PROJECT

Stabilized Power Supplies Part 4

Using the 723 to demonstrate a comprehensive 25V 2A power supply.

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A great variety of integrated circuit power regulators and indeed complete power supply systems are available these days, and earlier on we looked at the 78/79 series and their applications as fixed voltage regulators. It sometimes happens that we have a voltage regulator which has a first class specification, but does not supply us with as much current as we would like.

The LM723 14-pin DIP regulator is a case in point; it has a good ripple rejection with excellent load and line regulation, and an in-built current limiting facility. But its current output is restricted to a maximum 150mA.

This month we conclude the series by looking at a power unit design that makes use of the 723 as a driver unit for a beefier control system, one which will give us an output current of 2A while retaining the other desirable features of the 723 intact.

Regulator

The LM723 regulator, the pin connections of which are shown in Fig. 1, is a complete circuit system of the type already described, containing a series of emitter-follower controller, a current limiting transistor, together with an error amplifier and reference voltage. Most parts of the circuit are made available at the pins and a variety of different connections can be made to provide a variety of stabilized output voltages.

The basic internal circuitry of the 723 is shown in Fig. 3. By now, this should be a familiar system.

The reference voltage is derived from a constant current source and is available at pin 6. By connecting pin 6 to pin 5, the reference voltage can be applied to the

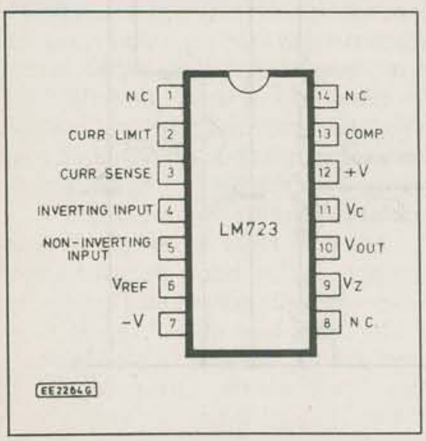


Fig. 1. Pinout details of the 723.

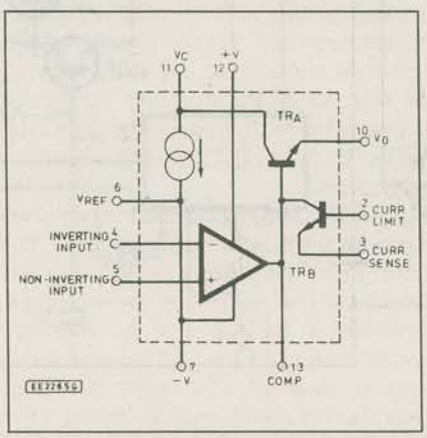


Fig. 2. Internal circuitry of the 723.

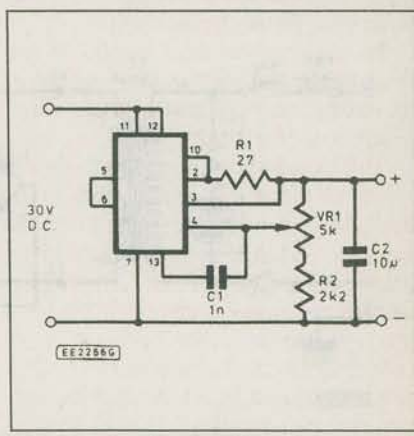


Fig. 3. Basic circuit using the 723 regulator to provide an adjustable low-current output.

non-inverting input of the error amplifier.

The inverting input is brought out to pin 4 and if this is controlled by a voltage derived from the output of the power supply, the difference will be detected by the amplifier and its output used to control the internal series regulator TR_A. This output is also brought out to pin 13 so that a compensating capacitor can be connected to the inverting input; this capacitor reduces the high frequency gain and maintains stability over the internal feedback system.

A current limiter, TR_B, is provided to take care of the effects of heavy load currents or short-circuits at the output, pin 10. This transistor senses the voltage developed across a resistor in series with the output (which in turn depends upon the current being drawn) and begins to conduct when the voltage is about 0.65V. As TR_B conducts, it puts a low resistance bypass across the base-emitter junction of TR_A, rendering it inoperative and shutting off the supply of current to the output.

So we have here, with the addition of a few external components, a complete power unit which will, using the values indicated in Fig. 3, provide us with an output ranging from about 5V to 25V. However, there are problems of dissipation to think about — we cannot expect to be able to draw large currents from a small IC package.

As we have noted, the 723 has a maximum permissible current rating of 150mA and a maximum permissible power dissipation in TR_A of 660mW at an ambient temperature of 25°C. This derates by 5.6mW/°C, so if we operate at the maximum temperature of 70°C allowed for by the manufacturers, we have lost about 250mW of our available power as internal heat. At 150mA output, we need have only 660/150 = 4.3V across TR_A before the power rating is exceeded.

In the circuit of Fig. 3, if we set the output to 5V, then there will be 25V across the regulator and the maximum current will be restricted to 660/25 = 26mA. So on its own, the 723 is rather restricted in its capabilities. This does not mean that the 723 is not an effective regulator in its own right; it is, and for outputs requiring relatively small currents it is an excellent device.

Strictly speaking, circuits of the kind shown in Fig. 3 should be used to provide *fixed* outputs rather than variable./ This then enables the maximum current to be calculated and so reduces the chances of it being inadvertently exceeded, as might well happen with a variable output.

Increasing Output Current

We can boost the output current if we use the 723 to drive an external emitter-follower as a series regulator. The internal current limiting facility can be retained and from this we can arrange a series of discrete current limiting levels at the output.

This has an advantage over the previous designs in this series; while the earlier circuits had short-circuit protection, there was nothing to prevent the full output current flowing into the load when a fault condition appeared, whether accidental or not. So although the power unit was protected, the attached current was not. A heavy current could still be capable of doing some damage in whatever piece of equipment was attached to the power supply.

In this design, the current output in the event of a short- circuit or excessive load, can be limited to any level you care to choose within the total range of current available, that is. 0 to 2A. The actual levels are simply a matter of your own personal preference.

Variable Stabilized Power Supply

The PSU is variable from 1.5V to 25V, with four switched current limits of 0.5A, 1A, 1.5A and 2A. The circuit diagram of

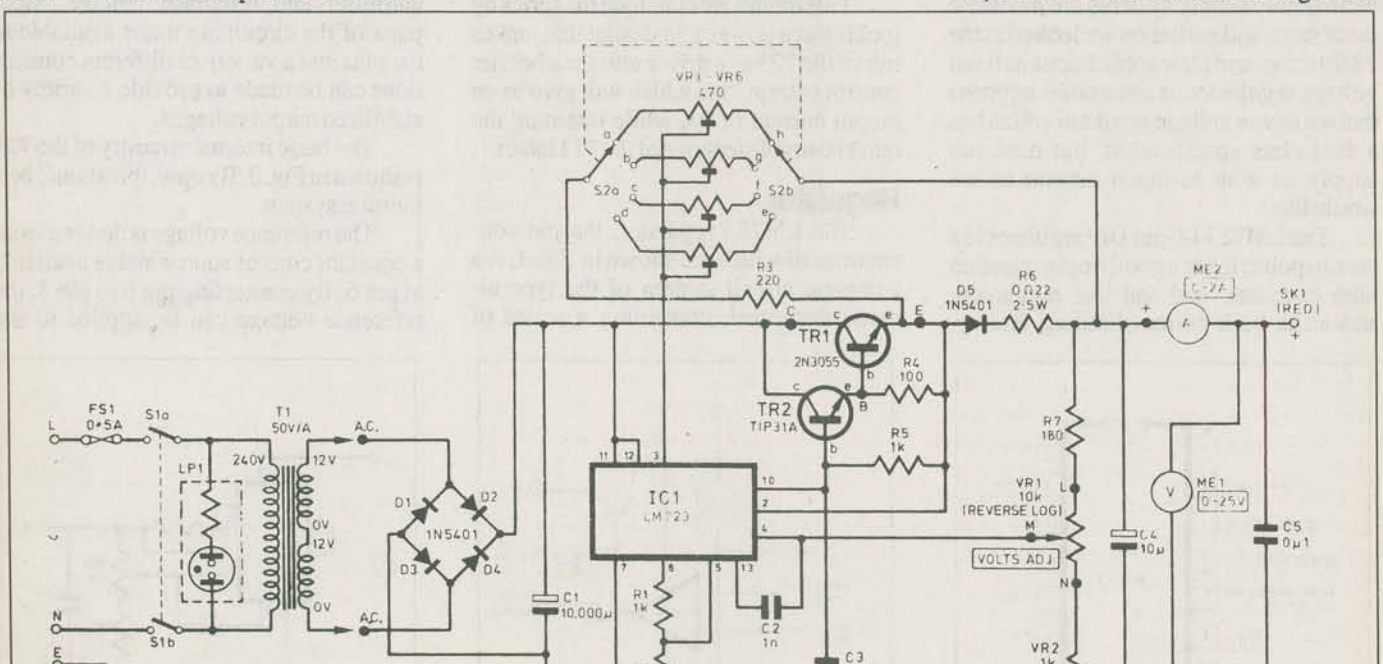


Fig. 4. Complete circuit diagram for the 1.5V/25V Variable Power Supply. The solid circles refer to circuit board connection points.

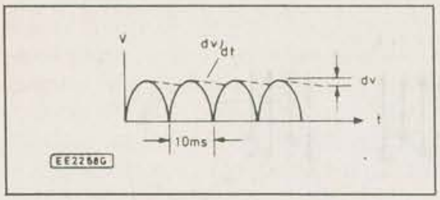


Fig. 5. Ripple voltage caculations for capacitor C1 selection.

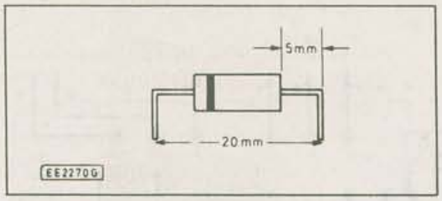


Fig. 7. Using longnose pliers, bend the diode leads to suit hole spacing.

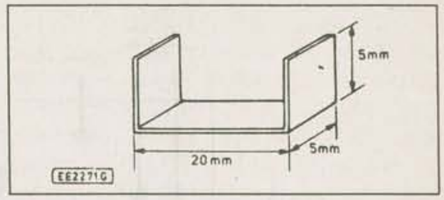


Fig. 8. Alternative heatsink dimensions for IC1.

the 2A power unit is shown in Fig. 4. Here a conventional bridge rectifier feeds the 723 (IC1) which in turn drives the power booster combination of transistors TR1 and TR2. Transistor TR1 (a 2N3055) is the conventional series emitter-follower controller which is itself driven by TR2, a small power transistor, type TIP31A. This is necessary as the output of IC1 (723) is insufficient to drive TR1 directly.

Resistor R6, in conjunction with diode D5, forms the current sensing resistor and a portion of the voltage developed across this arrangement is tapped off by one of the potentiometers VR3 to VR6 and applied to the current sensing input pin 3 of IC1. This determines the point at which the current output is limited.

The effect of diode D5 is that, being non-linear, the effective resistance of the sensing combination increases with lower current outputs and maintains a sufficient voltage across the potentiometers to ensure proper operation of the limiter in the 723 regulator. By selection of the potentiometers by ganged switches S2a and S2b, four current levels can be preset.

The output voltage is adjusted between about 1.5V and 25V by VR1 which connects to the inverting input (pin 4) of the error amplifier. This compares output variations with the internal reference, selected by the divider chain made up of resistors R1 and R2, and adjusts the output at the base of Transistor TR2. TR2 drives TR1 which then compensates for the output change, so stabilizing the output. Potentiometer VR1 is a *reverse* log type which allows a closely linear relationship between rotation angle and output voltage. A linear potentiometer leads to cramping at the lower end of its rotation.

The bridge rectifier (D1-D4) is made up from four discrete diodes, types 1N5401, which are 3A devices rated at 100Vrms. Smoothing is carried out by capacitor C1. This capacitor has to be rather large if a 2A output capability is required; taking it that the maximum input ripple voltage to the 723 regulator should not exceed 2V when the full current is being drawn, then since ripple gradient $dV/dt = 1/C$ (see Fig. 5) and $dV = 2V$, $dt = 10ms$ for 50 Hz supplies, we get $C = (2 \times 10^{-2})/2 = 10k\,uF$.

We also need a ripple current rating of at least twice the average worst case ripple current we are likely to draw from the capacitor. Therefore, for this unit we need a ripple rating of at least 4A. The specified capacitor has a rating of 5A which gives us something in hand. If you use an alternative capacitor, keep these figures in mind.

It is suggested that both voltage and current meters be fitted to the complete unit. A voltmeter is almost certainly necessary and an ammeter is well worth inclusion. The circuit for the two meters is shown between the Volts Adjust control and the output terminals in Fig. 4. These are wired between the board output terminals and the front panel of the unit. If the specified meters are used, no rescaling is necessary.

Construction

All components are mounted on a single-sided printed circuit board except the mains transformer T1, the power controller transistor TR1, the Output Voltage Adjust control VR1 and the Current Limit switch S2.

The printed circuit board component layout and a full-size copper foil master pattern is given in Fig. 6, with an indication of the wiring from edge Vero pins to the various external components and controls. The lettering on the board matched that shown on the circuit diagram and Fig. 10.

There are one or two points of importance to be noted about mounting components on the board. The first concerns capacitor C1. This is a PCB mounting type of capacitor and the component used has five fixing pins. Only two of these are for the positive and negative connections, the other three *must* be left isolated.

If you use the specified component, the board positions will be correct. However, you may obtain, or already have, an alternative capacitor; in this case the board will have to be drilled to accommodate the alternative pin arrangement.

Parts List

Resistors

R1,R5 1k
R2 390
R3 220
R4 100
R6 0.22 2.5W
R7 180
All 0.25W metal film, except where stated.

Potentiometers

VR1 10k reverse log.
VR2 1k min. preset, hori.
VR3-VR6 470 min. preset, hori.

Capacitors

C1 10,000u 40V 5A
C2 1n polyester
C3 4n7 polyester
C4 10u tantalum 35V
C5 0u1 polyester

Semiconductors

D1-D5 1N5401 3A 100V rec.
TR1 2N3055 or 2N3771 *npn* power
TR2 TIP31A *npn* power
IC1 LM723 regulator

Miscellaneous

S1 DPDT power toggle
S2 3-pole 4-way rotary
T1 25V/3A transformer, centre-tapped
ME1 0-25V moving coil meter
ME2 2A moving coil meter
LP1 220-250V neon indicator

PCB; case, 305mm X 159mm X 133mm; heatsinks; 14 gauge aluminum (see text), clip-on (for IC1, RS434-059) and finned (for TR2, RS 403-162); SK1, SK2 4mm type, 1 black, 1 red; 500mA cartridge fuse; connecting wire; solder, etc.

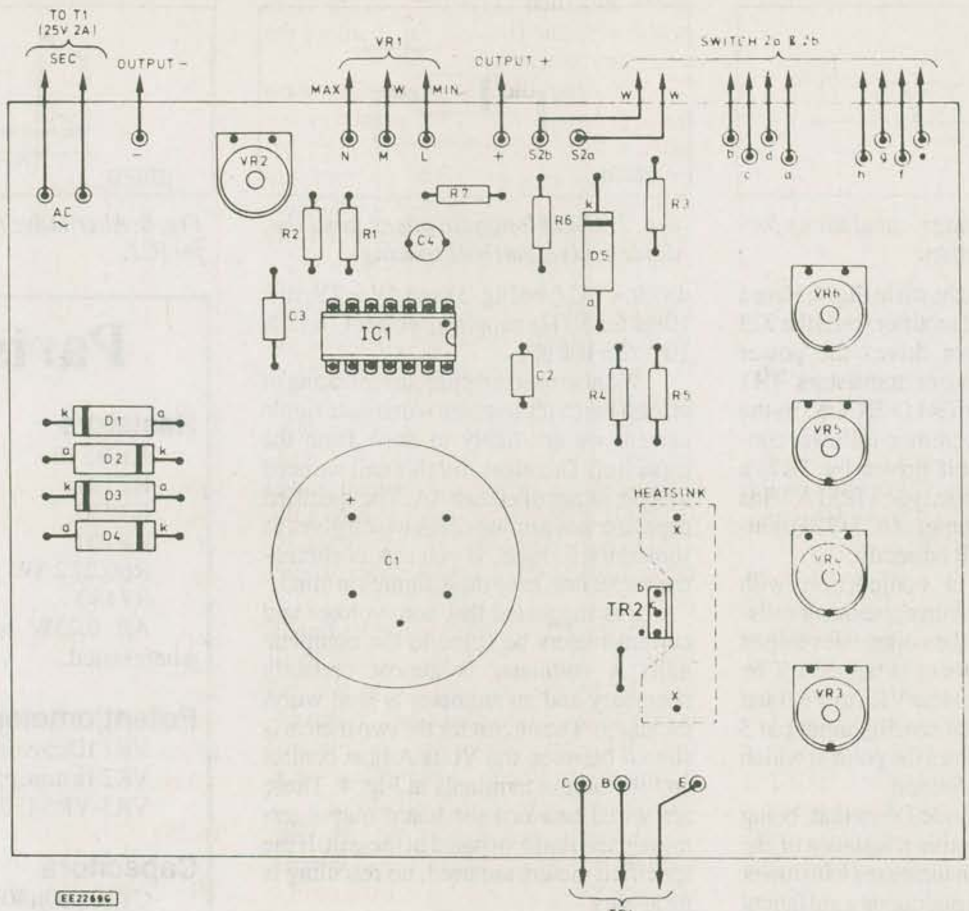
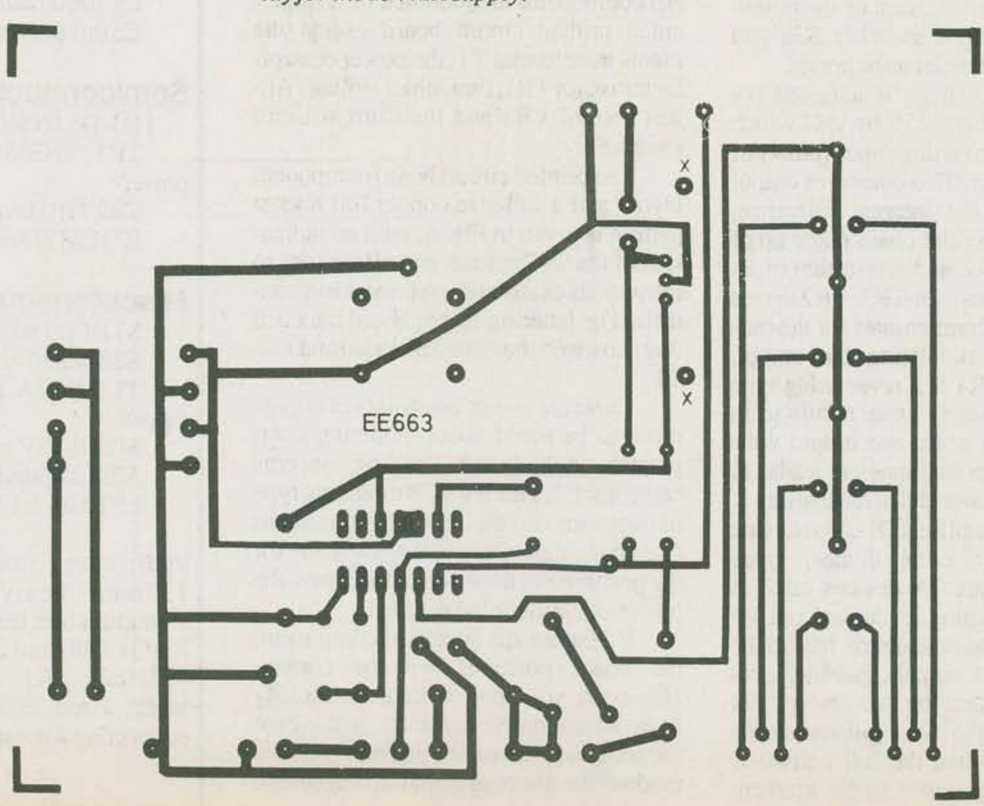


Fig. 6. The printed circuit and parts overlay for the 25V/2A supply.



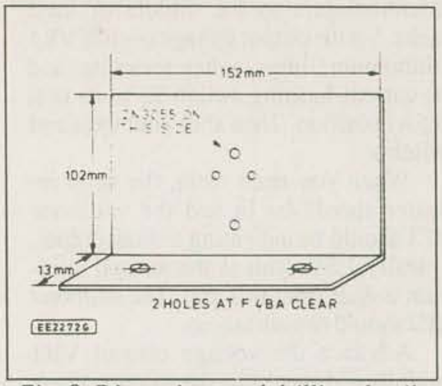


Fig. 9. Dimensions and drilling details for the heatsink.

This may necessitate linking up to the positive and negative copper rails on the board with a short length of wire but this should not be too difficult to cope with.

The essential thing is the physical size of an alternative; height is not too important, but diameter is. If the diameter is greater than some 45mm, there may be a problem of accommodation.

Diodes D1 to D4 and the solitary D5 have rather thick (1.3mm) connecting wires and great care must be exercised in bending these to suit the board spacing holes. It is best to grip the wire close to the body of the diode with a pair of thin-nosed pliers and then bend the wire at right angles with the fingers. Fig. 7 shows the necessary dimensions.

Fit these diodes snugly into their board positions, *noting the polarities*, but leave a space of about 3mm (1/8in) between them and the board; do *not* press them down hard on to the board. The same applies to the 2.5W resistor R6; let it stand clear of the board by at least 5mm (3/8in).

Heatsinks

The regulator IC1 needs a standard 14-pin DIP holder and a heatsink. The driver transistor TR2 also has a heatsink.

The regulator IC1 should have a clip-on type of heatsink but if this is not available, a piece of 16 gauge aluminum bent to the dimensions shown in Fig. 8 will do. This is simply glued to the top of the IC using a thin layer of a quick setting epoxy resin.

Transistor TR2 is attached to a small finned heatsink which is designed to fit into the board and soldered at the two points *X-X* (see photographs). When fitting TR2 to its heatsink (and to the board) take care that the three connecting leads are not shorting out to the heatsink.

Preset potentiometers VR3 to VR6 should be the enclosed rather than open skeleton types, but you can use the latter if you can't get hold of anything else. The rest of the components need no special comment. The usual care in soldering must be followed for the whole of the assembly, and watch out all the time for solder bridges and splashes, particularly around the IC connections and all parts where the copper track spacing are close.

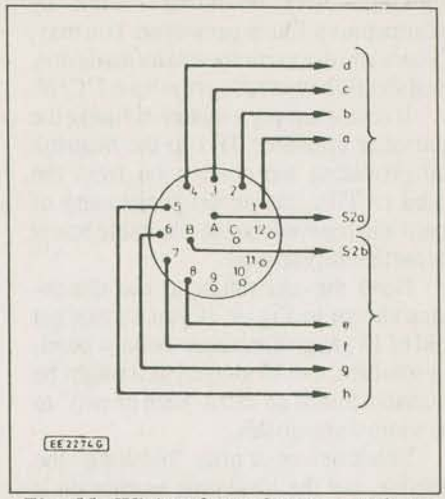


Fig. 11. Wiring from the current-limit switch S2 to the circuit board.

Main Heatsink

The main heatsink for the power transistor TR1 is made out of a piece of 14 gauge

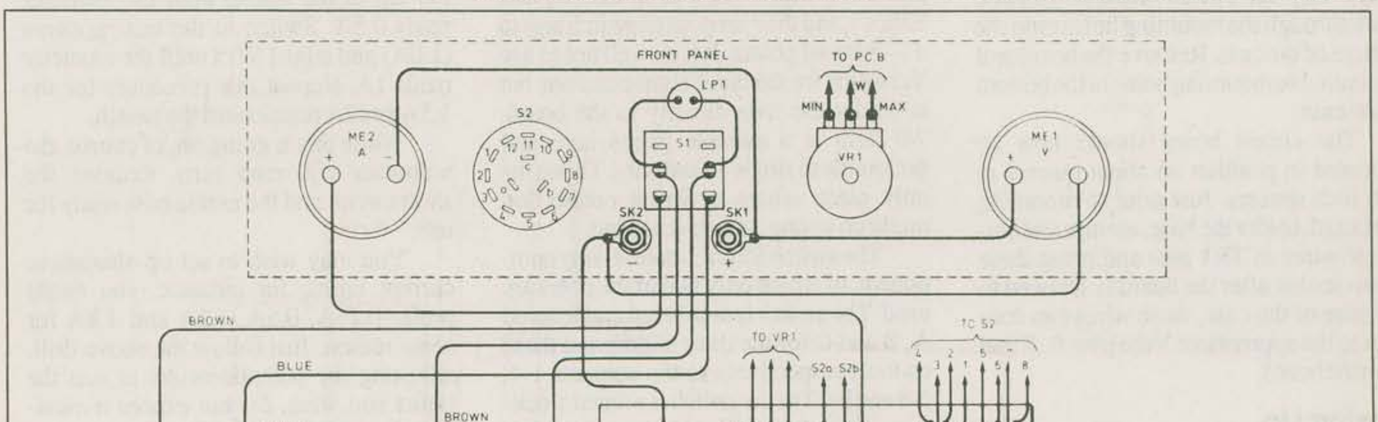


Fig. 10. Interwiring from the circuit bpoard to the front panel components, TR1, fuse and transformer. Note that capacitor C5 can be wired directly across the output terminals or across the voltmeter terminals.

aluminum sheet measuring 152mm by 102mm plus a 13mm turn-over. You may, if you wish, use a commercially made one, but it should have a rating of at least 2°C/W.

It is now simply a matter of fitting the controller transistor TR1 to the heatsink and providing the connection from the board to TR1, the actual positioning of board and heatsink inside a suitable box is not particularly critical.

Bend the aluminum to the dimensions shown in Fig. 9. If you cannot get hold of 14 gauge aluminum or have bending troubles, use 16 gauge but it might be advisable to add an extra "inch or two" to the width if you do this.

Either before of after "blacking" the heatsink, lay the insulating washer on it and mark through the three pinout hole positions on the heatsink. Drill the heatsink and mount the 2N3055 transistor slightly below center on the heatsink, using the insulating kit.

Position the heatsink at one end of the base of the case and mark through and drill suitable mounting holes in the bottom of the case. Mount the mains transformer at the other end of the case as indicated in the photographs.

There should now be enough space between the heatsink and mains transformer to take the completed circuit board. Lay the circuit board in position mark through the mounting holes onto the bottom of the case. Remove the board and drill suitable mounting holes in the bottom of the case.

The circuit board should now be mounted in position on about quarter to half inch spacers. Just prior to mounting the board, solder the base, emitter and collector wires to TR1 pins and bring these down so that after the board is screwed to the base of the case, these wires can connect to the appropriate Vero pins *B*, *E* and *C* on the board.

Boxing Up

The case used for the prototype was one of the vinyl covered types. This is a simple two-piece box which makes assembly very easy. Strictly speaking, it is a bit larger than is necessary for this job, but plenty of room never did harm, and the only thing to watch out for if you use an alternative is the height which should be at least 102mm.

The reason for this is that the heatsink panel should be mounted vertically. You *can* mount it horizontally if you wish, but the cooling isn't so efficient.

The only parts bolted to the floor of the case are the heatsink, circuit board and the mains transformer. Everything else is on the front panel, apart from the fuse which is best mounted at the rear, alongside the entry point for the mains cable.

A suggested front panel layout is shown in the photograph above. As the box is a plain aluminum finish, it is well to give a coat of suitable spray paint before attaching Letraset style lettering. The "current limit" ranges are shown as 0.5A, 1.0A, 1.5A and 2.0A. These can, in fact, be any values you like, so if you want other levels, mark your panel accordingly. Setting these levels up is discussed later.

Interwiring

The interwiring connections are made in accordance with the circuit diagram Fig. 4, board layout Fig. 6 and Fig. 10. It is best to start by wiring up the meters and connecting these to the positive (+) and negative (-) output points on the board. Use flexible 16/0.2mm wire for this.

Next, connect the pins *L, M and N* on the board to the Voltage Adjust control potentiometer VR1, noting that the *maximum* output voltage is obtained when the slider is at the VR2 end of the track. As already indicated, this control should be a *reverse* log potentiometer.

Wire two of the current limit switch poles or "wipers" to points S2a(w) and S2b(w), and their associated switch tags to *a — h* board points. It is as well not to use Vero pins for the latter eight positions but to solder the wire directly to the board. 7/0.2mm is a suitable gauge here and preferable to single strand wire. This is the only place where a wiring connection might go wrong, so care is needed.

The switch S2 is a 3-pole, 4-way component, of which only two of the poles are used. The switch is numbered and lettered A, B and C for the three sliders and these connect respectively to the contacts 1-4, 5-8 and 9-12 as the switch is rotated clockwise. If you follow Fig. 11, there shouldn't be any confusion. Keep all these wires in a neat bundle on their way across to the board; they do not carry heavy current.

The mains transformer secondary winding is now connected to the AC terminal pads and the primary wiring (neon LP1, fuse FS1 and on-off switch S1) completed. The fuse should not be more than a 1A rating. And, as always with any mains wiring, treat this side of the system with respect.

Setting Up

To set up the unit, first of all turn all preset potentiometers to the middle of their tracks. Set the output voltage control VR1 to minimum (fully counterclockwise) and the current-limiting switch S2 to its first (0.5A) position. Then shut your eyes and switch on.

When you open them, the neon indicator should be lit and the voltmeter ME1 should be indicating a small output, typically 1.5V. This is the normal minimum output from this unit. The ammeter ME2 should remain at zero.

Advance the voltage control VR1 carefully and check that the output voltage increases. When the control gets to its maximum position, adjust preset VR2 so that the voltmeter reads 25V. this completes the voltage setting.

Current Limiting

If all this has happened uneventfully and there has been no sign of circuit discontent, we can now get on with setting up four current-limiting stages. This procedure is best done fairly quickly, not that any damage is going to result if you happen to be slow, but unnecessary heating will be avoided.

Make sure that the current limit switch is in its most counterclockwise position (corresponding to the 0.5A limit), then put a temporary short circuit across the output terminals. Adjust VR6 (nearest the top of the board) until the ammeter reads 0.5A. Switch to the next position (1.0A) and adjust VR5 until the ammeter reads 1A. Repeat this procedure for the 1.5A and 2A positions of the switch.

While this is going on, of course, the voltmeter will read zero. Remove the short circuit and the unit is now ready for use.

You may wish to set up alternative current limits, for instance, you might prefer 0.25A, 0.5A, 1.2A and 1.8A for some reason. Just follow the above drill, adjusting the potentiometers to suit the limits you want. *Do not exceed a maximum current of 2A, however.*

Keep in mind when using this power unit, that once the current limit on any of the four ranges is reached, the voltages output will stay put and cannot be further increased. For example, suppose you have a load connected whose resistance is 20 ohms. Then on the 0.5A limit position, the greatest voltage you can have before 0.5A is reached is 10V, so the voltmeter will not go past the 10V position.

This completes our series of articles on power units and I trust you have found something that fits your requirements among them.