

If any circuit is to be accurately and safely tested a good power supply must be used. It is not sufficient for it to be just a stabilised supply, it must also include some form of protection against faults arising in the circuit under test. This usually takes the form of current limiting and output short circuit protection.

In order for it to fulfil its function correctly, a power supply should have the following facilities.

- The ability to deliver fairly high current levels at voltages of 24 V or more.
- It must be completely stable at all output conditions.
- The output must have some form of short circuit protection.
- Current limiting control up to the maximum current output.
- An output voltage control that is fully variable from 0 to maximum.
- Accurate indication of both current and voltage output levels.
- Sense inputs to allow compensation for voltage drops when long supply cables are necessary.

Although the last two points are not strictly necessary, their inclusion makes the power supply more versatile and easier to use.

The precision power supply here follows the standards set by commercial equipment and includes all of the above features. It has a variable output voltage range of 0 to 35 V and continuously variable current limiting up to 3 amps. The performance is on a par with fairly expensive commercial power supplies but approaches the stabilisation problems with a rather novel circuit design.

### The principles

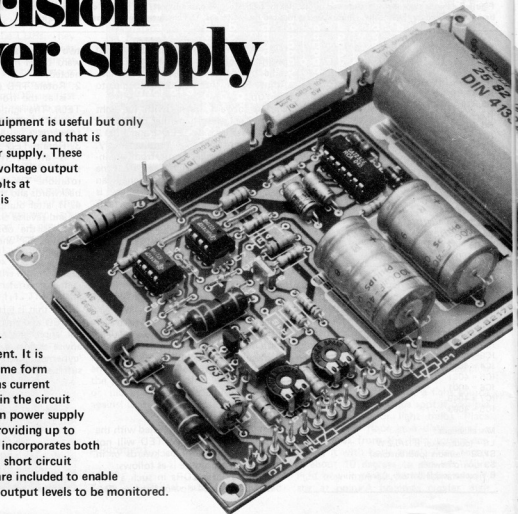
The vast majority of power supplies use either 'series' or 'pass' regulation. This means that the stabilising power transistors are connected (effectively) in series or in parallel to the load. In common with most designs the circuit here utilises series pass regulation. The originality in the circuit design is the method used for stabilisation.

The block diagram in figure 1a illustrates the principle of a conventional series regulator. The active element of the cir-

Good control  
with high power

# precision power supply

Any item of test equipment is useful but only one is absolutely necessary and that is some form of power supply. These normally provide a voltage output of up to 25 or 30 volts at about 1 amp which is fine for most purposes. However, this current level can be rather limiting when testing computers, audio amplifiers and other high power equipment. It is essential too that some form of protection such as current limiting is included in the circuit design. The precision power supply here is capable of providing up to 3 amps at 35 V and incorporates both current limiting and short circuit protection. Meters are included to enable current and voltage output levels to be monitored.



cuit is opamp A and its output is the source of the load current, that is, in series with the load  $R_L$ . The non-inverting input of the opamp is held at a reference voltage,  $U_{ref}$ . The inverting input of the opamp is at a voltage level that is a proportion of the input voltage — derived by potentiometer P. Under these conditions the output of the opamp will become stable at the point where the voltage difference between the two inputs is zero. That is, the opamp will maintain a condition where the reference voltage and that at the wiper of potentiometer P are equal. It will be obvious that the output voltage will therefore be dependant on the position of P. With the potentiometer in mid position the output will be double the reference voltage. The disadvantages of this system are that the stability factor is dependant on the setting of potentiometer P, the output can never be lower than the reference voltage and the operation of P will not be linear. Two of these points may not be so significant in some cases but an output minimum that is restricted to the reference voltage will be embarrassing to say the least!

The block diagram of figure 1b provides another solution. In this case, the opamp is used as a unity gain amplifier and P becomes a voltage divider connected across the reference voltage. The output of the opamp will now be proportional to the voltage level at the wiper of P.

In this configuration the output range will be between 0 and the reference voltage. This sounds better but it is still far from ideal. The opamp will now require a negative voltage supply rail, an added disadvantage.

The reference voltage must be at least as high as the maximum required output, not an ideal situation! Finally, the stability factor is still a question of potentiometer P.

Figure 1c goes a long way towards removing the problems by replacing the reference voltage, as far as the opamp is concerned, with a reference current. The output voltage is now determined by the current passing through P. The advantage is that the circuit is no longer dependant on the reference voltage level.

We now arrive at figure 1d which, in principle, is very similar to 1c. The ref-

erence current in this case is derived from the output voltage via a series resistor R. The idea is not entirely new but the method used here is a little unorthodox.

As previously mentioned, a current source is achieved by placing a resistor in series with a reference voltage derived from the output. However, for this to happen in practice, the value of potentiometer P has to be much lower than R. The opamp still tries to balance out the difference between the voltage levels at its inputs but now the output voltage will be equal to the level on its non-inverting input.

The series resistor is effectively placed between the two inputs of the opamp. However, due to the high impedance of the inputs, theoretically at least, no current can enter the opamp. In effect then, the current derived from the reference source follows the path shown as a dotted line in the block diagram. Since  $U_1 = U_2$  (the opamp ensures this) the current level is equal to  $\frac{U_{ref}}{R}$ . The

opamp will balance out the voltage across P and, in doing so, the reference current is compensated for any change in load. The result of all this is that the circuit conforms to what we are looking for, a constant reference current (even at 0 V) using a reference voltage source and a resistor.

### The precision power supply

The major difference between the block diagram of the precision power supply in figure 2 and that of figure 1d is the fact that two opamps and a series pass power transistor are included. The current source ( $U_{ref}$  and R) and the potentiometer P1 are very similar.

The second opamp A2 is responsible for output current limiting. The voltage across the emitter resistor  $R_S$  of transistor T is proportional to the output load current. A proportion of the reference voltage is derived by the setting of P2 and this is compared to the voltage across  $R_S$  by opamp A2. When the voltage across  $R_S$  becomes higher than that set by P2, the opamp reduces the base drive current to T until the difference is reduced to zero. The LED at the output of A2 functions as a current limiter.

### The circuit diagram

So much for the theory, now for its practical application. The circuit of the power supply, shown in figure 3, has two independent power supplies (if that makes sense!). The power for the output stage is provided by transformer Tr2 which, of necessity, will be rather a hefty beast. Transformer Tr1 provides power for the reference source and the opamps.

The reference source is derived with the aid of the inevitable 723 (the worlds longest living chip?). The components

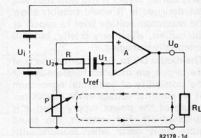
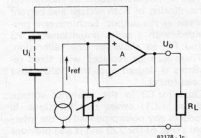
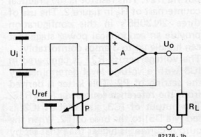
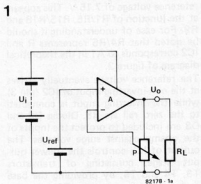


Figure 1. The drawings here, in conjunction with the text, illustrate the advantages of why the use of a constant current reference source is preferable to a reference voltage.

around this IC were chosen to provide a reference voltage of 7.15 V. This appears at the junction of R1/R5, R15/R16 and R9. For ease of understanding it should be noted that R4/R5 represents R and IC2 corresponds to A1 in the theoretical diagram of figure 2.

The reference voltage eventually arrives at the non-inverting input of IC2 (pin 3) while the inverting input is connected to the zero rail via R8. Diodes D2 and D3 are included to protect the inputs of the opamp against surge voltages. The output of IC2 controls the power output stage, consisting of transistors T3, T4 and T5, by providing the base drive current for transistor T2.

A word about transistors T3...T5. These are connected in parallel and their outputs are combined via emitter resistors to provide the power supply output via R21. This resistor is the practical counterpart of  $R_s$  in figure 2. The use of three 2N 3055's in this configuration provide an economical power stage that can handle up to 3 amps comfortably.

The voltage across R21 is compared in IC3 with a voltage level determined by the setting of P2. This latter is derived from the reference source via R15/R16.

The output of IC3, like that of IC2, is fed (via D5) to the base of T2. When the output current is higher than that set by P2, the output current is reduced by IC3 until the two levels are matched. Transistor T1 and its surrounding components cause the LED D7 to light when current limitation is in effect.

Two meters are included to allow direct monitoring of both voltage and current levels at the output. Each meter is provided with a series potentiometer, P3 and P4, to allow for fine calibration. These can be replaced with fixed resistors if desired once their values have been found.

Capacitor C3 in the reference voltage circuit (IC1) serves two functions. It reduces any noise produced by the internal zener of the 723 and it also provides a 'slow start' for the reference voltage supply. This means that when the power supply is first switched on, the opamps are giving time to 'settle down' before being asked to do any work, a sort of early coffee break! If this slow start was not designed in it could possibly allow the maximum voltage level to appear at the output, albeit very briefly, but still potentially damaging.

The diodes D1 to D8 in various parts of the circuit are included to guard against the possibility of accidental connection of an external voltage to the output terminals of the power supply when it is switched off. For instance, this could quite easily occur when working with a circuit that has a built in battery back-up.

Components R7 and C6 increase the reaction time of the circuit when changing output voltage levels while capacitors C7 and C8 eliminate the possibility of oscillation in the opamps. For stable operation of the circuit a minimum

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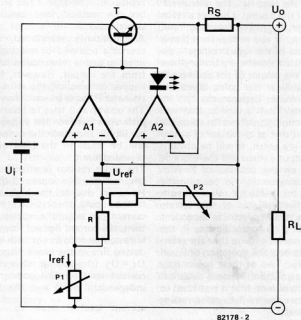


Figure 2. The basic block diagram of the precision power supply. Opamp A1 provides the voltage regulation while A2 takes care of the current limiting.



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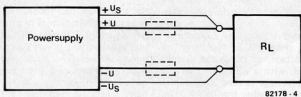


Figure 4. The two sense inputs are used in the manner illustrated here to enable the circuit to compensate for voltage drops caused by the use of long cables.

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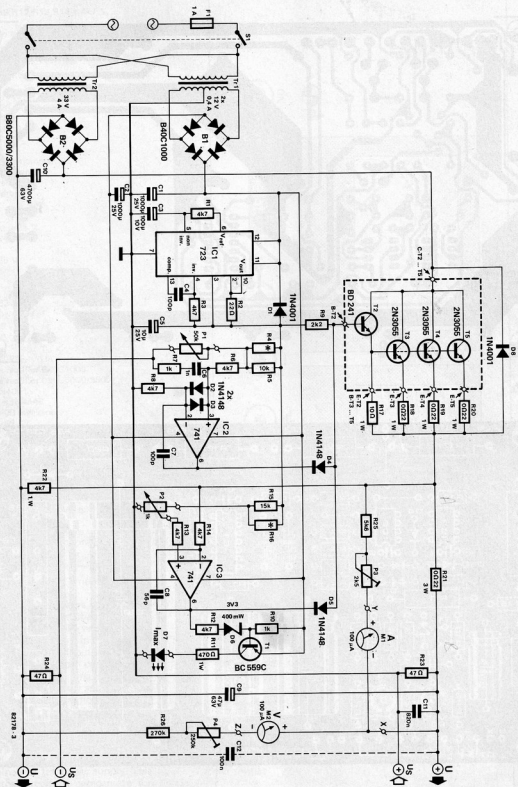


Figure 3. The circuit diagram of the precision power supply. Resistors R4/R5 correspond to R in figure 2, IC2 to A1, IC3 to A2 and R21 to R5. Of the two transformers, Tr1 provides the supply for the reference current source while Tr2 supplies the power for the output stage.

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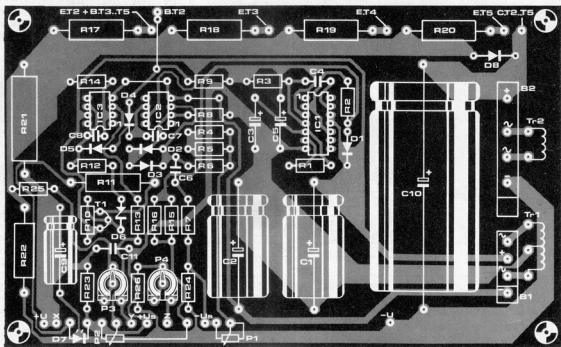
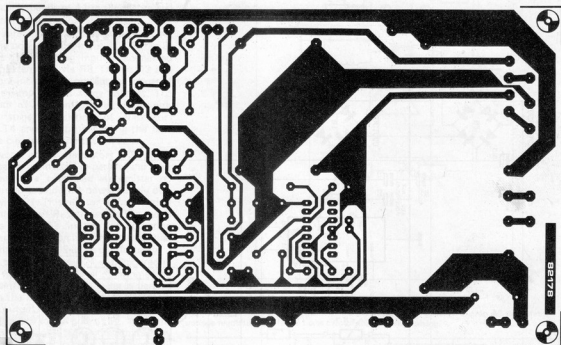


Figure 5. The track pattern and component layout for the printed circuit board used for the precision power supply.

## Parts list

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## Resistors:

R1,R3,R6,R8,R12,R13,R14 = 4k7  
 R2 = 22  $\Omega$   
 R4,R16 = see text  
 R5 = 10 k  
 R7,R10 = 1 k  
 R9 = 2k2  
 R11 = 470  $\Omega$ /1 W  
 R15 = 15 k  
 R17 = 10  $\Omega$ /1 W  
 R18,R19,R20 = 0,22  $\Omega$ /3 W  
 R22 = 4k7/1 W  
 R23,R24 = 47  $\Omega$   
 R25 = 5k6  
 R26 = 270 k  
 P1 = 50 k potentiometer  
 P2 = 1 k potentiometer  
 P3 = 2k5 preset  
 P4 = 250 k preset

## Capacitors:

C1,C2 = 100  $\mu$ /25 V  
 C3 = 100  $\mu$ /10 V  
 C4 = 100 p  
 C5 = 10  $\mu$ /25 V  
 C6 = 1 n  
 C7 = 100 p  
 C8 = 56 p  
 C9 = 47  $\mu$ /63 V  
 C10 = 4700  $\mu$ /63 V  
 C11 = 820 n  
 C12 = 100 n

## Semiconductors:

B1 = bridge rectifier B40C1000  
 B2 = bridge rectifier B80C5000/3300  
 D1,D8 = 1N4001  
 D2...D5 = 1N4148  
 D6 = 3V3 400 mW zener  
 D7 = LED red  
 T1 = BC 559C  
 T2 = BD 241  
 T3,T4,T5 = 2N3055  
 IC1 = 723  
 IC2,IC3 = 741

## Miscellaneous:

S1 = double pole mains switch  
 M1,M2 = 100  $\mu$ A meter  
 T:r1 = 2 x 12 V/400 mA mains transformer  
 T:r2 = 33 V/4 A mains transformer  
 F = 1 A fuse

output load resistance is necessary. This is taken care of by R22.

It will be noted that there appear to be more output terminals than the usual power supply needs. The two extra outputs, +U<sub>s</sub> and -U<sub>s</sub>, are in fact inputs. These so-called 'sense' inputs are used to allow for voltage drop compensation when working with long connecting cables between the power supply and its load. Figure 4 illustrates how the inputs are used. Two extra wires are connected as shown between the load and the sense inputs. The result of this is that the supply voltage level is now effectively measured at the load and not at the output terminals of the power supply. This enables the circuit to compensate for any voltage drop resulting from the resistance in the main supply cables. It should be noted that if the total resistance of the two main supply cables is 1  $\Omega$ , at the current level of 1 A the voltage drop will be 1 V. In normal use,

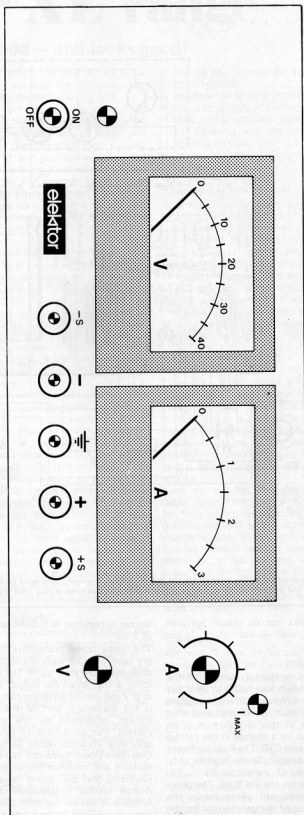


Figure 7. The design of the front panel that is available from Elektor. It is manufactured from scratch resistant polycarbonate material and is self-adhesive. The illustration is at a reduced scale, the actual size is 11 cm by 30 cm.

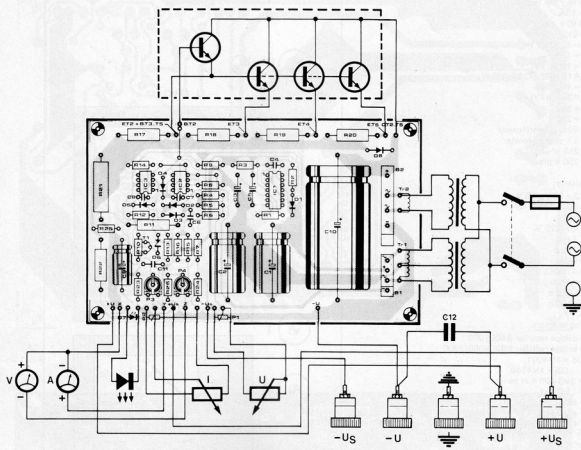


Figure 6. The practical wiring diagram for the power supply. Obviously care must be taken with connections, especially with respect to the transformers and power transistors. Errors in this area will not become visible until the smoke clears!

shorting links can be placed between  $+U$  and  $+U_S$ , and  $-U$  and  $-U_S$ .

### Construction

The maximum output current of the circuits as shown here is 3 A at 35 V but in principle different current ratings are possible. It must be remembered that any change in this direction must be accompanied by a change in the ratings of both C9 and C10. The limiting factor is the maximum collector/emitter voltage capability of transistors T2...T5. This is 60 V for the 2N 3055. The other deciding factor will of course be the current rating of the transformer for the power output stage. The maximum output of the power supply is a factor  $\frac{1}{\sqrt{2}}$  of the current supplied by the transformer which explains why a 4 A trans-

former is required to achieve an output of 3 A.

The three power transistors in parallel are used because each 2N 3055 cannot dissipate more than 50 W. The consideration is that when the output voltage is at 0 V the maximum dissipation required is the maximum level of the rectified voltage multiplied by the maximum current. For an output of 1 A at 35 V only one 2N 3055 would be sufficient. One more power transistor can be added without any modification to the circuit providing that the correct value for the emitter resistor is calculated. A  $2^\circ\text{C/W}$  heatsink is needed for each power transistor or a  $1^\circ\text{C/W}$  for each pair. Capacitor C12 is mounted directly onto the output terminals as shown in figure 6. Do not mount the resistors R4 and R16 initially as their value will depend on the maximum output voltage and cur-

rent. For this reason it will not be possible to mount the printed circuit board into the case until test and calibration is completed. Set P1 to maximum, switch on and connect a multimeter to the output of the circuit. By trial and error find the actual value of R4 which gives the maximum required output voltage. This can be done by connecting different resistors in parallel to R5. When the correct value has been found it can be soldered in place on the board. Repeat the exercise with P2 and R16 (in parallel with R15) until the maximum current level is found.

The remaining calibration is that of the meters by adjustment of P3 and P4. It is possible to build the power supply using only one meter. In this case a 2 pole 2 way switch connected to points x, y and z is required to switch between volts and amps.