Constructional Project

VERSATILE BENCH POWER SUPPLY

ANDY FLIND

A well-proven power supply that provides 0V to 20V with current limiting in two ranges of 100mA and 1A.

ONE of the most useful pieces of equipment an electronics experimenter can possess is a good workbench power supply. Indeed even for those who already have one, a second will often prove useful for projects requiring more than one source of supply or for the occasional design that requires long-term testing.

POWER SUPPLY IDEALS

Ideally a workbench supply should have an output voltage that can be adjusted right down to zero as it is occasionally useful to be able to power a circuit gradually from this when fault-finding. There should also be a fast and effective current limiting facility, again adjustable from zero as this also provides valuable protection when testing circuits.

If the supply can be set to deliver a constant output current instead of a voltage it can also be used as a charger for the many types of re-chargeable battery that are available nowadays, both alkaline and small sealed lead-acid types. The latter are normally charged to a constant voltage but until this is reached a current limit is often required to prevent an excessive charge rate.

Preferably the supply should have two meters so that the voltage and current supplied to the load can be seen at a glance, and most users would probably prefer analogue meters to the digital type for this.

Power supplies meeting these specifications can be expensive, but this project can be constructed at reasonable cost, especially if some of the parts such as the case and meters are already to hand, or are purchased from inexpensive sources such as surplus stores or amateur radio rallies.

The power supply described here provides an output of up to 20V with current in two ranges of 100mA or 1A, which should be more than sufficient for most of the projects which appear in *EPE*.

DESIGN POINTS

The design of a good power supply is more complex than might be supposed. It must provide a constant voltage or current whilst being able to react rapidly to any changes in the load it is supplying. This means that the circuit must have a fast response and remain stable for a wide range of output loads, voltages and currents, so the circuit is inevitably a compromise between speed and stability.

The design used for this project should be fast enough for most purposes and has good output stability.

The method of voltage control used may be a little difficult to follow so a simplified explanation is in order before a description of the full circuit. Some of the more common methods of controlling voltage are shown in Fig.1.

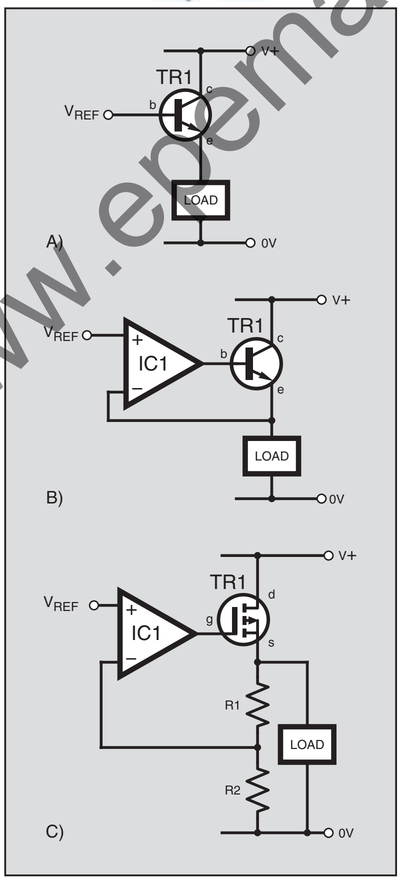


Fig.1. Various methods of voltage control: (a) transistor, (b) op.amp and transistor and (c) op.amp and power MOSFET.

In Fig.1a the controlling device is a simple transistor. A reference voltage is applied to the base and this is reproduced at the emitter to supply the load, minus about half a volt for the base-emitter drop of the transistor. This can suffice for simple designs but suffers from small changes with variations in load, partly because it draws a small current from the reference source, which is usually a variable resistor connected to a fixed voltage.

Use of a power MOSFET in place of the transistor would cure this, but these have a much larger and less predictable gate-source voltage drop.

An op.amp can be used to partly overcome these problems, as shown in Fig.1b, but there are still some disadvantages. As the required output voltage rises, the input voltage to the transistor must also rise so there is effectively less control voltage available as the output approaches the supply voltage. Also, this simple circuit cannot supply an output voltage greater than the reference.

A somewhat better solution is shown in Fig.1c. A power MOSFET is controlled by an op.amp and a pair of resistors causes the op.amp to multiply the reference voltage. But the problem of low drive voltage at high output voltages remains and it is difficult to sense the output current from any of these circuits.

BETTER CONTROL

An arrangement which overcomes these difficulties is shown in Fig.2. It uses two power supplies, a "main" one of about 25V capable of supplying up to 1A of current for the output, and an auxiliary "split" supply of +12V for the controlling circuit. The "0V" rail of this is the "ground" for the control section. It operates as follows:

A reference voltage is produced using regulator IC1 and applied to resistor R1. During normal operation op.amp IC2 uses feedback to maintain equal voltages at its inputs, so a constant current flows into R1. This current also flows through resistor R2, developing a voltage across it directly proportional to its value. If a linear variable resistor (potentiometer) is used for R2 it will provide linear control of the output.

Perhaps the easiest way to understand the action of the circuit is to consider what would happen if the voltage at the junction of R1 and R2 were to rise slightly. The output of IC2 would start to rise and thus turn on the MOSFET TR1 a little more. This would cause the 0V rail to rise with respect to the main negative supply rail so that more current would flow through R2 to bring the input to IC2 down again, restoring the balance.

The 0V rail, of course, is the positive output so the voltage developed across R2 is what is delivered to the load. Naturally, as the 0V rail rises with respect to the main supply, so do the positive and negative 12V rails, so that even when the output voltage is close to the maximum of the main supply there will still be a full 12V available for IC2 to use in controlling the gate of power MOSFET TR1.

OUTPUT CURRENT

It is also simple to measure the output current in this arrangement using the sensing resistor R3, which develops a current-dependent voltage with respect to the control circuit "ground". The only disadvantage of this arrangement is that the return path for the reference current from resistor R1 is via the main supply, TR1 and R3, so this current should be kept small to prevent any noticeable effect on the measured output current.

This also applies to the voltmeter which is connected directly across the output.

MAINS SUPPLY

The full circuit diagram for the Versatile Bench Power Supply is shown in Fig.3. The incoming 230V a.c. mains passes through a 2-pole isolating switch S1 to the two transformers T1 and T2, whilst the transient suppressor VDR1 removes any brief high voltage spikes that may occur.

No supply fuses are fitted to the prototype, a 3A fuse in the mains plug being considered adequate.

Transformer T1 is a 20V 20VA (1A) type and, with bridge rectifier REC1 and reservoir capacitor C2, produces a no-load voltage of about 30V. Under full-load conditions this drops to about 24V which is still sufficient to maintain the 20V output. Capacitor C1 and resistor R1 also help to eliminate transient voltage spikes.

Transformer T2 is a smaller 100mA type with a centre-tapped 9V-0V-9V output. Arranged as shown with bridge rectifier REC2, it develops both positive and negative supplies of about 12V each. A 5V reference voltage is generated by IC1, a standard 78L05 regulator.

DOWN TO EARTH

The earthing arrangements used in this project are slightly unusual and require some explanation. Earthing of a mains-powered project is essential both for safety and because capacitive coupling between windings in the transformer can transfer potentially damaging a.c. voltages to the output, even though from a very high impedance.

However, the output of a bench power supply is often required to have d.c. isolation from earth so that other earthed equipment, such as oscilloscopes, can be safely connected to any part of the circuit on test.

Commercially produced bench supplies often overcome this problem by using transformers with internal foil screens between the primary and secondary windings which are earthed to eliminate the capacitive coupling. These are not readily available to the home constructor, so a different method must be used.

Switch S2 allows the mains earth to be connected directly to either the positive or negative output terminal or left "floating", where capacitively coupled a.c. voltage is grounded through capacitors C3, C4 and resistor R2. Although not ideal, this system works well in practice and reduces noise and a.c. voltage at the output to a few millivolts

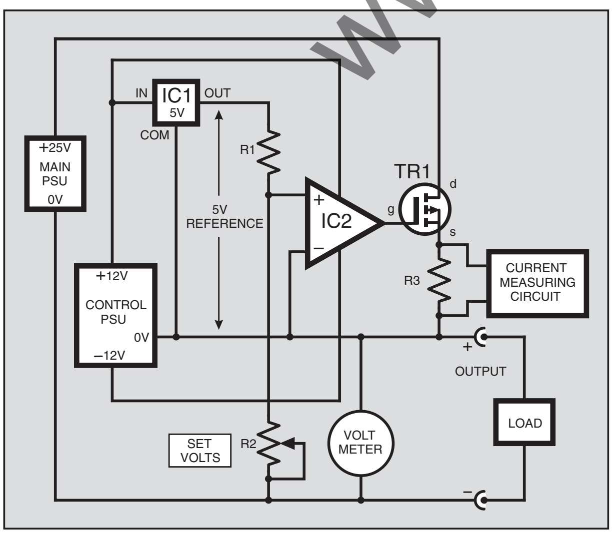


Fig.2. Simplified schematic of the voltage control method used.

COMPONENTS

Resistors

R1, R2	10Ω (2 off)
R3, R6, R8, R9	4k7 (4off)
R4	22k
R5	220k
R7, R15, R19	1k (3 off)
R10	1Ω (7W wirewound)
R11	180k
R12	1k8
R13	220Ω
R14	2k2
R16	27k
R17, R18	10k (2 off)
R20	820Ω
R21	68k
VDR1	250V a.c. transient supp.

All 0·6W 1% metal film, except where stated.

See SHOP TALK page

Potentiometers

VR1	10k 18-turn cermet preset
VR2	100k, rotary carbon, lin.
VR3, VR4	50k 18-turn cermet preset (2 off)
VR5	1k rotary carbon, lin.
VR6	500Ω 18-turn cermet preset

Capacitors

C1, C3, C4	470n 250V, class X2 suppression (3 off)
C2	2200µ radial elect. 63V
C5, C7, C9, C11, C14 to C16	100n ceramic, resin-dipped (7 off)
C6, C8	470µ radial elect. 16V (2 off)
C10	10µ radial elect. 50V
C12	22p ceramic, resin-dipped
C13	100µ radial elect. 63V

Semiconductors

REC1	PW01, 6A 100V bridge rectifier
REC2	W005 1·5A 50V bridge rectifier
D1 to D5	1N4148 signal diode (5 off)
D6	BZX61C30V 30V 1·3W Zener diode
D7	red l.e.d. 3mm
TR1	BUZ11 power MOSFET
TR2	BC214L *pnp* transistor
IC1	78L05 +5V 100mA voltage regulator
IC2 to IC4	TL071 op.amp (3 off)

Miscellaneous

ME1, ME2	100µA moving coil meter (2 off)
S1, S3, S4	d.p.d.t. toggle switch, 250V a.c. (3 off)
S2	1-pole 3-way rotary switch
T1	20V 20VA transformer
T2	9V-0V-9V 100mA trans.
SK1, SK2	4mm screw terminal post/socket (1 red, 1 black)

Printed circuit board, available from the *EPE PCB Service*, code 333; case with metal front and rear panels or metal case, 205mm x 140mm x 110mm; plastic feet (4 off); cable ties (see text); knob (2 off); 8-pin d.i.l. socket (3 off); heatsink, 100mm x 65mm; fixings; connecting wire; solder, etc.

Approx. Cost Guidance Only **£39** *excluding meters & case*

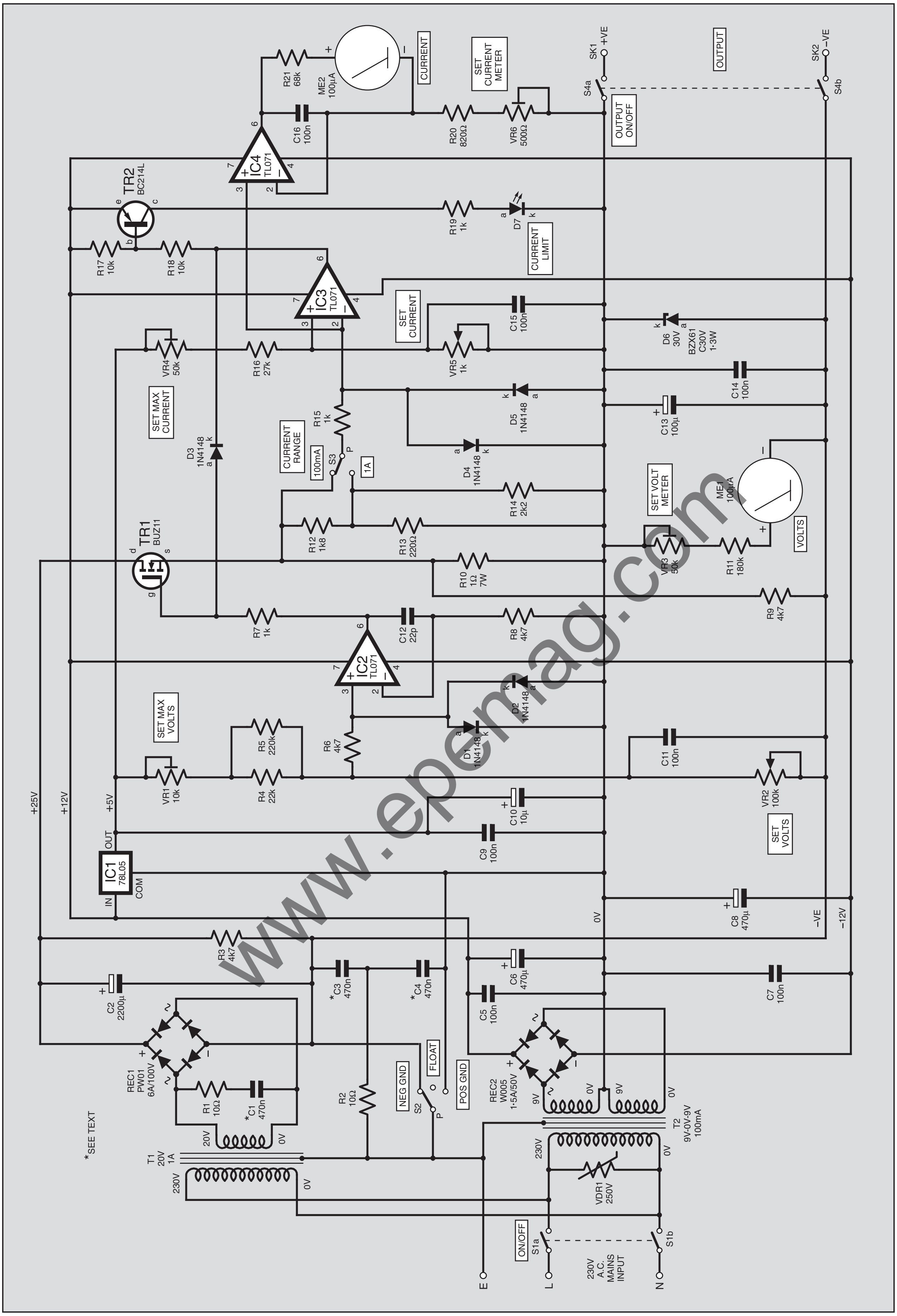
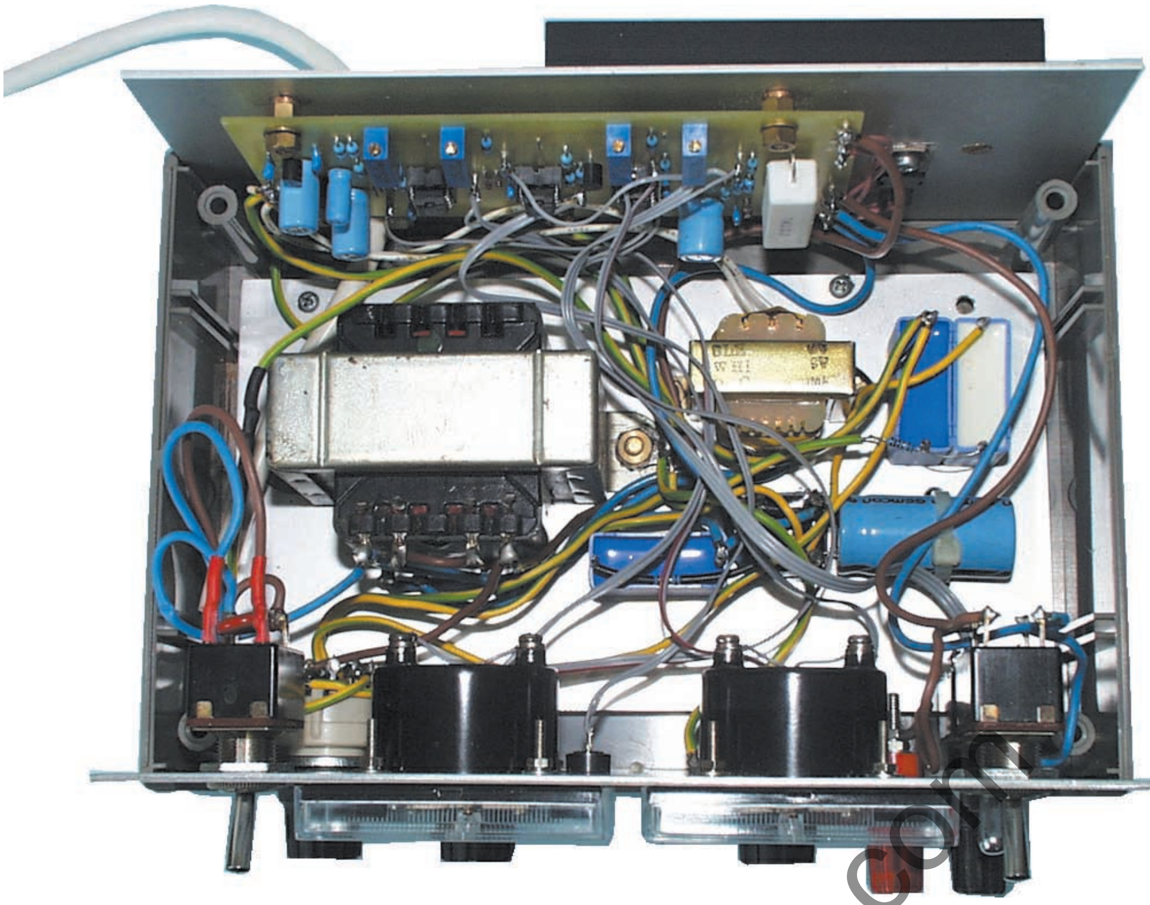


Fig.3. Complete circuit diagram for the Versatile Bench Power Supply.



Internal view of the prototype showing the a.c. supply components.

at most. **For safety, capacitors C3 and C4 must be 250V class X2 suppression types.**

VOLTAGE CONTROL

The voltage controlling part of the circuit is constructed around op.amp IC2 and operates as described earlier. The resistance to which the reference voltage is applied includes the preset VR1 so that the maximum output voltage may be set to exactly 20V.

The input to IC2 has a pair of protection diodes, D1 and D2. Capacitor C12 ensures stability but is small enough to allow a fast response to output load changes. Power MOSFET TR1 handles the full output current. Output voltage is indicated by meter ME1 with VR3 allowing preset adjustment for calibration to 20V full-scale.

Load current is sensed by the one ohm resistor R10. At full output this dissipates a watt of heat, so a 7W type is used to dissipate this safely. A potential divider across R10, consisting of R12 with R13 and R14 in parallel, allows selection of either the full potential across it or one tenth through switch S3, giving the 100mA and 1A current ranges.

The voltage from S3 is compared by op.amp IC3 with an adjustable voltage derived from the reference by divider network VR4, R16 and the current control VR5. When the S3 voltage exceeds this secondary reference voltage, the output of IC3 goes low, pulling the gate voltage of TR1 down through diode D3 to limit the current flow through this transistor.

It also turns on transistor TR2, which illuminates light emitting diode (l.e.d.) D7 to indicate that current limiting is taking place. Preset VR4 allows the current ranges to be set precisely to 100mA and 1A, whilst VR5 gives control from zero to the selected maximum.

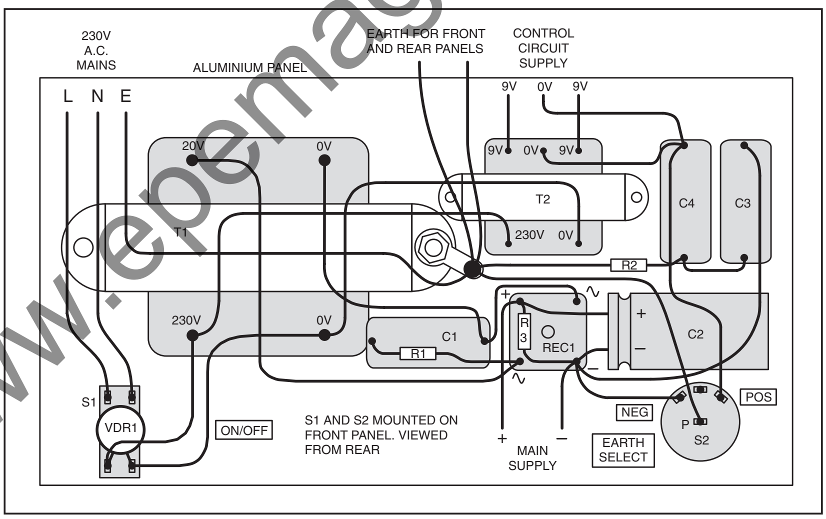


Fig.4. Layout and interwiring of power supply components mounted on an aluminium base plate. The plate also acts as the heatsink for the 6A bridge rectifier REC1. S1 and S2 are mounted on the front panel.

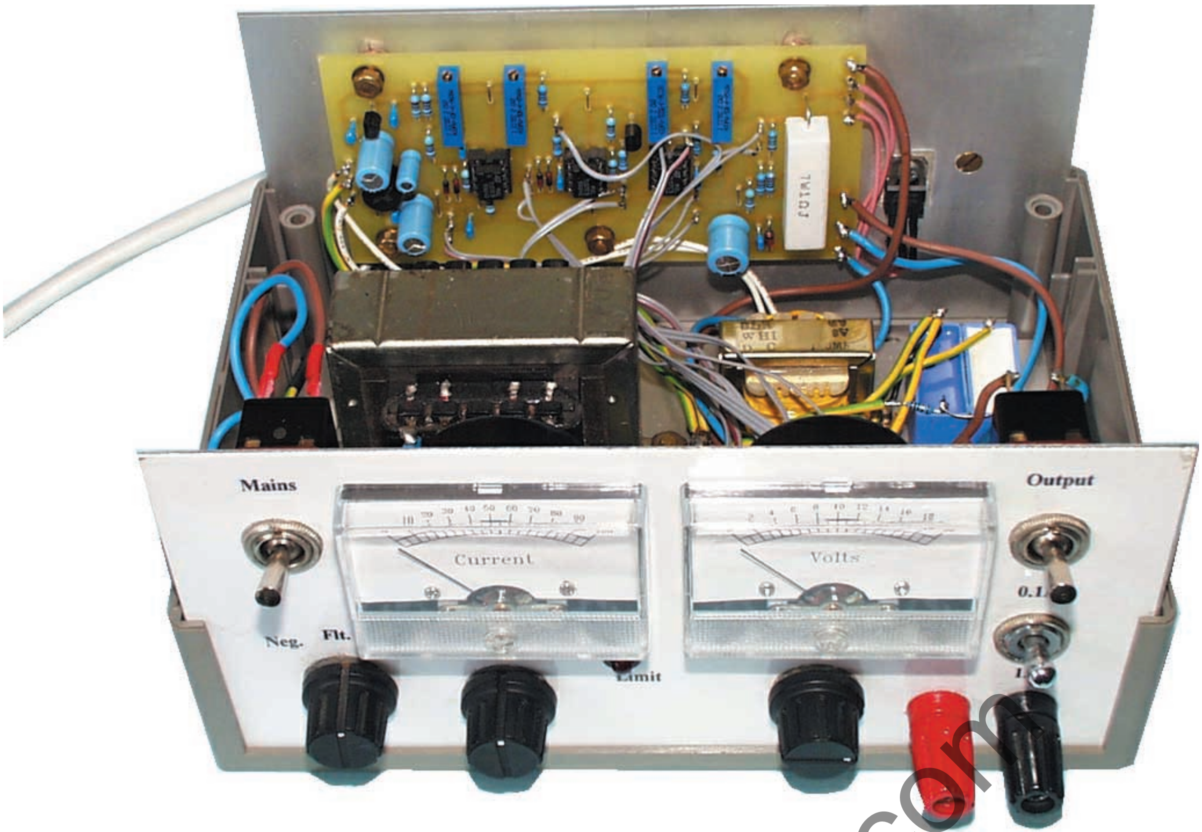
Op.amp IC4 also receives the voltage from S3, and converts it into a 1-100μA drive for the current indication meter ME2. Preset VR6 allows calibration of this meter for full-scale corresponding to the 100mA and 1A signal inputs. The high value of resistor R21 prevents any possibility of meter damage through overdriving.

Double-pole switch S4 allows the output to be switched off independently and also provides instant isolation from the circuit connected to it at any time.

Zener diode D6 protects TR1 from any high voltage pulses arising from the connected load. This can happen with some types of inductive load and, whilst normally tolerant of brief high currents, semiconductors are easily damaged by excessive voltage.

CONSTRUCTION

As this unit is mains powered, its construction should only be carried out by those who are suitably experienced or supervised. All mains connections should be fully insulated using heat-shrink or other suitable materials.



Completed power supply with the top-half of the plastic case removed to reveal the circuit board and power MOSFET TR1 bolted to the metal rear panel.

Construction should begin with the transformers, the rectifier REC1 and earthing arrangements. These can be assembled in any manner preferred by the constructor. The layout used in the prototype is shown in Fig.4.

These components are attached to a 190mm × 100mm metal plate drilled to fit the threaded mounting pillars provided in the plastic enclosure. The two transformers and rectifier REC1 are bolted in place so that the plate acts as the heatsink for the rectifier.

The large electrolytic capacitor C2 is fastened with a cable tie passed through holes to each side of it. The three 470nF capacitors, C1, C3 and C4 are glued in place. *It is essential that you ensure that good adhesion occurs. Preferably also use cable ties for these components as well to prevent them from contacting mains connections should they become detached.*

Note the arrangement of the earth wiring, which uses one of the main transformer mounting bolts as a "common" point for all earth connections. *Any other metal parts of the case used, such as front and rear panels, must also be connected to this point.*

This part of the circuit can now be fitted into the case and tested. When connected up and powered, the output of the "main" supply should be about 30V d.c. across capacitor C2 and 9V-0V-9V a.c. should be available from the 100mA transformer. These supplies will be needed for testing the remainder of the circuit.

FRONT PANEL

The front panel should be drilled as shown in Fig.5 and assembled next. The earthing selector switch S2 should be fitted and tested with a continuity testing meter. Mains switch S1 can also be connected up. The mains input is taken to the upper two

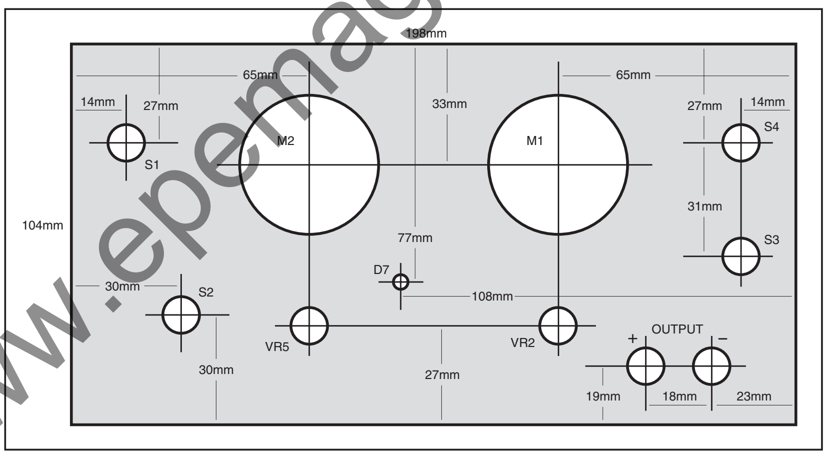


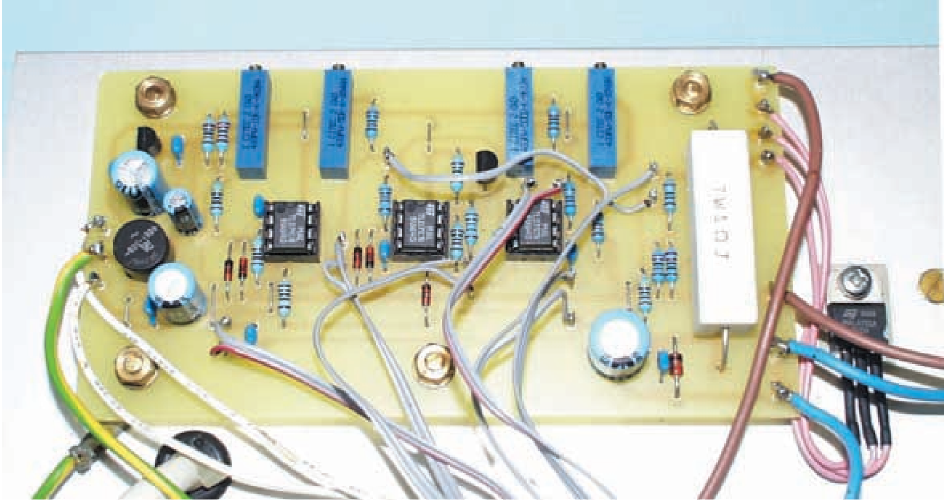
Fig.5. Front panel drilling details and dimensions. The general layout of components and front panel lettering are shown in the photograph below.

connections on this. Transient suppressor VDR1 is fitted directly to the lower two connections on the output side.

The rear metal panel of the case has four mounting bolts for the printed circuit board (p.c.b.) which can be used as a template to mark out for drilling. It also has an external heatsink to aid dissipation of heat from TR1, which is secured to the inside with an insulating mounting washer and a bolt passing right through the heatsink. Four nuts are used as spacers for the p.c.b. when it is fitted.

P.C.B. ASSEMBLY

Most of the rest of the circuit is constructed on the p.c.b. whose details are



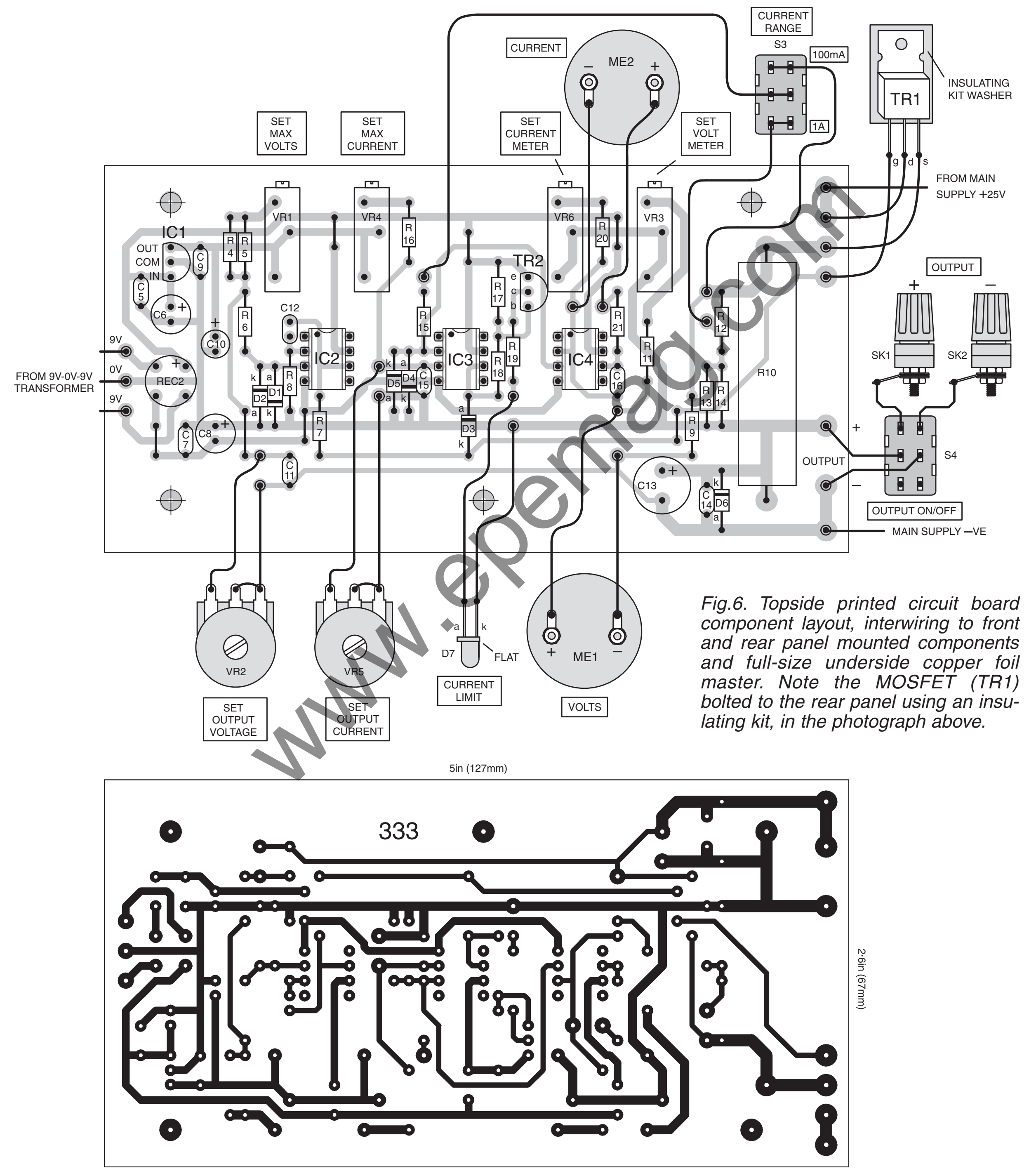


Fig.6. Topside printed circuit board component layout, interwiring to front and rear panel mounted components and full-size underside copper foil master. Note the MOSFET (TR1) bolted to the rear panel using an insulating kit, in the photograph above.

shown in Fig.6. This board is available from the *EPE PCB Service*, code 333.

After ensuring that the board will fit on the mounting bolts, the pins for external connections can be fitted, there are 23 of these, and then the links, of which there are seven. Next fit the 0·6W resistors, diodes, dual-in-line (d.i.l.) i.c. sockets, the small ceramic capacitors, presets VR1, VR3, VR4 and VR6 , transistor TR2, regulator IC1, rectifier REC2, the four remaining electrolytic capacitors and 7W resistor R10, preferably in this order for ease of assembly.

Fully check your assembly for correctness of the soldering, component positioning and polarity. The board is then ready for testing.

TESTING

The aim of using separate op.amps for the various functions is partly to make testing and trouble shooting easier, so hopefully this will be the case.

The first test is to connect the 9V-0V-9V transformer as shown in Fig.6. Using 0V (the centre-tap connection) as a reference, the circuit should be powered up and the presence of +12V and –12V checked at pins 7 and 4 respectively of the three d.i.l. sockets.

The presence of +5V from regulator IC1 can also be checked at its output pin. Next, the MOSFET TR1 and VR2, the Voltage control, should be connected, along with the two leads from the main power supply, from REC1 and C2. IC2 should now be inserted into its socket.

Whilst monitoring the output with a voltmeter, the circuit should be powered up, and it should now be possible to vary the output from zero to around 20V with Voltage control VR2. If so, VR2 can be turned right up and the voltage set to exactly 20V with preset VR1. If the voltmeter ME1 is now connected this can be adjusted for an indication of 20V (full scale) with preset VR3.

CURRENT AFFAIRS

Next the current range switch S3 should be connected and set to 100mA, and the current control VR5 should be connected. The current control op.amp IC3 should be inserted into its socket, and a meter set to read a current of about 100mA connected in series with a 100 ohm resistor across the output. The circuit should again be powered and the voltage control turned right up.

Potentiometer VR5 should now control the current, from zero to around 100mA. Preset VR4 can be adjusted for a maximum output of exactly 100mA. The 1A range should automatically be correct following this.

Rear of the completed power supply unit showing the finned heatsink bolted to the rear panel to aid dissipation of heat from the power MOSFET.

The l.e.d. D7 can be connected, this should light whenever current limiting is active.

Finally, the current meter ME2 should be connected, op.amp IC4 inserted, and preset VR6 set for full scale at 100mA. As before, the 1A range should now automatically be correct following this adjustment.

COMPLETION

Once these tests are concluded, the board can be attached to the rear panel to complete the assembly. It might be worthwhile re-checking the adjustments, the presets have been arranged for easy access with the case top half removed to make this simple.

The unit will normally be used to supply a constant voltage to circuits on test, but it may also be operated continuously in constant current mode which is very useful for charging NiCad batteries of various types.

Although the heat-sinking will be adequate for most purposes, the fact should be borne in mind that it could dissipate over 20W and therefore get rather hot. *The supply of low voltages at high currents for long periods is not recommended.* However, most loads of the kind that are likely to be found in the average workshop should present no problems.

If in doubt, just place a hand on the heatsink now and again to check temperature. The prototype has been used continually for weeks on end to power circuits used with electric clocks, and is also the favourite for programming PICs in the workshop, leaving another supply free for operating the PIC-driven circuitry.

CURRENT LIMITATIONS

It should be noted that the current limit takes a finite time to operate so there are some applications where external limiting is needed. The output of IC3 has to come out of saturation and slew through about eight volts before limiting begins, and this will take a microsecond or two!

The limit protects the supply itself against short circuits, and in almost every practical fault situation it is fast enough to prevent damage to faulty circuits on test as these are rarely total short circuits anyway.

However, it should be remembered that the MOSFET output device can handle very high currents and has a large capacitor behind it so, for the brief time it takes for the limit to operate, many amperes can be delivered into a short! An obvious example is the testing of l.e.d.s.

The limit should never be relied upon on its own for this, a suitable series resistor should *always* be used. □