dc Power Supply

This new power supply has high current, high voltage capability.

SPECIFICATION - ETI 142

Output voltage	0 - 30V
Output current	0 - 15A
Regulation	20mV (0 - 15A)
Ripple and noise	10mV
Metering	
Voltage	0 - 15V, 0 - 30V
Current	0 - 1.5A, 0 - 5A, 0 - 15A

Overload indication	
Warning	if run continuously in this mode supply may shutdown.
Shutdown	if transformer gets too hot due to a continuous overload the supply will shut down until it has cooled.
Maximum output (not continuously)	24V 15A 26V 12.5A 28V 11A 30V 8A

THIS POWER SUPPLY was designed to extend the range of dc supplies we have published over recent years. It is capable of supplying voltages from zero to 30 volts and current up to 15 amps. The techniques used allow a high power output while retaining a small physical size.

Design Features

Once again, as with all power supply designs, there is a choice to be made as to the technique of regulation to be used. Starting from the most efficient we have:

The switched-mode power supply
With this system the mains voltage is rectified to give 340 volts dc and an inverter using an inexpensive ferrite transformer gives the low voltage required. While regulation against line and load changes can be built in, it is not suitable where the output voltage has to be variable over a large range.

Switching regulator
This utilizes a conventional transformer/rectifier but the regulation is done by switching the output at about 20 kHz with a variable markspace ratio. The output is filtered by an LC network with a diode protecting the switching transistor. This system is efficient but is fairly complex where good regulation is needed and some 20 kHz ripple appears on the output.

SCR regulator
This simply uses two SCRs in the rectifier circuit with the phase angle of their firing controlling the output voltage. This scheme has the disadvantage of having a slow response time and normally a choke input rectifier/filter is necessary.

Series regulator
This is the most common regulator in use today and has good response time, ripple rejection and regulation. Power dissipation however is high when drawing high currents at low voltages on a variable output unit. It is usually used up to about 100 watts with other systems used above this.

Shunt regulator
This is normally limited to about 10 watts, for, while the performance is very good, the dissipation is more than the maximum output on no load.

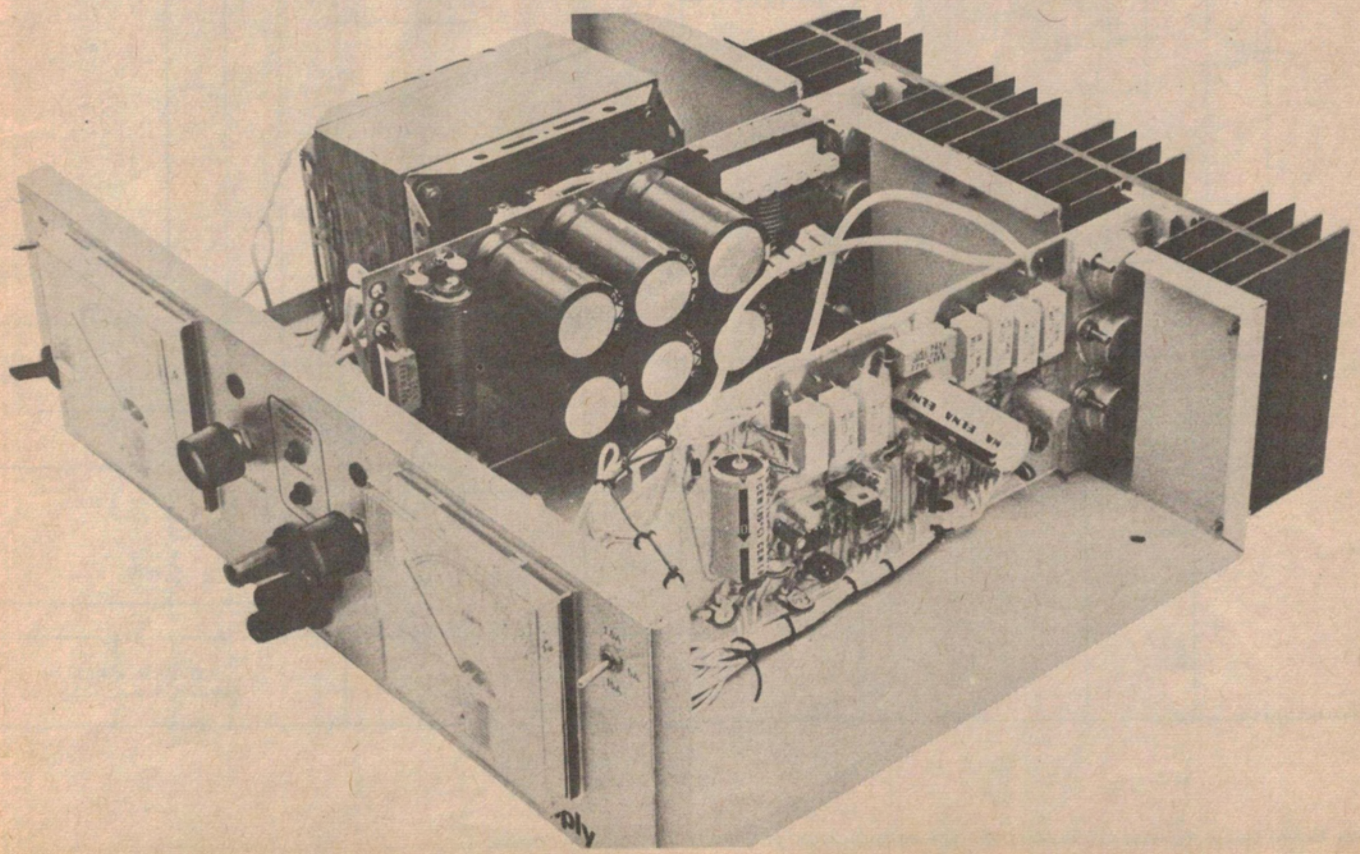
When we originally built the unit we intended using an SCR pre-regulator followed by a series final regulator. The SCR pre-regulator was to give an output about 5V above the required output. To reduce cost and size we chose not to use a choke input filter. While we could regulate the output the transformer became hot with low (dc) output voltage. The reason soon became apparent when some maths was done.

At low voltages a very short SCR conduction time is used and as the current out times time must equal current in times time for the main capacitor the input current can be 5 or 10 times the dc load current. As heating of the transformer is due to the current in the windings and not the thru-power it got hot.

We then changed to a switching pre-regulator with a series final regulator. With this design the transformer output is rectified and filtered before being regulated. This system allows higher load currents to be taken at lower output voltages without the necessity of a range switch.

Problems arising from the use of a switching regulator are mainly due to the high current and fast voltage transients generating radio frequency interference (RFI) and voltage transients in the output. The RFI problem was solved mainly by the use of an earthed shield on one side of the pc board and the addition of input and output filters.

Initially we intended to vary the mark-space ratio to compensate for the 100 Hz ripple making it easier on the series regulator. However the prototype exhibited a tendency to oscillate at around 1 kHz due to the delays in the output filter; either a more complicated control circuit would be needed or we should let the series regulator get rid of the 50 Hz ripple. We chose the second approach.



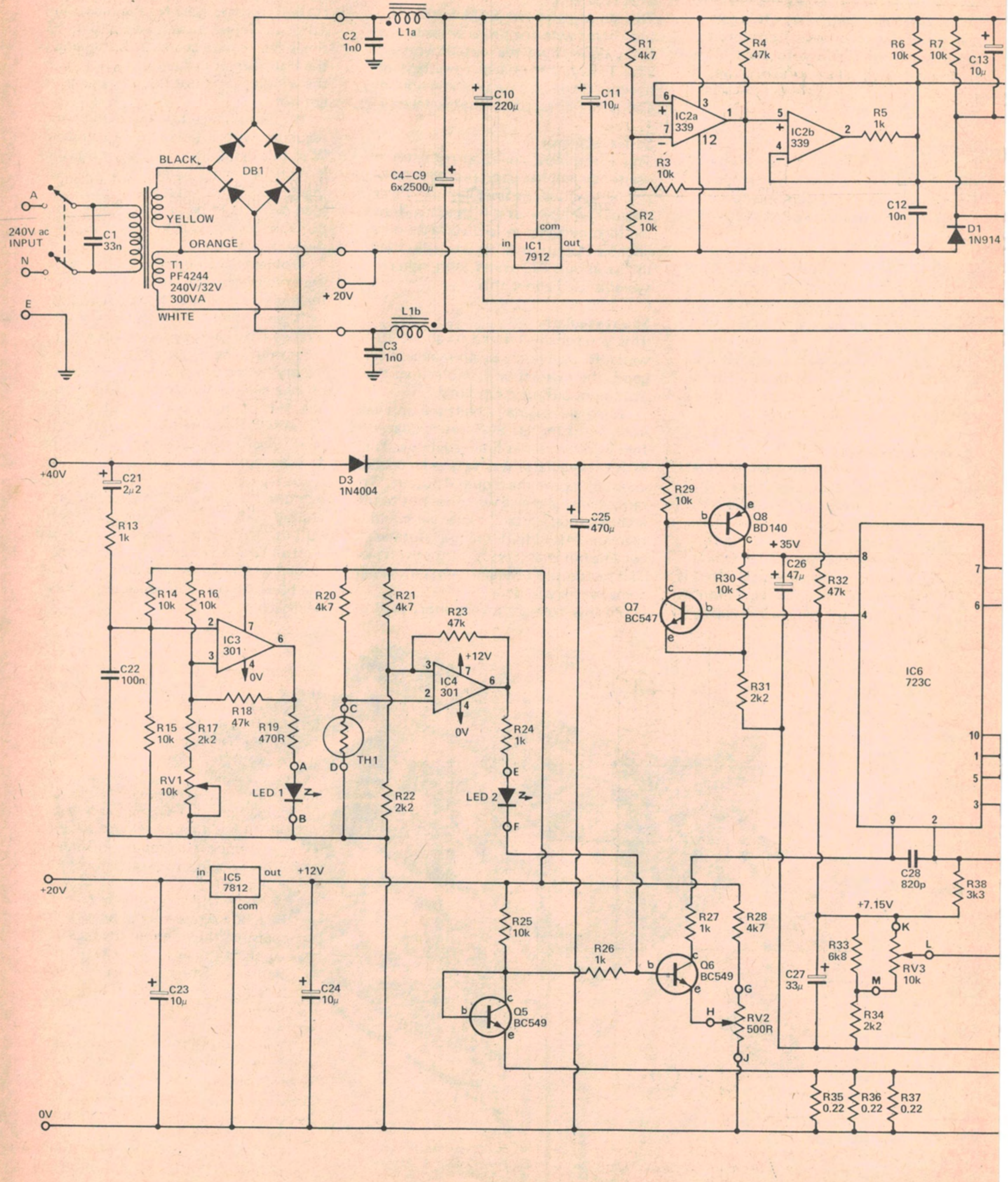
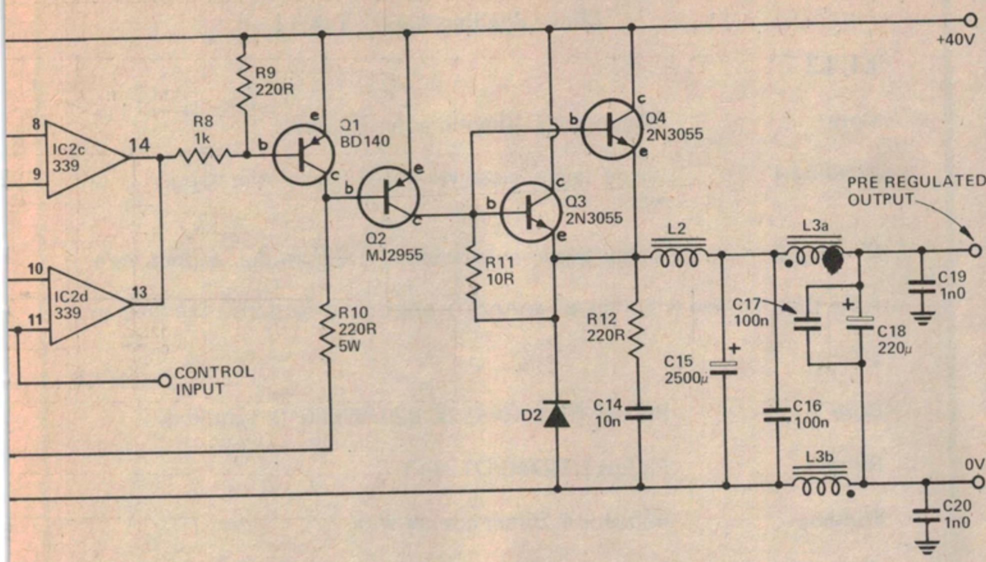
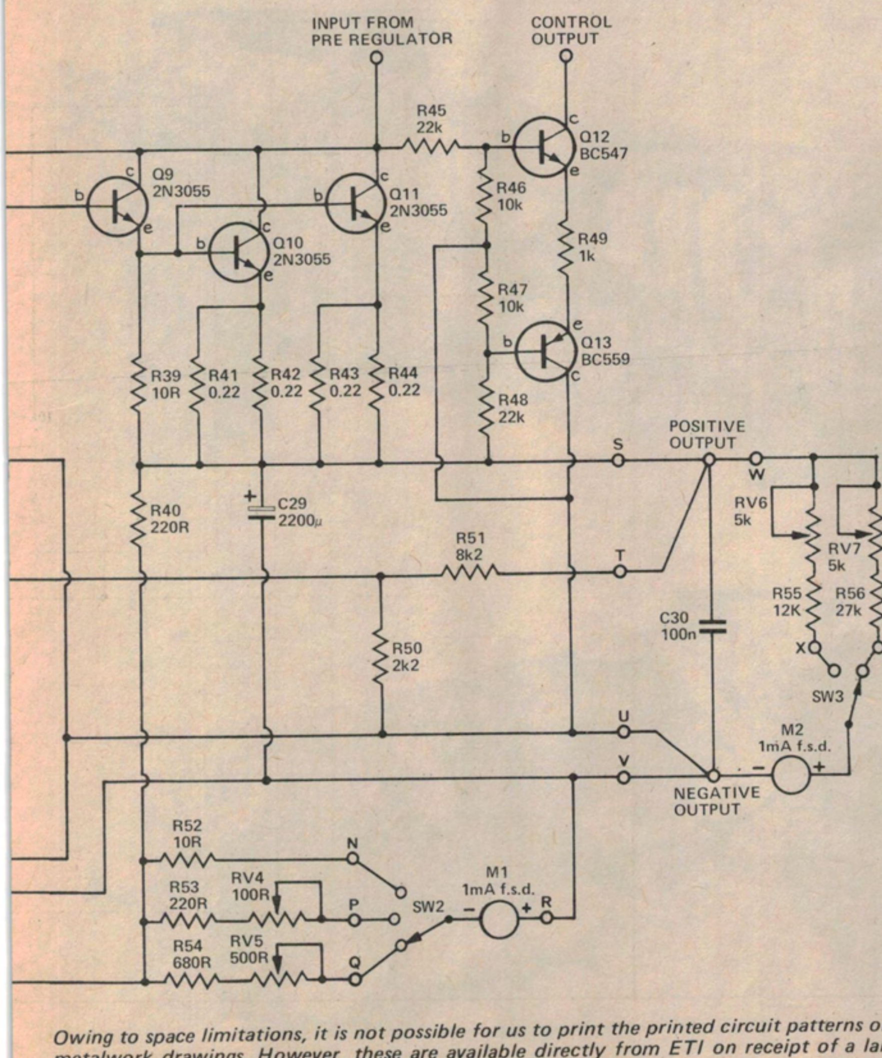


Fig. 1. The circuit diagram of the switching pre-regulator (top) and the series regulator (lower).





Owing to space limitations, it is not possible for us to print the printed circuit patterns or the metalwork drawings. However, these are available directly from ETI on receipt of a large, stamped self-addressed envelope. Send it to: PSU Drawings, Electronics Today, 15 Boundary Street, Rushcutters Bay, NSW 2011.

Construction

The two chokes on the ferrite rods can be wound according to table 1, and the appropriate diagram. Note that the two layers are wound in *opposite* directions and that the start and finish of each coil occurs on diagonal corners. After winding the first layer it is best to smear epoxy cement over it so that it will stay in place.

The main choke can now be wound with four close-wound layers of wire. Bring the start and finish out through the slots in the bobbin. Smear some epoxy over the outer layer to prevent movement and, after it has set, break the ends of the bobbin off as shown in the photograph. This is to enable the coil to be fitted through the hole in the pc board. Break the ends on the *opposite* side to the start/finish.

In the switching regulator the only emitter resistor used with the output transistors is a length of pc board track. It is necessary to ensure that the two transistors used have reasonably close base-emitter voltages. A selection can be made from the five used in the unit by joining the base and collector with a lead and passing 2 to 3 amps from collector to emitter (unless a current source is available it may be simplest to use a 12V battery with a 24-32W globe in series). The two which have the closest base-emitter voltages should be used.

Begin assembly of the switching pre-regulator board by mounting the board on the heatsink brackets with the transistors. As the current passes through the mounting screws it is recommended that 4BA or 4 mm brass screws be used. Also, tin the area where the screws contact the board. Some insulating tubing should be inserted in the holes to prevent the screws touching the sides. Mica insulation washers should be used under the transistors with silicon grease on *both* sides of each washer and also between the two brackets. Before tightening up, temporarily mount the brackets onto the heatsink to ensure that the mounting surface mates well. Tighten a couple of the screws holding the brackets onto the board remove the bracket from the heatsink, then tighten the rest of the screws on the board. As it takes the silicon grease some time to spread out it is best to re-tighten these screws again just before the unit is finally mounted on to the heatsink.

Check that the insulation washers are doing their job and solder the base and emitter leads of the transistors. The diode can also be mounted onto the heatsink using mica and insulation around the stud.

The rest of the components can now be mounted with the exception of the main choke, L2. Be careful that none

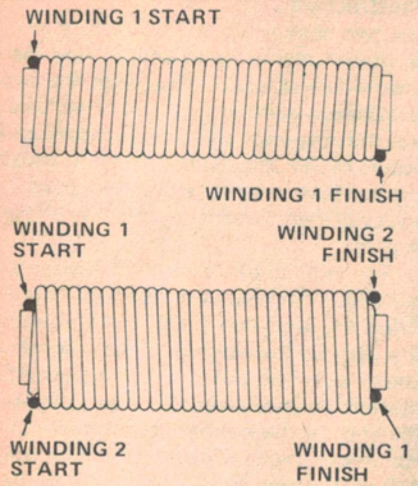
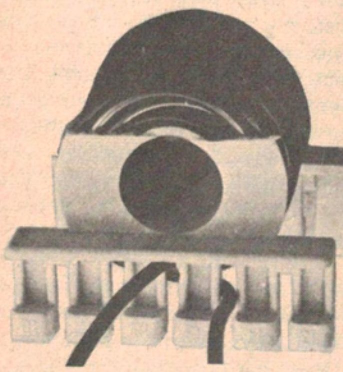


Fig. 2. L 1, 3 with the first layer wound (top) and with both layers wound (lower).

Choke Winding Data Table 1

L1, L3	
Core	50mm long, 10mm dia. ferrite rod
Winding 1	single layer, close wound, 1.25mm dia. copper wire
Winding 2	single layer, close wound, 1.25mm dia. copper wire
Note that the two windings are wound in opposite directions. See diagram.	
L2	
Core	Philips FX3740/4322 020 52520 (2 required)
Bobbin	Philips DT2740/DT2743
Winding	48 turns 1.25mm copper wire
Gap	5mm



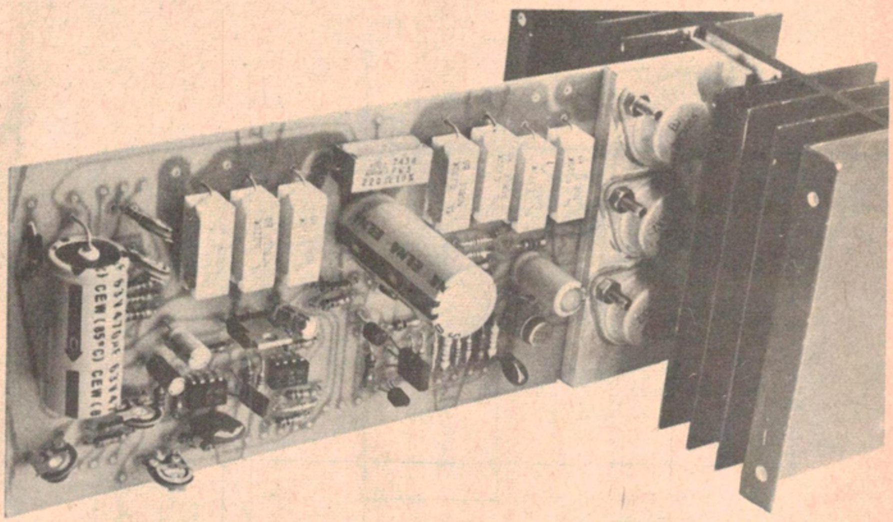
of the components touch the earth screen (with the exception of C2, 3 and C19, 20 which go to ground).

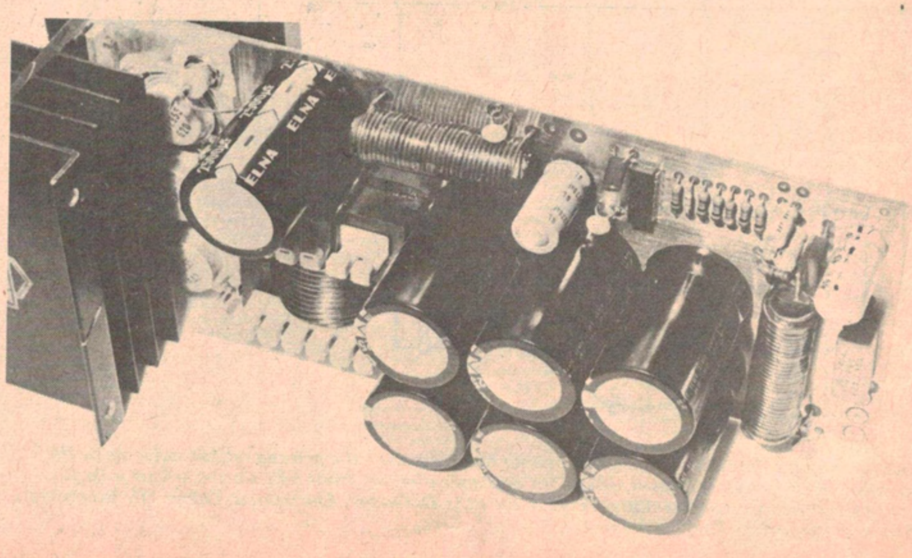
Mounting the Core

Cut two pieces of card or some other non-ferrous material, about 10 mm x 10 mm with a thickness of about 5 mm. These are glued onto the outer legs of one half of the core of L2. Several pieces can be laminated to give the required thickness if required. Slide both halves of the core into the former and bend the leads into such a position that the assembly will fit into the holes provided with no stress on the leads. Lift the coil out, clean the insulation off the leads where needed, place some epoxy on the side of the cores which contact the pc board and refit to the board. When the epoxy is set, the leads can be cut and soldered.

The start of the assembly of the series regulator board is similar to the first board with the exception that there is no power diode used. The board can be assembled according to the overlay — the only point to watch being that the 5 watt resistors should be mounted off the board by 1 or 2 mm, especially if anything but a fibreglass pcb is used (the resistors get warm!).

Start wiring by cutting 17 pieces of





hookup wire about ½ meter long, baring one end and soldering them into the lower row of holes in the series regulator board. Add similar wires to the switching regulator board for the +40V and control input connections. To the output pads on this board, add about 200 mm of wire capable of handling 15A.

Mark the ends of all these wires with the letter on the overlay (a small square of paper held on with tape is easiest). The two boards can now be mounted onto the appropriate heatsinks using silicon grease on the contact area.

Before fitting the pc board to the chassis, mount the transformer, rectifier DB1, 3 core flex, front panel and front panel components. The pcb/heatsink assemblies can now also be added. On our prototype unit the transformer had lugs on the transformer but others will have leads. Note that the wiring that carries the power must be capable of carrying 15 amps or more.

The front panel can now be wired in accordance with fig. 3. Note that C30 is mounted directly across the output terminals on the front panel and similarly C1 is mounted on the power switch. Insulate the bare connections of the power switch with insulation tape to prevent accidental contact.

The thermistor should be soldered onto the appropriate leads (C and D), initially cutting the leads to about 5 – 6 mm long. It should then be epoxied onto the side of the coil in the power transformer. Use the 'slow dry' type of epoxy as this normally works better at elevated temperatures.

Testing and calibration

With a power supply as big as this one, initial power-up is always nerve-wracking and sometimes dramatic. If one is available use a variac to bring up the voltage. If a variac is not available set both the voltage and current limit adjustments to about mid position and switch on.

The voltmeter should now read about 15 volts and it should be adjustable using the voltage control. Measure the voltage between the input and output of the series regulator – this should be about 6 volts. This checks the operation of the switching regulator.

Add a load to the unit to check the operation of the series regulator. If it is correct the meters can now be calibrated. For the low current range (1.5A) it is necessary to select R52 to calibrate the meter (the value is too low for a trim potentiometer).

To set the trim pot for the "warning" LED it is necessary to adjust the unit to 12V output and to load it to 10 amps. The potentiometer can now be adjusted until the led just lights.

HOW IT WORKS - ETI 142

Rectifier

The 240V AC is transformed to 32 V AC by T1 with DB1 rectifying it to give about 45V DC. On full load this voltage will fall to about 35 volts. For the purposes of this description we will refer to this as +40 volts (nominal value). The centre tap of the transformer is used to derive a centre tap DC voltage, reducing power dissipation in some of the electronics.

Switching pre-regulator

In this section, IC1 is used to generate a supply voltage 12 volts *below* the positive supply rail and this powers IC2. This IC has two functions: IC2a and IC2b form a triangular wave generator and IC2c and IC2d a comparator. The voltage on pins 8 and 10 of IC2 is the triangular waveform, varying from -3.6V to -6.3V (referred to the positive rail) with the rising part taking about 50 μs and the falling edge being about 4 μs. This gives a frequency slightly less than 20 kHz.

The comparators IC2c and d are connected in parallel simply to give additional drive capability. The output stage of the 339, for those unfamiliar with it, is simply an open-collector NPN transistor with the emitter joined to the negative supply rail. If the voltage on the control input is within 3.6V of the positive supply rail, the comparator output will be high and so Q1 will be off, Q2 on and Q3 & 4 on. Transistors Q3 and Q4 are in parallel to give additional drive and current sharing is helped by emitter resistance made up of about 60 mm of copper track on the pc board. These transistors should however be the same brand and selected to have similar base-emitter voltages.

If the control voltage is more than 6.3V from the supply rail the comparator output will be low, turning on Q1. This turns Q2, 3 and 4 off. The control voltage oscillates between -3.6V and -6.3V and so the transistors will be turned on and off at 20 kHz, the mark to space ratio being controlled by the control voltage. This effectively varies the output voltage.

The output of Q3, 4 is filtered by L2 and C15 to give a smooth DC voltage. A flyback diode, D2, is necessary and must be a fast recovery type to reduce power dissipation in the transistors. While the choke has an AC voltage across it the current is DC with an AC ripple. For this reason a substantial air gap is used to prevent the core saturating when the current rises to around 15 amps.

Series Regulator

The basis of the regulator is the familiar 723 monolithic regulator IC. The output of this IC is buffered by Q9-Q11 giving the required 15 ampere capability. Normally this IC cannot regulate to below 2V because of the limitations of the comparator. To get around this problem resistor R38 provides some bias current such that when the output voltage is zero the comparator input (pin 2) is above the 2V lower limit. Similarly the potentiometer which controls the output voltage varies not from zero, but from about 2 volts up to the reference voltage from the IC (pin 4) at 7.15 volts.

For those not familiar with the IC, it compares the voltage at pins 2 (inverting) and pin 3 (non-inverting) and adjusts the output on pin 6 to compensate. While this IC can vary the output voltage to within 3 volts of the positive supply rail, it does have a maximum supply of 40V. With this circuit, on no load the supply rises to about 45 volts, too high for the IC. To overcome this we have used a two transistor regulator (Q7, 8) using the reference voltage in the 723 IC to give about 35V on pin 8 of the 723. On full load the regulator ceases to operate as the ripple on the supply rail drops below the 35 volts required. An additional isolation diode and storage capacitor are used to maintain as high a voltage as possible.

Control of the preregulator is done by Q12 and Q13. The voltage from the preregulator and the actual regulated output voltage are both divided by three; if the differential voltage is greater than about 3.6 volts Q12 and Q13 will start to conduct. The collector of Q12 goes to the control input of the preregulator card to vary the voltage from the preregulator. The action of these transistors is to maintain about 5-6V differential between the desired output voltage and the preregulator output.

Current limiting is done by measuring the voltage across R35-37 using Q6. A second transistor Q5 is used to compensate for the 0.5-0.6 volt base-emitter voltage of Q6 and also to compensate for any temperature variations, in the base-emitter voltage.

If the current exceeds the preset value Q6 will start to conduct pulling current out of pin 9 of the 723 IC. This will reduce the output voltage to prevent the current rising above the preset limit.

Current measurement is done simply by measuring the voltage across R35-37. Three ranges are provided. Voltage measurement is done directly across the output terminals with two ranges provided.

The supply is capable of delivering high currents at high voltages for short periods; overload indication is provided by IC3 and IC4. The first of these, IC3, measures the amplitude of the ripple voltage on the main filter capacitors. This effectively gives an indication of the current being drawn from the transformer. When it exceeds a preset level, IC3 changes state, lighting up LED1.

The second indication is given by IC4 which measures the resistance at a thermistor glued onto the transformer. If the resistance drops below about 2.2k ohms the output of IC4 will go high, lighting LED2 and also shutting down the output by overriding the current limiting.

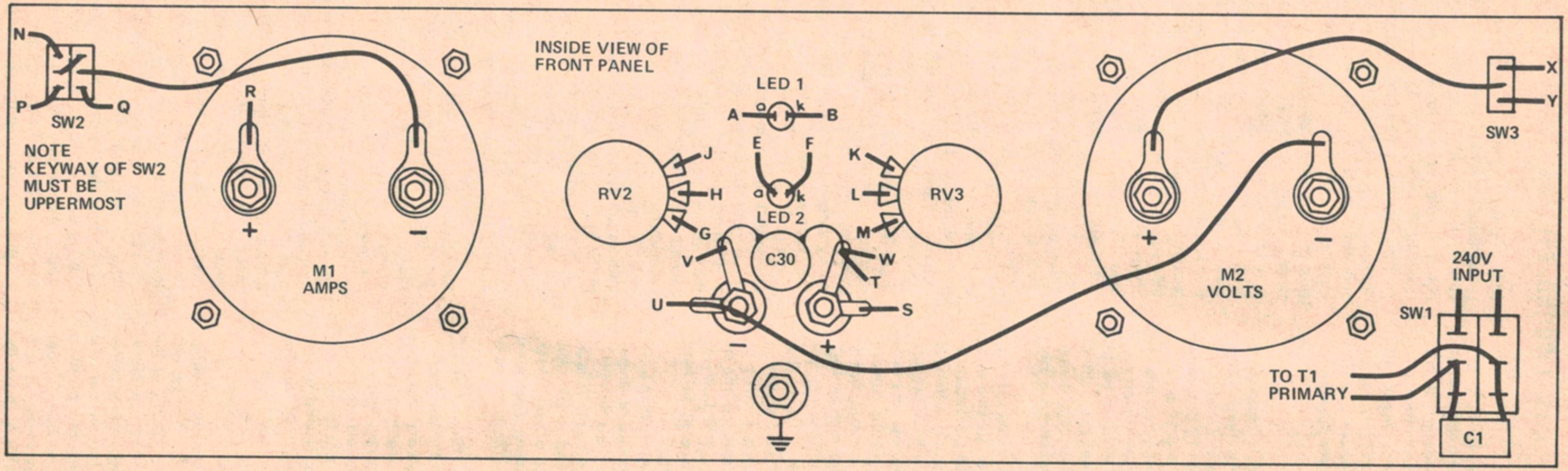


Fig. 3. The front panel wiring diagram.

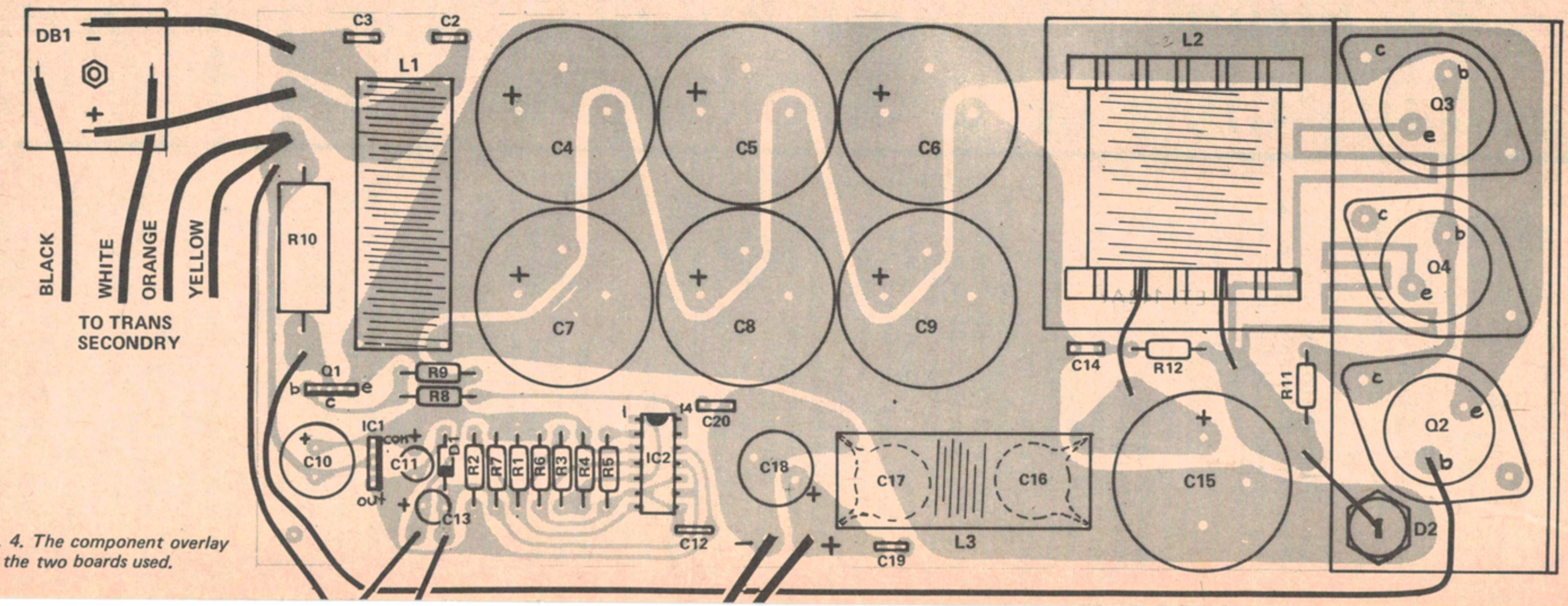
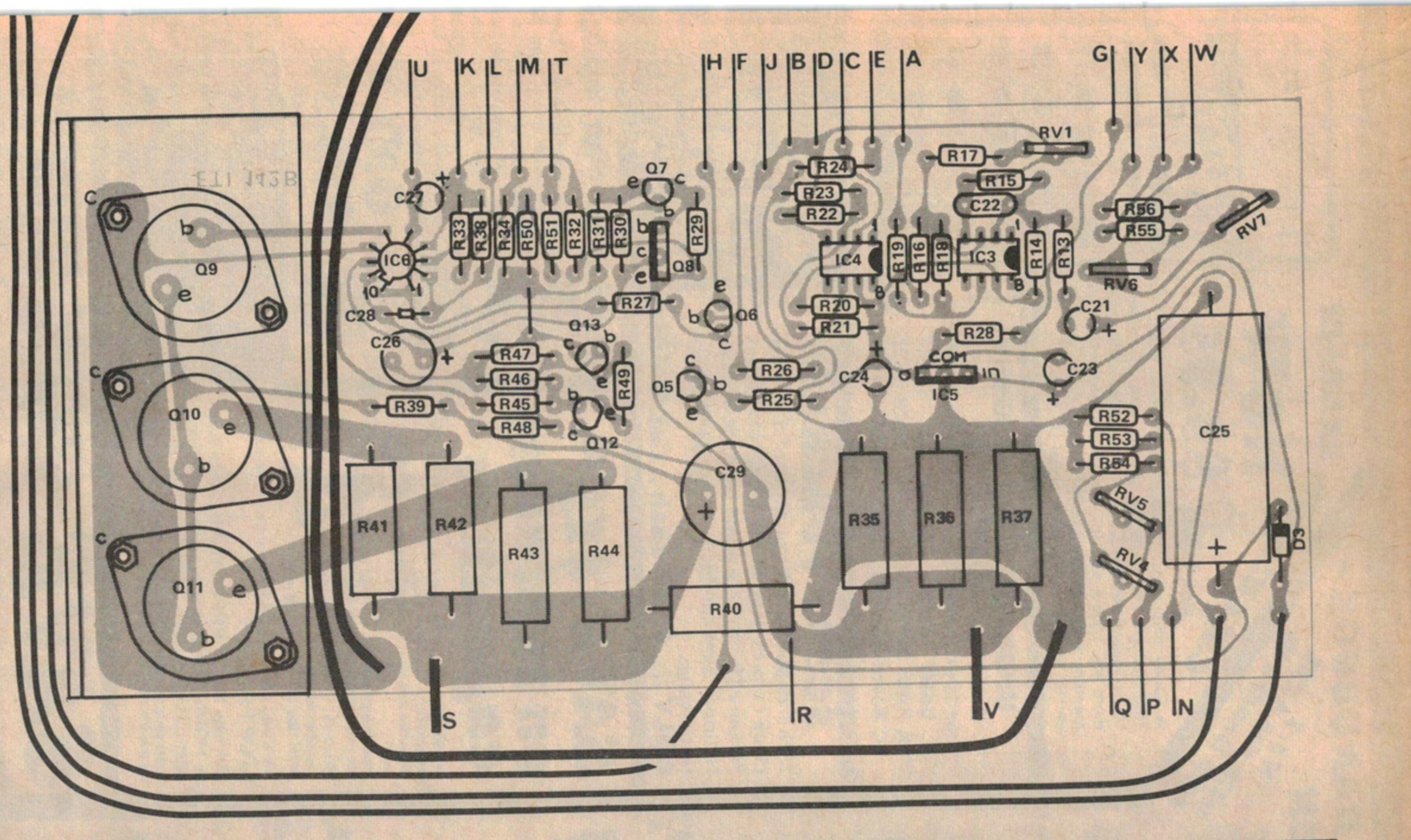


Fig. 4. The component overlay for the two boards used.



PARTS LIST – ETI 142

Resistors all ½W, 5% unless stated
R1 . . . . 4k7
R2,3 . . . . 10k
R4 . . . . 47k
R5 . . . . 1k
R6,7 . . . . 10k
R8 . . . . 1k
R9 . . . . 220R
R10. . . . . . . 220R, 5W
R11. . . . . . . 10R
R12. . . . . . . 220R
R13. . . . . . . 1k
R14–R16 . . . 10k
R17. . . . . . . 2k2
R18. . . . . . . 47k
R19. . . . . . . 470R
R20,21. . . . . 4k7
R22. . . . . . . 2k2
R23. . . . . . . 47k
R24. . . . . . . 1k
R25. . . . . . . 10k
R26,27. . . . . 1k
R28. . . . . . . 4k7
R29,30. . . . . 10k
R31. . . . . . . 2k2
R32. . . . . . . 47k
R33. . . . . . . 6k8
R34. . . . . . . 2k2
R35–R37 . . . 0.22Ω, 5W
R38. . . . . . . 3k3
R39. . . . . . . 10R
R40. . . . . . . 220R, 5W
R41–R44 . . . 0.22Ω, 5W
R45. . . . . . . 22k
R46,47. . . . . 10k
R48. . . . . . . 22k
R49. . . . . . . 1k
R50. . . . . . . 2k2
R51. . . . . . . 8k2
R52. . . . . . . 10R
R53. . . . . . . 220R
R54. . . . . . . 680R
R55. . . . . . . 12k
R56. . . . . . . 27k

Thermistor
TH1. . . . . . . Philips 2322 640 90004

Potentiometers
RV1 . . . . . . 10k trim
RV2 . . . . . . 500R lin rotary
RV3 . . . . . . 10k lin rotary
RV4 . . . . . . 100R trim
RV5 . . . . . . 500R trim
RV6,7 . . . . . 5k trim

Capacitors
C1. . . . . 33n 250Vac
C2,3 . . . . . . 1n0 disc ceramics
C4–C9 . . . . . 2500µ 63V RP electro
C10. . . . . . . 220µ 35V RB electro
C11. . . . . . . 10µ 35V RB electro
C12. . . . . . . 10n polyester
C13. . . . . . . 10µ 35V RB electro
C14. . . . . . . 10n polyester
C15. . . . . . . 2500µ 63V RP electro
C16,17 . . . . 100n disc ceramics
C18. . . . . . . 220µ 50V RB electro
C19,20 . . . . 1n0 disc ceramics
C21. . . . . . . 2µ2 63V RB electro
C22. . . . . . . 100n polyester
C23,24 . . . . 10µ 35V RB electro
C25. . . . . . . 470µ 63V RT electro
C26. . . . . . . 47µ 63V RB electro
C27. . . . . . . 33µ 16V tantalum
C28. . . . . . . 820p ceramic
C29. . . . . . . 2200µ 35V RB electro
C30. . . . . . . 100n disc ceramic

Inductors
L1. . . . . see table 1
L2. . . . . see table 1
L3. . . . . see table 1

Semiconductors
IC1 7912
IC2 . . . . LM339
IC3,4 . . . . . . 301A
IC5 7812
IC6 . . . . 723C (metal pack)

Q1 . . . . BD140
Q2 . . . . MJ2955
Q3,4 . . . . . . 2N3055
Q5,6 . . . . . . BC549
Q7 . . . . BC547
Q8 . . . . BD140
Q9–Q11 . . . . 2N3055
Q12. . . . . . . BC547
Q13. . . . . . . BC559

D1 . . . . 1N914
D2 . . . . 1N3891R,BYX30-200R
D3 . . . . 1N4004

DB1. . . . . . . MDA3502 or similar

LED1,2. . . . . Red LED with mounting

Miscellaneous
PCBs ETI 142A, ETI 142B
Transformer PF4244 (16+16V@300W)
Two 1mA TD86 meters scalled to fig.5
One 10A two pole power switch
One 7101 toggle switch (SPDT)
One 7211 toggle switch (SP3T)
Three terminals posts (red, black, green)
Two knobs
Two 45D4CB heatsinks
Two each, heatsink brackets
Metal box and cover
Front panel
3 core flex and plug
Cable clamp
Rubber feet etc.