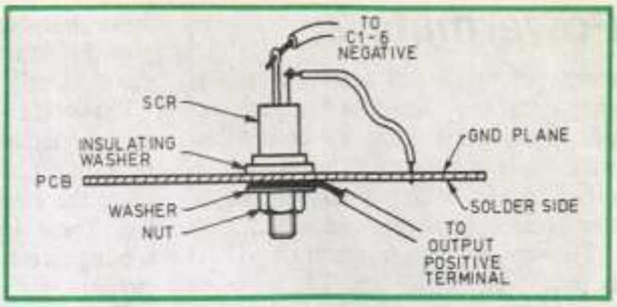
More recently, the VK Powermaster supplied a continuous 14A, with a peak capability of about 25A. However, a typical 100W transmitter or amplifier required around 20A on transmit, and if high duty-cycle modes such as FSK or FM are being used, this current can be drawn from the supply for a considerable period of time, causing overheating of the power transformer.

The new VK Powermate 25, as the name implies, is capable of supplying 25 amps on a continuous basis, with a peak capacity of 35A. This is more than enough to supply an active transmitter and a couple of other rigs on receive.

In common with all previous Powermate designs, the Powermate 25 is based around the LM723 regulator. This chip provides a temperature-compensated voltage reference, error amplifier and current limiting circuitry in a single package. A minimum of external components are required to build a complete power supply.

The mains input to the supply passes through a 3A slow-blow fuse (FS1), and then through a double-pole illuminated switch to the primaries of the two transformers. A slow-blow fuse is necessary to stop the initial inrush current of the capacitor bank from blowing the fuse.

Two transformers are used to provide the necessary current capacity at a reasonable cost. We found that a custom-made transformer of the required capacity would cost more than the two off-the-shelf items added together!



Mounting details for the SCR used as an over-voltage crowbar. As it only conducts briefly in the event of a fault, it is mounted directly on the PCB as shown.

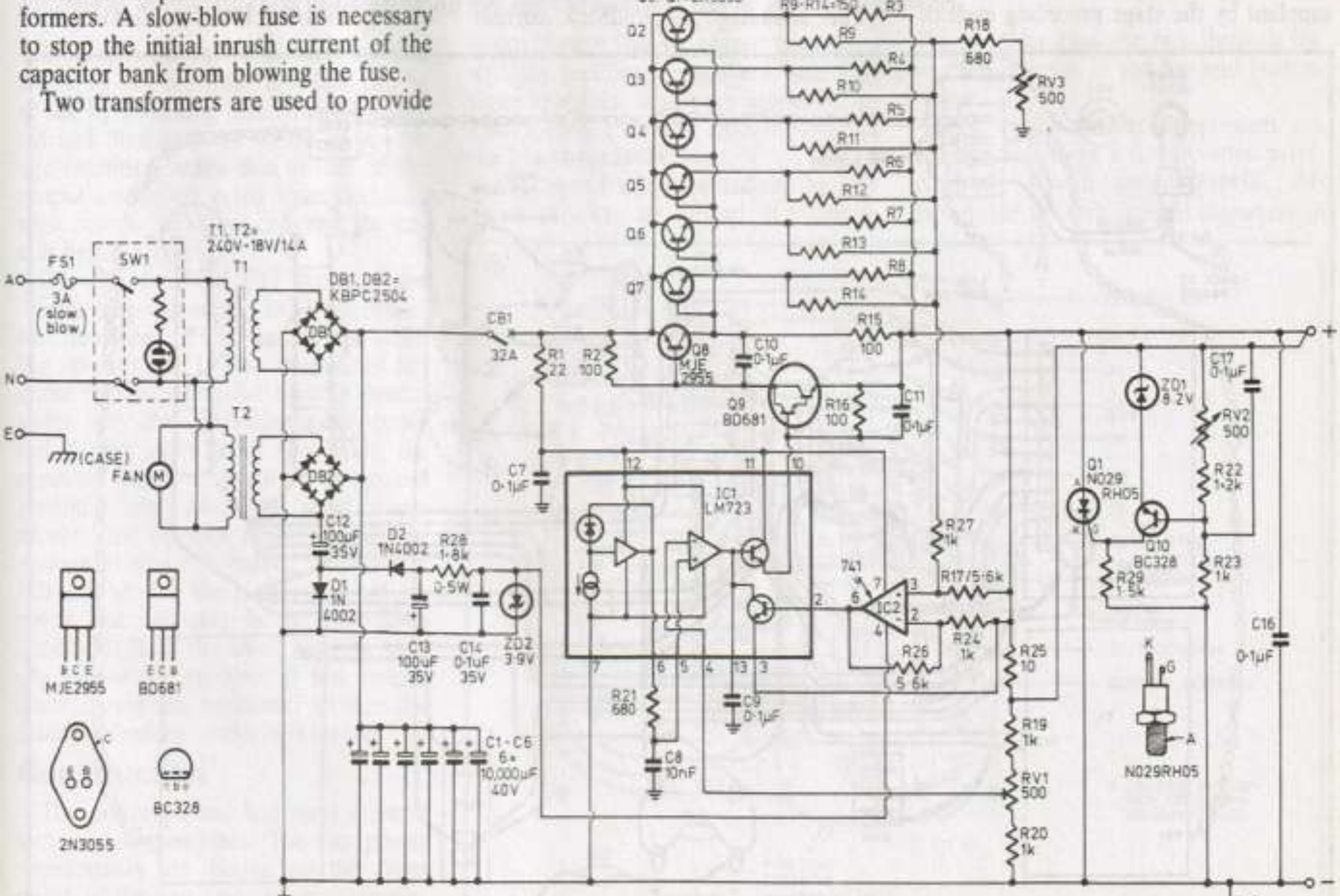
The resulting low voltage AC is rectified by two 25 amp bridges, one for each transformer. The use of two bridges rather than one is done for two reasons. One is to prevent a circulating current resulting from slight differences in the two transformers, which would waste current capacity.

The other reason is that each bridge only has to carry half the total current, reducing stresses in these components. Indeed, we managed to destroy a single 35A bridge early in the development of the project, although it was only carrying an average current of 25 amps at the time.

In practice, the current-sharing scheme works quite well, with the two transformers and bridges sharing the total current within a few percent.

Six 10,000uF (10mF) electrolytic capacitors serve to filter the raw DC from the rectifiers, so that the regulator does not drop out (lose regulation) between voltage peaks. Such a capacitance presents a very low impedance to the transformers and bridges when the supply is initially switched on. In fact, depending upon the exact time in the half-cycle that the mains switch is closed, the initial peak value of this current can easily reach several hundred amperes!

This current settles down within a



The complete circuit for the supply, which uses twin transformers and bridges to share the load.

couple of half-cycles as the capacitors charge up, and the stresses in each rectifier are lower than would be the case with a single rectifier. This is yet another benefit arising from the use of two bridges rather than one.

The supply to the regulator chip (IC1) is decoupled via R1 and C7, to lessen the chances of a feedback loop appearing through the supply, which could result in instability. The internal reference voltage is connected to the non-inverting input of the error amplifier via R21, with C8 ensuring a low impedance at high frequencies.

The inverting input of this amplifier is derived from the output of the supply, via a resistive voltage divider formed by R19, RV1 and R20. The output of the error amplifier drives a transistor (also internal to the IC), which in turn provides base current to Q9, a BD681 darlington. This transistor then controls the base current of Q8, an MJE2955. This long chain of command enables the 723 to drive the bases of the output transistors (Q2-7).

Resistors R2, R15 and R16 ensure that their respective transistors turn off when they are supposed to, as the drive supplied by the stage preceding each of those transistors is only capable of providing current to turn the next transistor on, not off.

The emitters of the output transistors are connected together via 0.1 ohm resistors, to ensure that the transistors share the total current as well as possible. These resistors also serve as the sensing elements for the current limiting circuitry.

The operation of the current limiting circuitry used in this supply is known as *foldback* limiting, because under short-circuit conditions, the output current drops back to a level well *below* the maximum current capacity of the power supply under normal operating conditions.

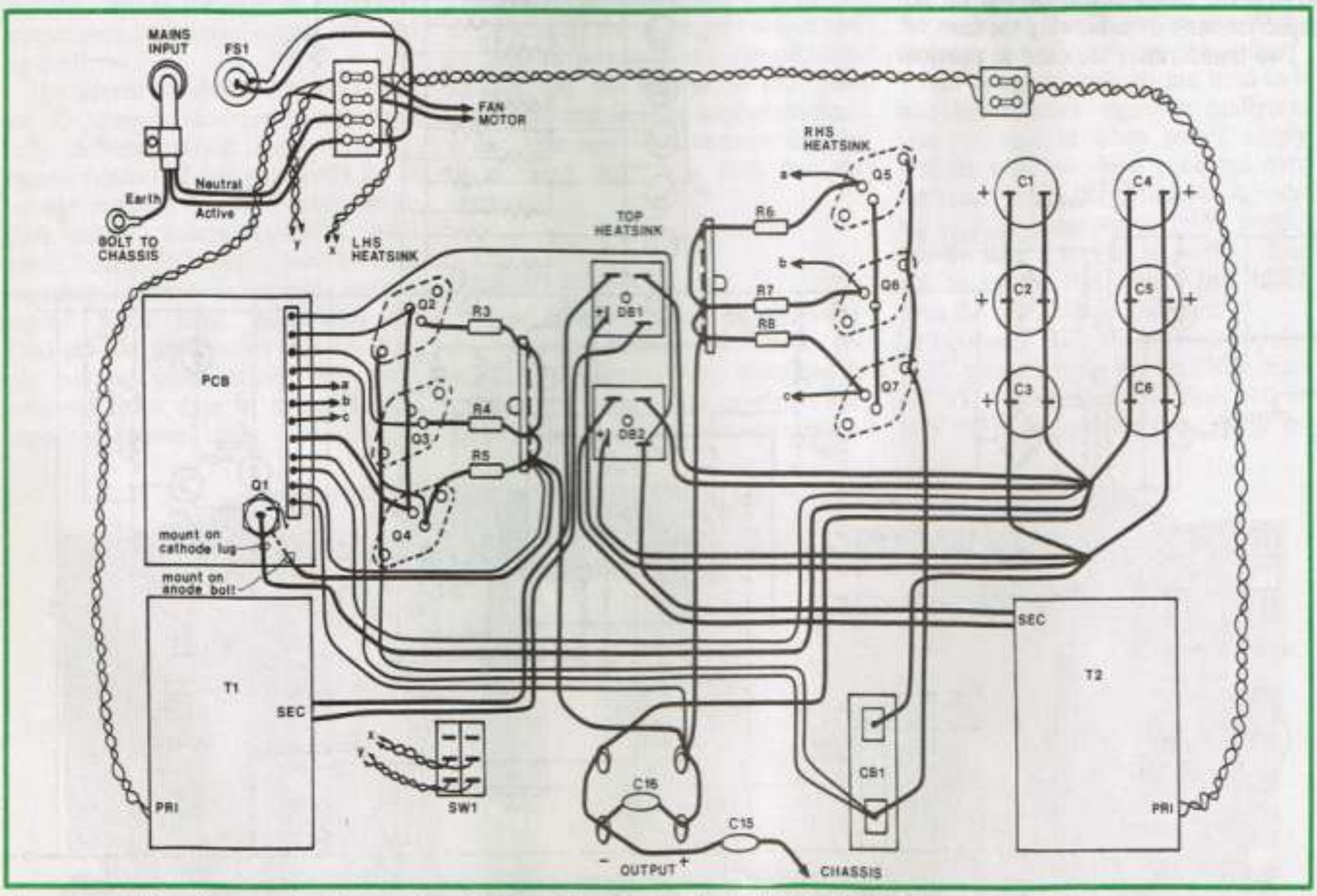
The reason for this is that, under short-circuit conditions, the full unregulated supply voltage appears across the output devices, and if the current is limited only to the maximum current capacity of the supply, the power dissipation in the output transistors would fall outside their safe operating area, resulting in their premature demise. With foldback current limiting, the short-circuit current drops to about 5 amps, so that the dissipation in the output transistors is contained within acceptable limits.

The advantage of foldback current limiting over other forms of protection such as an over current cut-out is that, once the overload condition is rectified, the supply returns to normal operation without further intervention on the part of the operator.

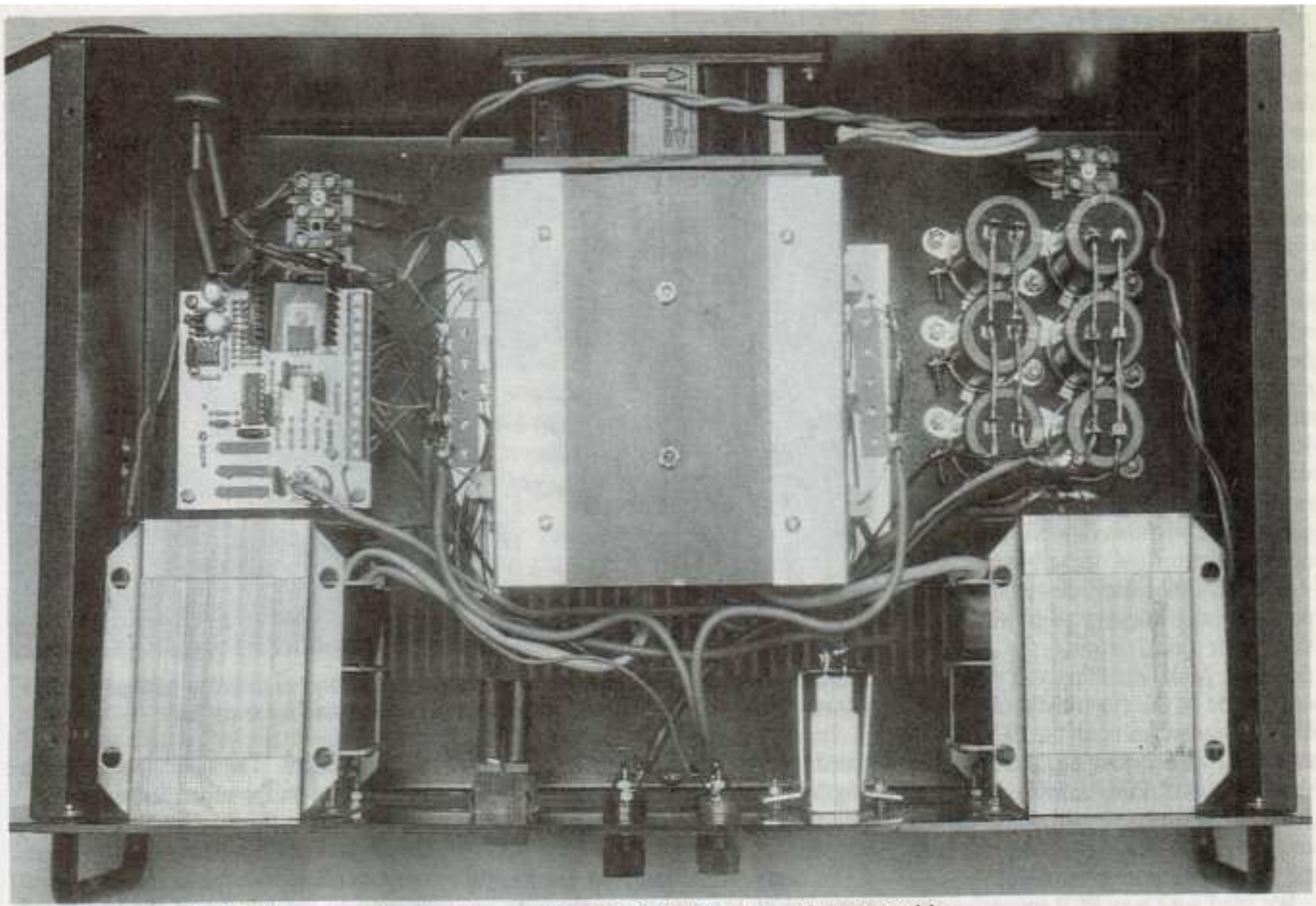
Resistors R9-14 effectively sum the individual voltage drops across the current equalising resistors, thus ensuring that the current limiting circuitry's effectiveness is not compromised by the failure of a single output transistor. IC2 serves to increase the sensitivity of the current limiting transistor in the regulator IC1 (the one with its base connected to pin 2). If this were not done, the best that could be achieved would be a short-circuit current of about 25 amps.

In the unlikely event of the output voltage rising above a pre-set limit, the load is protected from damage by a 'crow-bar' circuit, comprising Q1, Q10 and associated components. The output voltage is connected to a voltage divider, formed by RV2/R22 and R23. Zener diode ZD1 provides a reference voltage, and when the voltage across RV2 and R22 exceeds the Zener voltage by about 0.6 to 0.7 volts, the transistor turns on, triggering the SCR (Q1) into conduction – which short-circuits the output.

At this point, the foldback current limiting will come into play, limiting the



The main wiring diagram for the supply, showing all wiring not handled by the PCB.



An overall shot inside the case, showing the central heatsink tunnel and fan assembly.

short-circuit current to around 1.5 to 2 amps. In this case, the 'crowbar' can be re-set by switching the circuit breaker off and then back on. If the over-voltage condition arises due to one of the output transistors going short-circuit, a high current will flow, tripping the circuit breaker again.

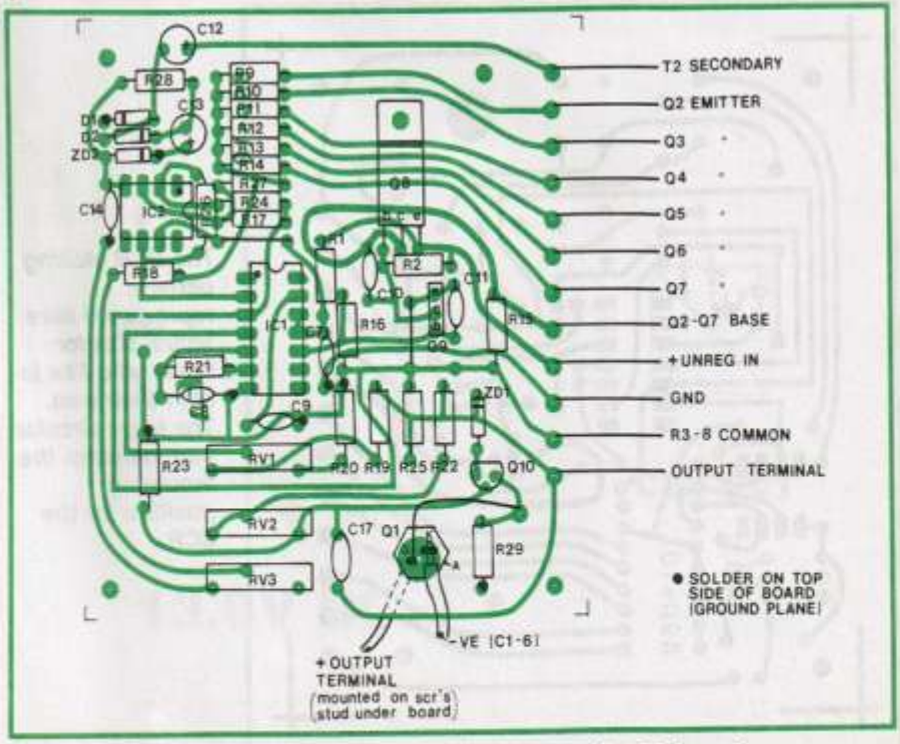
D1, D2, C12 and C13 derive a low current negative supply rail from one of the transformers, for the current limiting op-amp (IC2). This is required because the output of the op-amp cannot swing very close to its negative supply rail. Under short-circuit conditions, the positive output terminal is at ground potential, and when the short is removed, the op-amp cannot swing low enough to turn the limiting transistor in IC1 off, so that the supply will not recover, but will stay in the shut-down condition. With the small negative supply rail to the op-amp, it has proper control over the transistor, so that the foldback limiting works as it should.

Construction

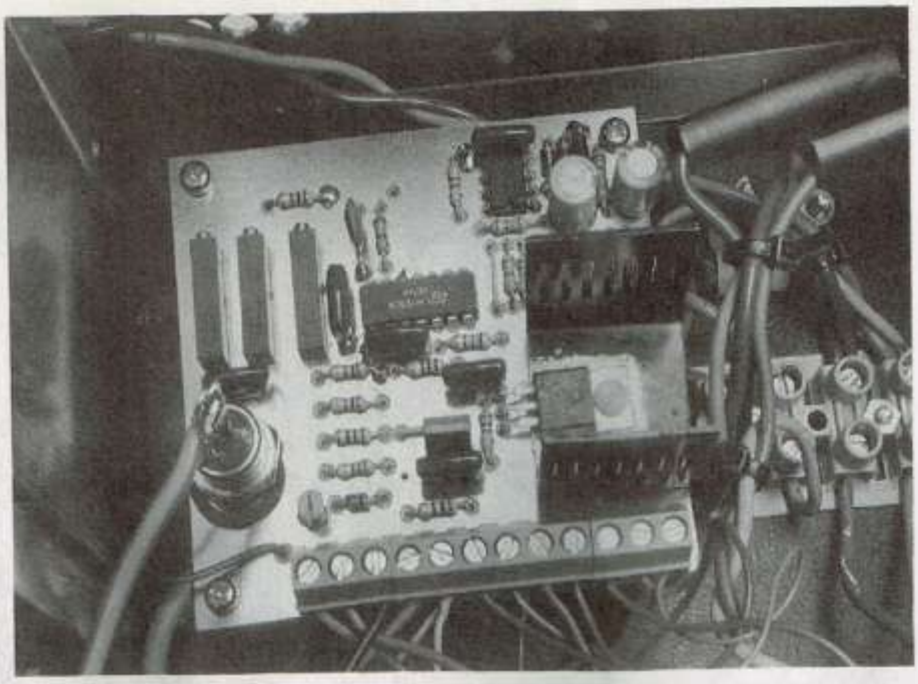
The prototype was built into a 3-unit rack mounting cabinet. The two power transformers are bolted to the front panel of the box, one in each corner, with the mains switch, circuit breaker and output terminals accommodated between them. The six output transistors and the rectifier bridges are bolted to three heatsinks, which are assembled to form a tunnel, running from the back of the box towards the front.

A 120mm fan is mounted on the rear panel, to force air through the tunnel. The air then exits the box through the ventilation holes in the top and bottom panels.

Most of the smaller components are accommodated on a double-sided printed-circuit board, coded 89ps10. Although the artwork printed elsewhere in



Use this overlay diagram to guide you in wiring up the PC board.



A close-up of the assembled PCB inside the supply, to provide further help in wiring it up. Note that the board has a ground plane layer on top.

this article implies only a single-sided board, the top side of the board is used as a ground plane, to provide a safeguard against RF energy – which tends to find its way into everything in a typical amateur shack.

If you are constructing your own board, the top layer is not etched at all (it should be covered fully with resist when etching the other side). When the board has been etched and drilled, the copper around the holes on the top side of the board should be removed with a large drill, so that the component pins do not touch the ground plane. The exceptions are those holes which are marked on the overlay as being soldered on both sides of the board.

Begin by mounting the smaller components, and working your way up to the larger ones, leaving the two ICs until last. Make sure that you watch the orientation of the electrolytic capacitors, diodes, transistors and the ICs. Q8 is mounted on a U-shaped heatsink, and should be electrically insulated from it. An appropriately shaped mica washer and a nylon bolt are probably the easiest way in which to achieve this.

We used a 12 way PCB-mounting terminal strip to bring all external connections to the board, although this may be considered optional, with the wires being soldered directly to the board. PCB pins are not recommended, as it is too easy to get shorts to the ground plane. Leave the SCR (Q1) off the board for the moment, although a small length of wire should be attached to the pad to which the gate will ultimately connect.

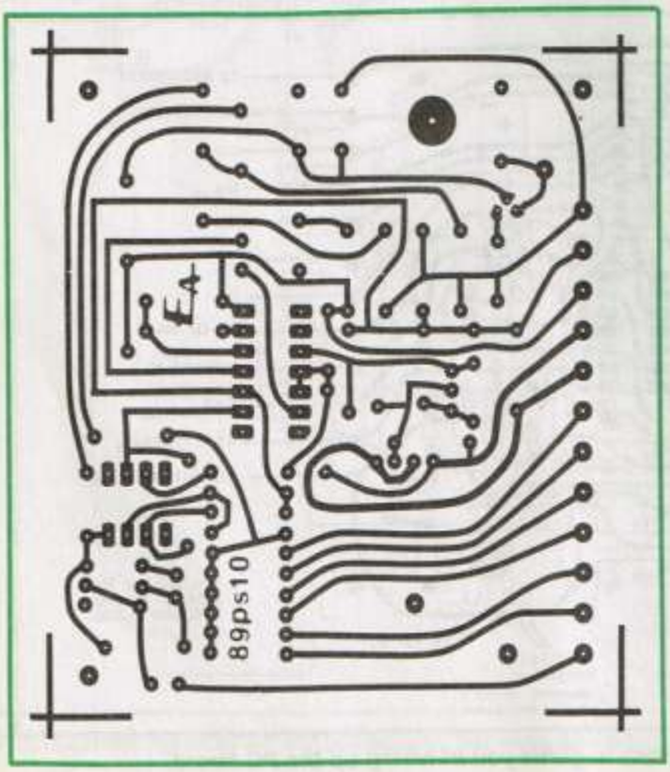
The best place to start the mechanical assembly of the power supply is to assemble the heatsink tunnel. Three 'fan' cross-section heatsinks 135mm long were used on the prototype, two for the output transistors, while the third cools the rectifier bridges. Drill the transistor heatsinks so that the three transistors on each are equally spaced along the length of the heatsink. The same applies to the two bridges on the other heatsink.

However, before actually mounting the semiconductors on the heatsinks, arrangements to bolt the heatsinks together, and to the bottom of the box, need to be made. We used four 135mm lengths of 25 x 25mm angle aluminium. One of these is to mount each of the transistor heatsinks vertically on the bottom of the box, and the other two attach the rectifier heatsink to the other two, forming the top of the tunnel.

Two tag strips are also attached to the tunnel, one on each side, above the central transistor on each of the vertical heatsinks, and the holes for these should be drilled at this point also. Now bolt the transistors to their heatsinks, making use of insulating washers and liberal amounts of heatsink compound. Heatsink compound should also be applied to the two rectifiers, but as they are isolated from their cases, insulating washers are not necessary here.

Now the tunnel may be put together – not forgetting to mount the aforementioned tagstrips at the same time. Before putting the tunnel assembly aside, a 0.1 ohm 5W resistor should be soldered between the emitter of each of the transistors and one of the tags on the adjacent tag strip (not the centre one, though!). Using a multimeter on its ohms range, check that all of the transistors are indeed isolated from the heatsinks.

The rear panel is home for three components – the mains input cable, the associated fuse, and the cooling fan.



The PCB etching pattern, reproduced here actual size for those who like to etch their own. The large circular pad indicates the mounting position for the SCR.

The holes for the first two should be drilled in the lower right-hand corner (when looking from the outer side of the panel), allowing adequate clearance around them for safety and ease of assembly. The fan is mounted so as to line up with the ultimate location of the heatsink tunnel, and should be tackled next.

A good template for the fan mounting holes is the finger guard which is supplied with it. The bottom edge of the fan should just rest on the bottom of the box, and it should be centered in the left-right axis. Once this is completed, the fuse and fan may be fitted in place. Also insert a rubber grommet in the hole intended for the power cord.

The front panel should be tackled next. The two power transformers are mounted as close to the front corners of the box as possible, and are mounted centrally between the top and bottom edges of the panels. We used 4BA cheese head screws, spray-painted black before mounting, to secure the transformers to the panel.

Before finally mounting the transformers, the holes for the rest of the components on the front panel should be cut. A photocopy of the front panel artwork is useful here, taped so that it lies in the centre of the panel, both vertically and horizontally. Two holes need to be drilled, one each side of the circuit breaker cut-out, and countersunk to accommodate 6BA screws.

Once this is completed, two countersunk screws should be inserted in the holes and held in place with tightly secured nuts. Finally, the stick-on front panel may be put in its final position, and the holes in it cut out with a sharp art knife.

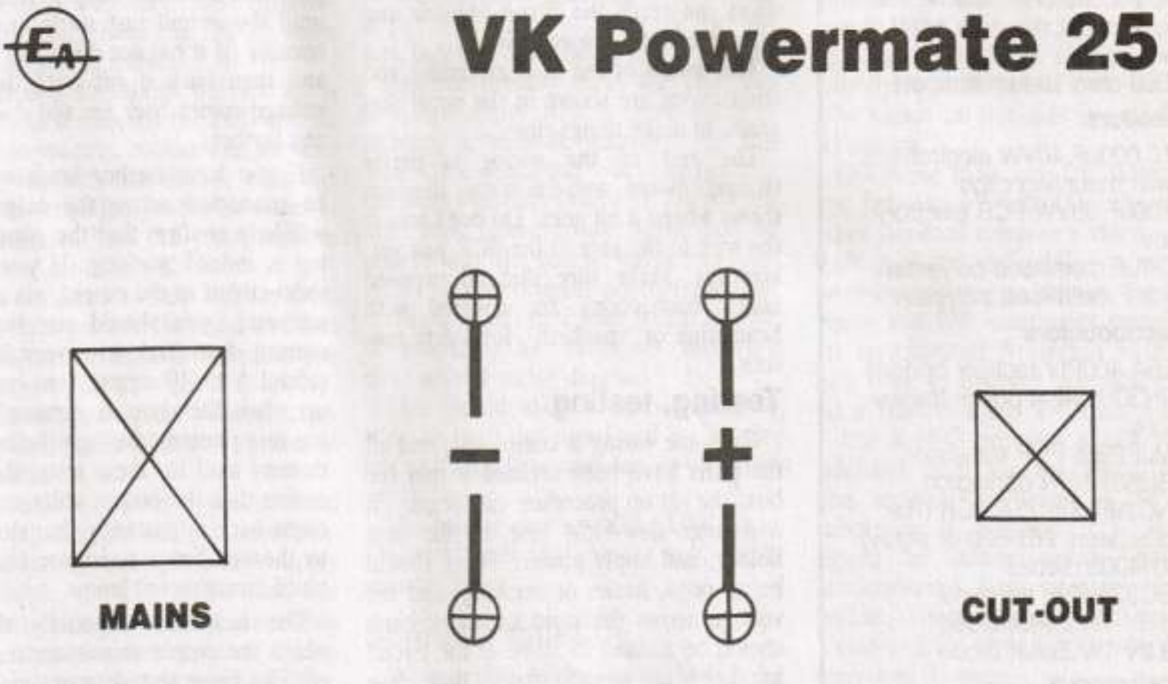
The power switch simply snaps into its hole, secured by moulded-in 'fingers' on each side. The circuit breaker, however, is a little more difficult, as it is not designed for mounting in this way. We fashioned an aluminium 'U' bracket to hold the breaker against the front panel, using the two screws mounted earlier on. Wrap a bit of insulating tape around the bracket to prevent it shorting against the terminals of the breaker.

Now mount the two transformers, so that the secondary connections emerge from the edge closest to where the heatsink tunnel will be located. Before assembling the box, holes should be drilled into the bottom panel, using the internal photographs as a guide, to support the six capacitors, the PCB, the two terminal blocks and the mains cable clamp. Try to separate the mains components from the PCB as much as possible. Also drill the mounting holes for the heatsink tunnel, so that it is as close to the fan as possible, without actually touching it.

Now, the side panels may be attached to the front panel (at the same time, securing the handles to the box), followed by the rear and bottom panels. The stand-off insulators for the PCB may be put in place at this point too. Temporarily mount the board on top of these, and mark out three holes in the side panel to allow easy adjustment of the trimpots later on. Make sure that you remove the board before drilling, just in case the drill bit 'grabs' on the way in.

Wiring

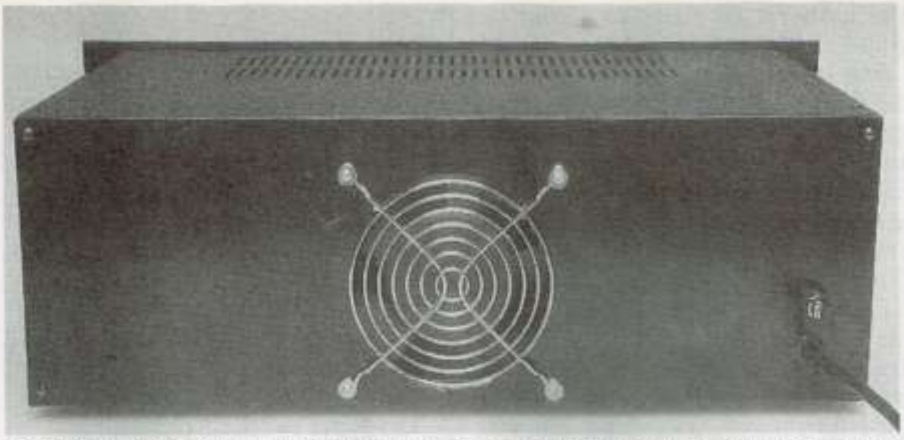
There is a fair amount of wiring in the power supply, which should be tackled next. We used 2.5mm^2 (16 amp) building wire for the high current connections. The transformers have just



The front panel artwork, again reproduced actual size.

enough cable length to reach the rectifiers, and the cables are already terminated in spade connectors, ready to push onto the AC terminals of the bridges.

The six capacitors are mounted in the rear right-hand corner of the box, and connected in parallel with bared 2.5mm² wire, so that the common connections for the bank of capacitors are between the two front-most capacitors. Heavy wire is then used to connect the appropriate terminals of the capacitors to the two bridges, before the heatsink tunnel is finally secured in place.



The rear of the supply, with the cooling fan grill in the centre and the mains cord entry at lower right.

PARTS LIST

1 PCB, 80 x 75mm, coded 89ps10
1 3 unit rack mount box (DSE H-2481 or equiv)
2 18V/14A transformers (DSE M-2010 or equiv)
1 32A circuit breaker (GEC 'Super Switch' or equiv)
1 DPDT illuminated rocker switch
1 4-way mains terminal block
1 2-way mains terminal block
1 3AG fuseholder and 3A slow-blow fuse
1 120mm cooling fan
4 Heavy duty binding posts (2 red, 2 black)
1 Mains cord and plug
3 135mm lengths of 'fan' cross-section heatsink

Resistors

All 1/4W 5% unless noted:
6 x 0.1 ohm 5W, 1 x 10 ohm, 1 x 22 ohm, 3 x 100 ohm, 6 x 150 ohm, 2 x 680 ohm, 5 x 1k, 1 x 1.2k, 1 x 1.5k, 1 x 1.8k 1/2W, 2 x 5.6k
3 500 ohm 10-turn trimpots

Capacitors

6 10,000uF 40VW electrolytics with mounting clips
2 100uF 35VW PCB electrolytics
8 0.1uF metallised polyester
1 10nF metallised polyester

Semiconductors

2 25A 400PIV rectifier bridges
6 2N3055 NPN power transistors
1 MJE2955 PNP transistor
1 BD681 NPN darlington
1 NO29RH05 25A SCR (Radiospares 261-520 or equiv)
2 1N4002 diodes
1 BC328 PNP transistor
1 3.9V 1W Zener diode
1 8.2V 1W Zener diode

Miscellaneous

Heatsink compound, cable clamp, cable ties, heavy duty hookup wire, hookup wire, insulating washer for SCR, aluminium angle, scrap aluminium sheet, nuts and bolts, etc.

Two lengths of heavy wire should also be attached to the SCR, as it is mounted on the PCB. The anode (bolt end) of the SCR is connected by simply wrapping the bared end of the wire around the bolt (under the PCB) before the nut is tightened. Make sure that the strands of wire do not touch any tracks on the board though. Leave enough length so that the anode and cathode wires can reach the circuit breaker and capacitor bank, respectively.

The details of the SCR mounting and connections are shown in the small diagram, to make things clear.

The rest of the wiring is pretty straightforward, and the wiring diagram shows where it all goes. Do not connect the wire to the gate of the SCR just yet, however. Make sure that all exposed mains connections are covered with heatshrink or 'spaghetti', for safety reasons.

Testing, testing

Once the wiring is completed, and all the parts have been secured within the box, the set-up procedure can begin. Fit a 3 amp slow-blow fuse to the fuse holder, and apply power. There should be no pops, fizzles or smoking, and the voltage across the main capacitor bank should be around 25 volts. If the circuit breaker is not already closed, then close it, and measure the output voltage of the supply. Adjust RV1 until the meter reads about 15 volts (or whatever value you want the crowbar protection circuitry to operate).

Now, turn off the power, and also open the circuit breaker. Now connect the gate of the SCR to the appropriate pad on the PCB, and rotate RV2 fully counterclockwise. Re-apply power, close the breaker, and slowly rotate RV2 clockwise, until the voltmeter reading drops. Now back off RV1 a few turns, and reset the breaker. Finally adjust RV1 for the desired 13.8 volts output.

The setting of the current limiting requires the availability of a load which will draw a suitably large current (about 35 amps) from the supply. A high current ammeter is also useful, although if the impedance of the load is known, the current can easily be calculated.

Connect the load to the output terminals of the supply, and observe the output voltage of the supply. Rotate RV3 until the output just starts to drop noticeably (if it has not done this already), and then back it off until the output voltage comes back up and doesn't rise any further.

If you have further loads which can be connected across the output, these will help confirm that the current limiting is indeed working. If you apply a short-circuit to the output, via a suitable ammeter, you should see the output current drop back to a very low value (about 5 to 10 amps), and come back up when the short is removed. If you are using automotive light bulbs as your dummy load for these tests, then you'll notice that the output voltage does not come back up instantly, but slowly, due to the non-linear resistance characteristic of incandescent lamps.

The heatsinks, especially those on which the output transistors are mounted, can be expected to get quite warm to the touch under continuous use at the 25 amp level. If you intend to run the supply at higher currents than specified here, or at high ambient temperatures, then it would be advisable to increase the amount of heatsinking on the transistors.