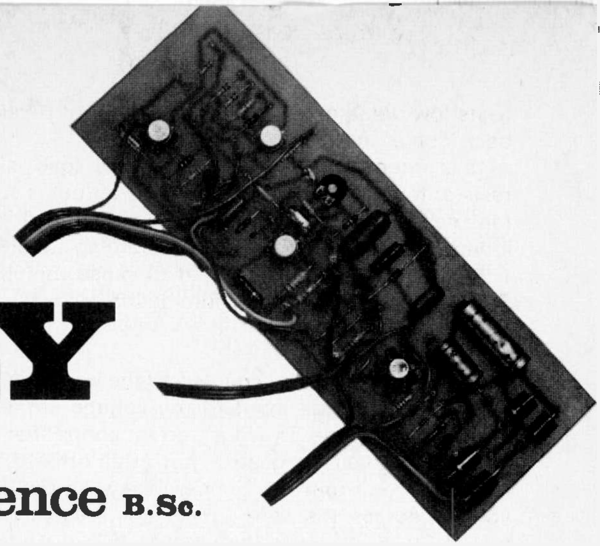
High Performance POWER SUPPLY UNIT



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THIS article describes a high performance power supply with voltage control down to zero (yes, zero, not two and a half volts or five and a quarter or, as in the case of many supplies, whatever the Zener voltage used in the system happens to be) and current limit from a few milliamps to several amps.

This ability to have current limit down to such low values allows one to, for example, work with low power circuitry knowing that even if something drastic happens nothing will be destroyed. One can even use this facility for measuring the values of larger electrolytic capacitors!

SPECIFICATION . . .

- **Voltage Control** 0–30V
- **Current Control** 2mA–2A
- **Output Resistance** Less than 0·001Ω
- **Ripple and Noise** Less than 1mV
- **Line Regulation** Less than 0·001%
- **L.e.d. indicator current limit mode**
- **Sharp voltage/current mode transition**
- **Instant switch off**

CIRCUIT ACTION

The reference voltage is generated in the circuitry around IC1 (see Fig. 1). D5 is a 5·6V Zener diode run at its zero temperature coefficient current. Values of most Zener series (BZY88 in particular) exhibit positive temperature coefficient below 5·6V and varying degrees of negative t.c. above this value.

R5 and R6 set the output of the reference generator at twice the Zener voltage and in addition a low output impedance feed to the rest of the p.s.u. is guaranteed by the high degree of feedback employed.

The circuit operates as follows; the output of the op amp IC1 increases until D8 conducts, whereupon the circuit stabilises with the Zener voltage appearing across R5. Negligible current flows into the non-inverting input of IC1 and therefore all the current in R5 flows into R6 yielding twice the Zener voltage at the output of IC1.

AMPLIFIER

Unlike most power supplies, instead of providing voltage control by means of varying the feedback factor in a control system, this design uses what is in effect a "uni-phase power amplifier" arrangement.

The reference section provides 2 x 5·6 = 11·2V, and we require 30V out, hence the gain of the amplifier is 30/11·2.

The resistors R11 and R12 determine the gain, and this is given by:

$$\bar{A}_v = \frac{R11 + R12}{R11}$$

which can be re-written in terms of V_{ref} (11·2V), and the output voltage V_{out} (30V) as the ratio of the two resistors:

$$\frac{R11}{R12} = \frac{V_{ref}}{V_{out} - V_{ref}} = 0{\cdot}59$$

PREFERRED VALUES

Two preferred values which give this ratio whilst at the same time approximately maintaining an equivalent impedance looking back from either the inverting or non-inverting inputs of the op amp (this keeps temperature drift effects in the input bias currents common-mode and therefore self-cancelling) are 33kΩ and 56kΩ.

ADVANTAGES

One of the advantages of using a "power amplifier"-type system in the voltage section is that the control of output voltage down to zero can be achieved easily. Other designs allow this to be performed but solutions sometimes can appear somewhat contrived. With the amplifier system zero input means zero output.

For perfectionists a preset has been provided which allows one to trim out any remaining millivolts which can be caused by offset in the 741 or possibly the voltage control potentiometer not yielding exactly zero output voltage when turned fully anti-clockwise.

CURRENT LIMIT SYSTEM

The current limit system sets the maximum output current available from the p.s.u. and also provides an indication that the unit has shifted from constant voltage mode to constant current mode.

Current limit comes into operation when the voltage across a sensing resistor (R7) reaches a predetermined value. This value is set by VR3 and is derived from the reference voltage line from IC1.

OPERATION

All the current that flows from the output terminals must also flow through R7. If we now consider the circuitry around IC3: the inverting input is biased at 0V via R21, whilst the non-inverting input can be adjusted to any voltage between 0 and 2V. Say it is set at 1V and the output voltage at several volts. If the load is increased the voltage output will be held at a constant value by the voltage amplifier section and the presence of R7 will have a negligible effect due to its low value and because it is situated outside the feedback loop of the voltage control circuitry.

It is interesting to note that if the load is constant (a resistor for example) and the voltage output is constant, then the current through R7 is constant and substantially independent of any ripple in the incoming supply.

If the load is now increased to cause the voltage across R7 to reach 1V, IC3 comes into action.

COUPLING

The output of IC3 is coupled to the non-inverting input of IC2 (essentially the input to the voltage amplifier arrangement) with a diode. Thus the current control can "cut in" and override the voltage control, but at all other times is totally disconnected from it. Hence, when in our example the voltage across the sensing resistor reaches the predetermined 1V, IC3 adjusts the input to IC2 in such a fashion as to maintain this voltage across the resistor and thereby form a second dominant control system—except this time controlling output current and not voltage.

C8 provides compensation in this loop to maintain stability.

INSTANT "SHUT-DOWN"

In order to prevent any spurious effects that may occur as the negative rail voltage decays away when power is removed from the unit, transistor TR1 removes drive to the output stage as soon as the rail collapses.

Under normal operation TR1 is held off by R14, but when the negative rail fades TR1 comes on and holds the output of IC2 low. This does no damage to the i.c. as the 741 has comprehensive internal output current limit circuitry built into it which limits its output current to a safe 15–20mA.

The fact that the output from the p.s.u. disappears virtually instantaneously can be an asset when doing test or experimental work. It allows one to kill the supply and perform circuit modifications without having to wait first for the power supply's internal capacitor to slowly discharge.

CONSTRUCTION

Construction should commence with the etching of the p.c.b. and then assembling components onto this as shown in Figs. 2 and 3. As this layout has been proven, it is wise to stick to it as much as possible to ensure stability. The remaining peripheral components should then be connected.

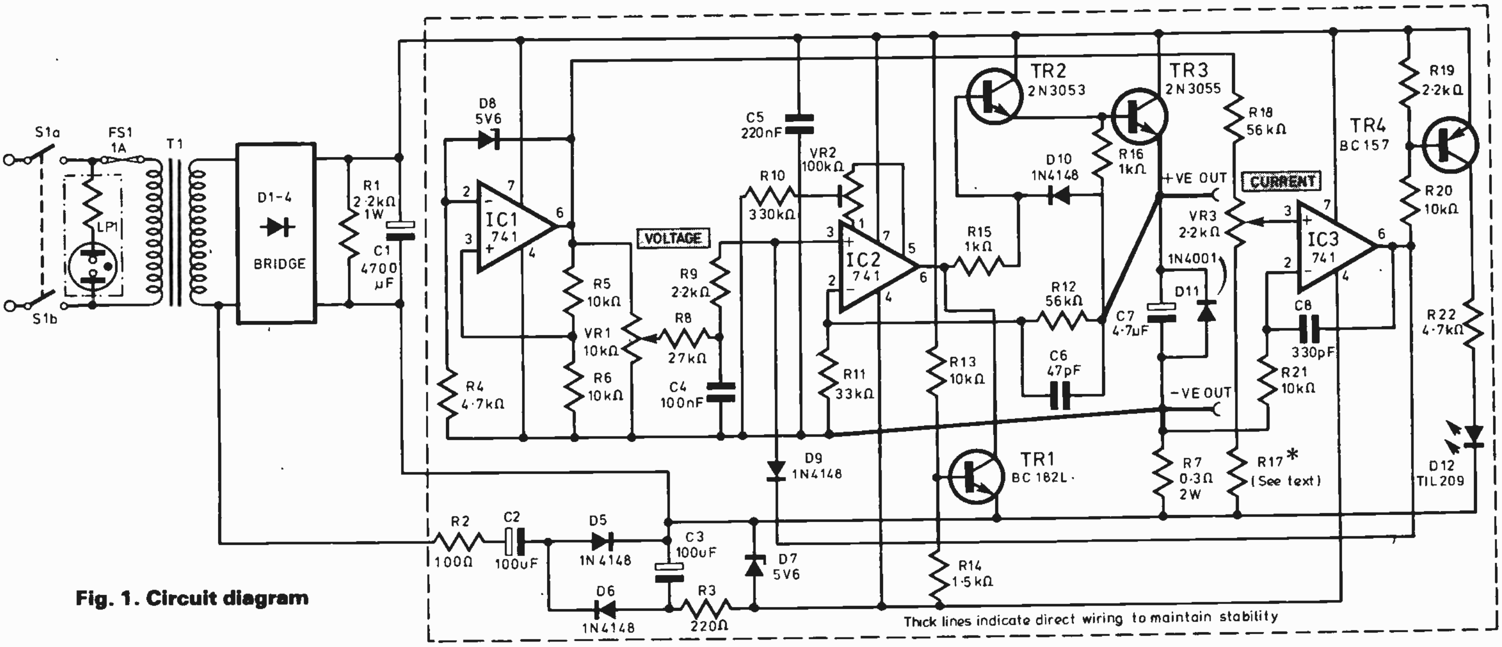

Fig. 1. Circuit diagram

SUPPLY CURRENT

There is a small amount of current which flows through R7 which does not go to the load. This constitutes the negative supply current to IC1 and the Zener current. This is the reason for R17. It allows voltage appearing across R7 due to this current, and also any due to remanent resistance in VR3 (when fully anti-clockwise) to be offset. Normally it should lie in the range 0-100Ω (typically about 33Ω).

NEGATIVE RAIL GENERATOR

The circuitry around C2 and C3 forms the negative rail generator. This is required to enable IC2 to control the output voltage down to zero. Similarly since IC3 has to control the input of IC2 down to zero, it too requires a negative supply. IC1 is operating under fixed conditions, however, and therefore can be run between the positive unregulated input and earth.

The negative generator is simply a pump system with simple stabilisation on its output (R3 and D7).

TESTING

When building p.s.u.s, power amps. etc. initial switch-on can be a little nerve racking, as small mistakes can easily result in drastic burn-ups. Ideally a Variac should be used here, as then the input current to the system can be watched whilst the input voltage is slowly increased. If it is seen that the current has risen beyond a reasonable value then the circuit can be checked and the replacement of burnt, charred components is happily avoided.

However, in the absence of a Variac a low value resistor (20-50Ω) of a Watt or so rating can be used in series with the secondary of T1, together with a multimeter set to 1A a.c.

When power is applied the meter should just give an initial kick and then settle down to a low value (10-30mA). A fault condition exists if the resistor overheats and/or the current is substantially higher than the above readings.

Assuming the first switch on has been successfully accomplished and the unit is drawing the correct current, short out the series resistor and make sure the current is still around 30mA.

Now check that the output of IC1 is between 11V and 12V with respect to the negative output terminal. Check that pin 3 of IC2 varies in voltage with the position of VR1, and that when VR1 is fully anticlockwise there is in fact zero volts at this point.

Next check that the negative supply pins of IC2 and IC3 are at between −5V and −6V with respect to the negative output. After this check the output of the supply can be varied from zero to 30V. With VR1 fully anit-clockwise adjust VR2 to trim out any remaining millivolts.

CURRENT LIMIT

Once the voltage system is known to be satisfactory the current limit system can be checked. Diode D9 connects the output of IC3 to the non-inverting input of IC2 and it is worth noting that if IC3 output is staying low for some reason this will override VR2. If it is suspected that there is a fault in the current limit system, D3 can be removed and the two systems isolated. It should of course be replaced before the current limit system is examined.

To check the current limit system, first make sure that pin 3 of IC3 varies from 0V to about 2V when VR3 is adjusted. Turn VR3 to a minimum. If D12 lights it means R17 is too

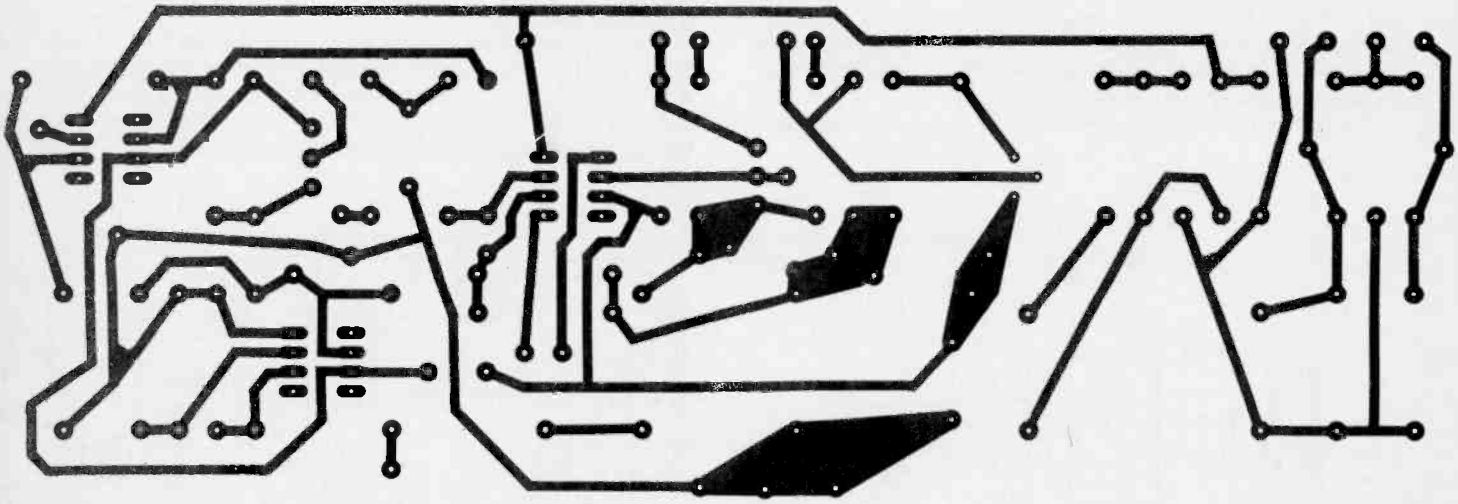

Fig. 2. P.c.b.

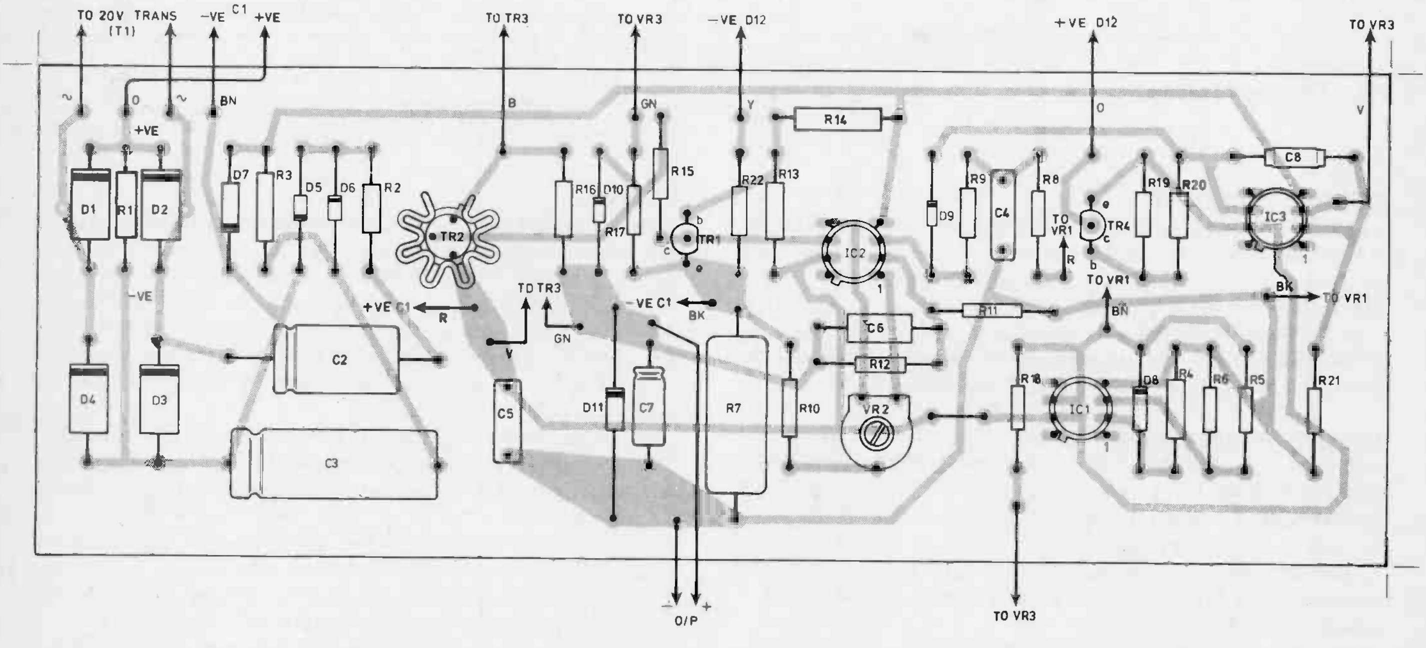

Fig. 3. Component layout. If bridge rectifier used R1 can be connected directly to C1

low. Ensure first though that it is not a fault condition.

Now turn VR1 to give zero output voltage (check this with a multimeter). Set the multimeter to about 100mA d.c. and slowly turn up the output voltage with VR1. If all is well, D12 should light and the current should limit at a low value (2-5mA). If this does not happen check D9 and IC3 and associated circuitry, with the usual attention being payed to such things as dry joints and solder splashes.

When this stage has been reached a value can be given to R17 if D12 still comes on at VR3 minimum setting. As mentioned above it should allow current control down to 3-5mA.

METERING

A meter is a very useful feature to have on a power supply. It is possible to do without one by having calibrated voltage and current controls but this does restrict the unit somewhat.

A circuit which allows switchable current/voltage monitoring is given in Fig. 4. Current is measured by monitoring the voltage across R7. This means the unit's very low output impedance is preserved.

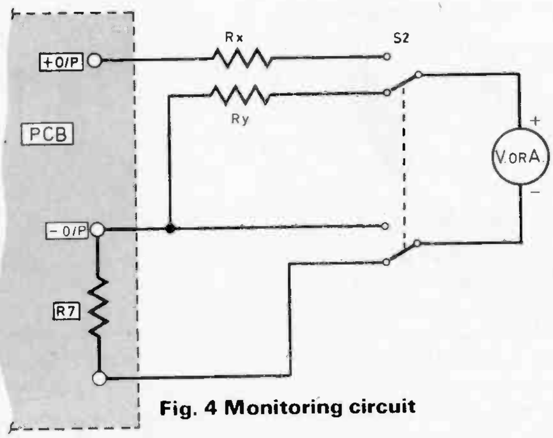

Fig. 4 Monitoring circuit

R_x and R_y are determined by the meter sensitivity and resistance. If the meter sensitivity is ImA for f.s.d. and it has a resistance of $R_m\Omega$, then R_x will be obtained from:

$$R_x = \left(\frac{30}{I} \times 1000 - R_m\right)\Omega$$

Similarly R_y is obtained from:

$$R_y = \left(\frac{1}{I} \times 1000 - R_m\right)\Omega$$

If two meters are available, of course, both voltage and current can be monitored simultaneously and S1 can be done away with.

HEATSINKING

Any linear power supply with a reasonable output should be equipped with generous heatsinks, and this is no exception. The worst-case condition for these "linear" type supplies is when they are supplying a high current at a low voltage. The dissipation in the series pass transistor can reach as high as 50W in this case and to keep the junction temperature of the series transistor down to a safe value a heatsink of around one degree C per Watt or better should be used.

The constructor's discretion can be resorted to here: if it is apparent that the unit is severely overheating and the transistor TR3 far too hot to touch (don't get misled however, they can take junction temperatures in excess of 150 degrees C) then greater heatsinking should be employed. ★

COMPONENTS . . .

Resistors

R1	2·2kΩ 1W
R2	100Ω
R3	220Ω
R4	4·7kΩ
R5	10kΩ
R6	10kΩ
R7	0·3Ω 2W
R8	27kΩ
R9	2·2kΩ
R10	330kΩ
R11	33kΩ
R12	56kΩ
R13	10kΩ
R14	1·5kΩ
R15	1kΩ
R16	1kΩ
R17	0–100Ω (33Ω typ. see text)
R18	56kΩ
R19	2·2kΩ
R20	10kΩ
R21	10kΩ
R22	4·7kΩ

All ½W carbon except where otherwise stated

Potentiometers

VR1	3 good quality 10kΩ log.
VR2	100kΩ miniature carbon preset

Capacitors

C1	4,700μF 40V elect.
C2	100μF 40V elect.
C3	100μF 40V elect.
C4	100nF polyester
C5	220nF 63V plastic or ceramic
C6	47pF plastic or ceramic
C7	4·7μF 35V tantalum (or elect.)
C8	330pF plastic or ceramic

Semiconductors

IC1-3	741 (any manufacturer as long as good quality, esp. for IC2)
TR1	BC182L
TR2	2N3053
TR3	2N3055
TR4	BC157
D1-4	Any 3A 50V bridge (or 4 discrete 3A diodes) e.g. RS type 261-457
D5-6	1N4148, 1N914
D7-8	BZY88-5V6
D9-10	1N4148, 1N914
D11	1N4001
D12	Any suitable l.e.d. (TIL 209 etc.)

Miscellaneous

Mains transformer 240V primary, 20 to 25V, 2A secondary. Heatsink for TR3, approx. 1 deg. C per Watt (plus mica insulation kit) RS type 401-807
Box to suit, on-off switch etc.
Meter (if required) see text
Switch (S1) if required (d.p.d.t.) + R_x & R_y values (see text)