POWER SUPPLIES

C Part 1

1. Introdution

The block diagram of a voltage regulated power supply is shown in Figure 1. The methods of implementing the functions of each block will be considered separately. The basic functions are:-

a) D.C. Power Unit - to convert mains power (240V a.c. at 50Hz) to low voltage d.c. The resulting d.c. will however still contain some a.c. (50Hz or 100Hz) ripple component, and will not be regulated.

b) Voltage Reference - to provide a constant voltage source which is, ideally, independent of temperature, supply voltage and load variations.

c) Control Unit - to regulate the output voltage (between limits) and supress the a.c. ripple voltage.

d) Error Amplifier - to feed the Control Unit with a signal derived from the difference between the reference voltage and a sample of the output voltage.

e) Current Limiter - to limit the maximum output current to some preset value.

f) Overvoltage Protection - to ensure the output voltage does not exceed a preset value.

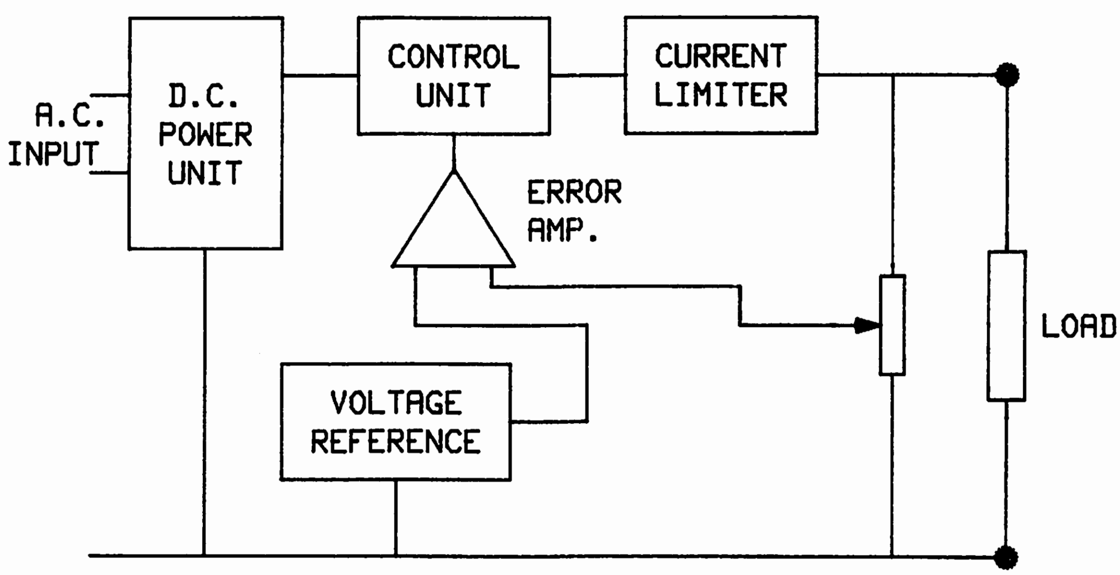


Fig. 1. Power Supply Block Diagram

POWER SUPPLIES

2. D.C. Power Unit

Power transformer secondary voltages are usually quoted in r.m.s. values. Assuming a pure sinusoidal waveform the peak value is √2 times the r.m.s. value.

$$V_{pk} = \sqrt{2} \times V_{r.m.s.}$$

The Peak Inverse Voltage (P.I.V.) rating of a rectifying diode is the maximum allowable voltage across it when it is reverse biassed (non-conducting). The P.I.V. required of a diode will depend on the circuit. A rectifier circuit may be either half wave, full wave or a bridge type of configuration. The table in figure 2 summarises the characteristics of these configurations.

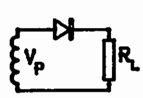
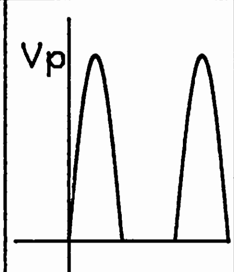
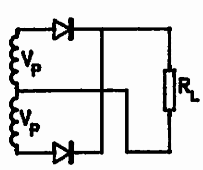
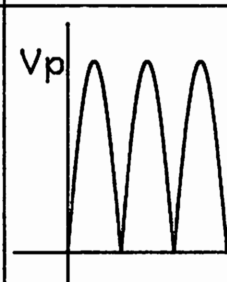
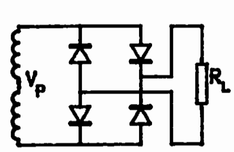
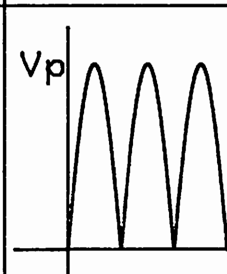
	CIRCUIT	O/P W/F	P.I.V.
HALF WAVE			V_p ($2V_p$ if O/P smoothed)
FULL WAVE			$2V_p$
BRIDGE			V_p

Fig. 2 Characteristics of Rectifier Circuits

2.1 Ripple Voltage

If the output of a half wave rectifying circuit is smoothed with a large value capacitor, the output waveform will be as shown in figure 3.

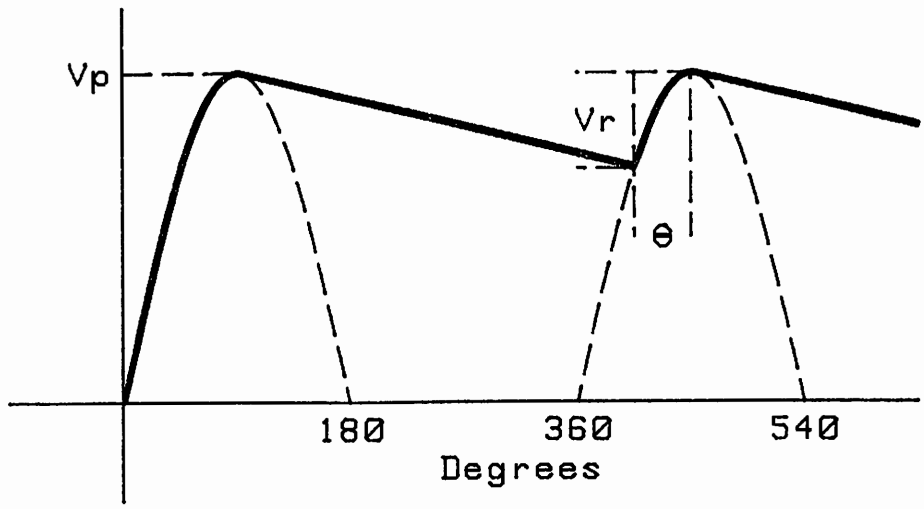


Fig. 3 Half-wave Smoothed Waveform

The capacitor discharges to the load during (360-Θ)°, and recharges from the supply during Θ°. If the discharge time constant (CR) is very long compared with the perioed of the a.c. supply ($\frac{1}{f}$ = 20m sec for 50Hz), the exponential decay may be considered to be linear as shown in figure 4.

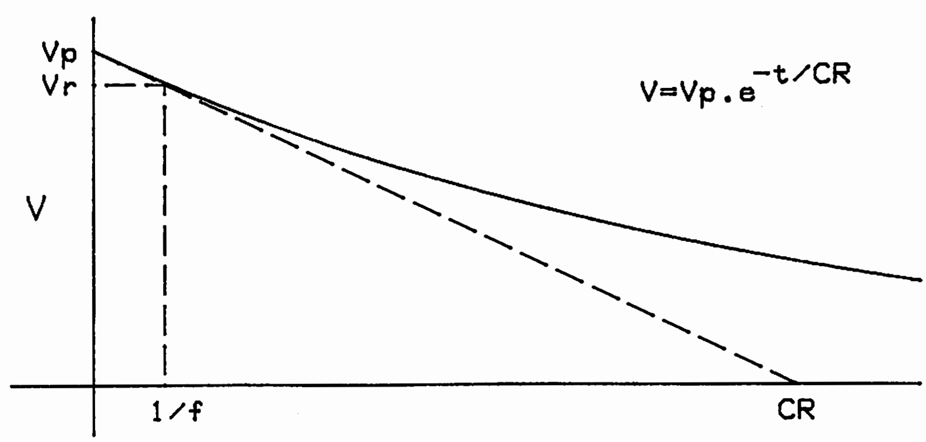


Fig. 4 Exponential Discharge of Smoothing Capacitor

Slope of decay $= \frac{V_p}{CR}$ volts/sec.

$V_r = \frac{V_p}{CR} \times \frac{1}{f}$ volts

but $I_L = \frac{V_p}{R}$

$V_r = \frac{I_L}{Cf} = \frac{V_p}{CRf}$

The ripple voltage could be reduced by increasing the value of the smoothing capacitor. If the capacitor had a very large value e.g. 10,000 µF, the ripple voltage would be very small and hence a very large charging current would be required. Equating the charge lost to that gained per cycle gives:-

$I_L \times 360° = I_c \times \theta°$ where I_L = d.c load current (I_p) and I_c = mean charging current.

$I_c = I_L \times \frac{360}{\theta}$

This formula assumes constant charge and discharge currents.
Doubling the ripple frequency (by using full wave or bridge rectifiers) will halve the ripple voltage.
Very high value short charging pulses will produce a high I^2R power loss in the transformer and will necessitate diodes and capacitors capable of carrying these high currents.
Many power supplies are now designed with a high ripple voltage which is subsequently removed electronically.
The table in figure 5 shows some typical values for comparison.

	HALF WAVE		FULL WAVE	
Capacitance (μF)	500	10,000	500	10,000
Ripple Voltage (Vr)	8V	0.4V	4V	0.2V
Conduction Angle (Θ)	53°	11.5°	2 x 37° = 74°	2 x 8.1° = 16.2°
Charging Current (Amps)	1.35A	6.25A	1A	4.4A

Fig. 5 Table of Charging Currents and Ripple Voltages

3. **Voltage Reference**

Shunt regulation using a low power Zener diode is usually used to provide a constant voltage reference source.

The characteristic of a typical low power Zener diode is shown in figure 6.

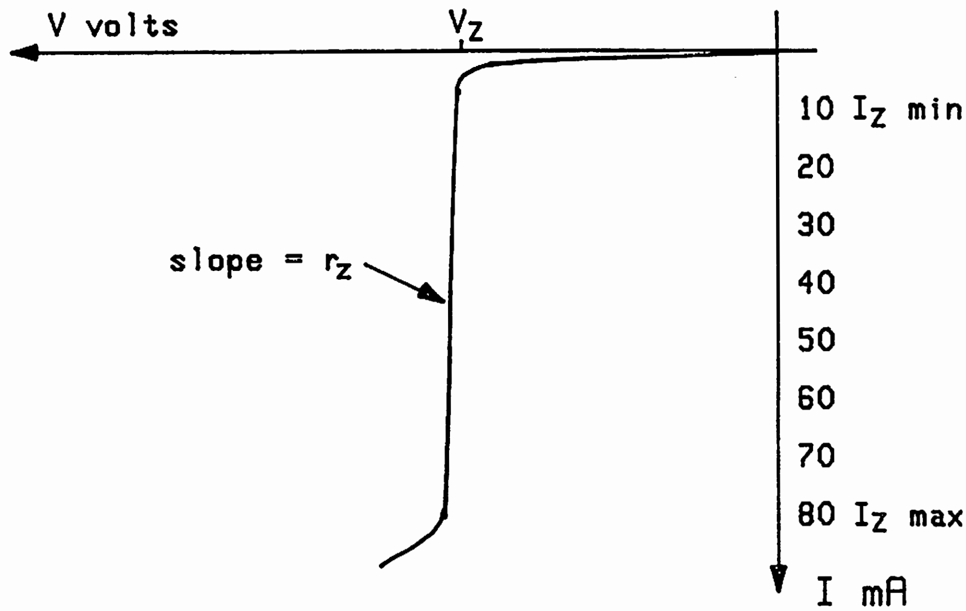


Fig. 6 Typical Zener Diode Characteristics

A Zener diode stabilizer circuit must include a series resistor, R_Z .

With maximum load current being drawn ($I_{L(max)}$), a minimum Zener diode current ($I_{Z(MIN)}$) of about 10mA must pass through the diode to maintain its required voltage. On no load, the diode must pass $I_{L(MAX)}$ in addition to $I_{Z(MIN)}$, and a value of R_Z is chosen to achieve this.

i.e. $R_Z = \dfrac{V_{IN} - V_Z}{I_{ZT}}$ Where V_{IN} = supply voltage

and $I_{ZT} = I_{Z(MIN)} + I_{L(MAX)}$

The power rating of the Zener diode must be sufficient for it to pass the total current (I_{ZT}) on no load conditions.

A typical Zener shunt stabilizer circuit is shown in figure 7.

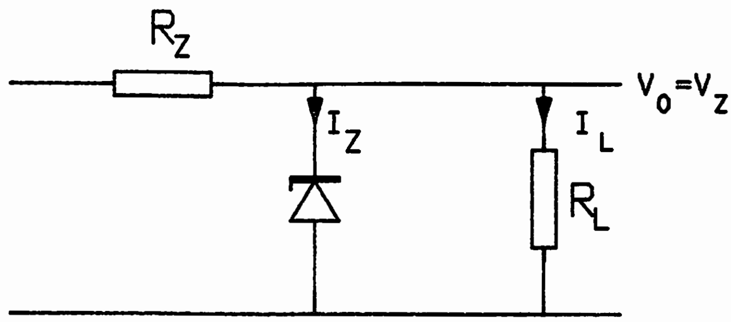


Fig. 7 Typical Zener Shunt Stabilizer Circuit

Typical Values for a 9V stabilizer

V_{IN} = 12V

V_0 = 9V

$I_{Z(MIN)}$ = 10mA

$I_{L(MAX)}$ = 50mA (R_L = 180Ω)

I_T = 60mA

R_Z = $\frac{3V}{60mA}$ = 50Ω

$P_{Z(MAX)}$ = 9 x 60 = 540 mW

The amount of reduction of ripple is dependent on the a.c. resistance of the Zener diode (r_z). This is represented by the slope of its characteristic and is typically about 5Ω.

If V_{ri} is the ripple voltage input to the circuit, then the output ripple voltage, V_{ro} , is given by the potential divider formula:-

$$V_{ro} = V_{ri} \times \frac{r_z}{r_z + R_Z}$$

Choosing a value of reference voltage of about 6-8 volts will result in the lowest value of r_z . It will also be the most stable against temperature drift since the diode is operating at a point where the zener breakdown converts to avalanche breakdown.
The ripple voltage output could be further reduced by splitting the series resistor, and decoupling the mid point with a capacitor, C_Z , as shown in figure 8.

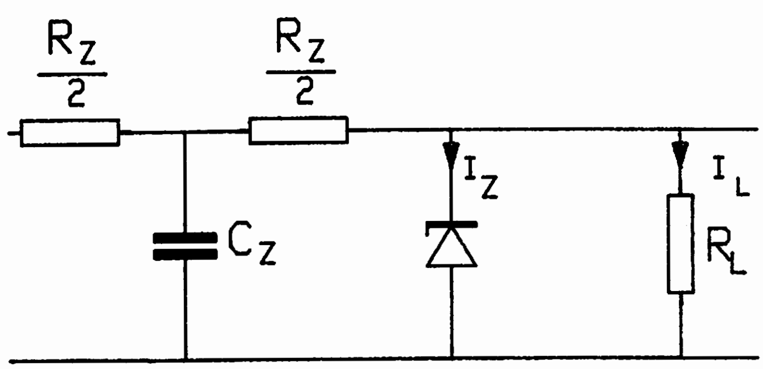


Fig. 8 Filtered Zener Voltage Supply

4. Control Unit

If a Zener voltage reference is fed to the base of an emitter follower stage, then the emitter will be maintained at about 0.6 volts less than the stabilised base (assuming a silicon npn transistor). A constant voltage obtained at the low output impedance of the emitter follower performs the requirement of a constant voltage supply. It's circuit is shown in figure 9.

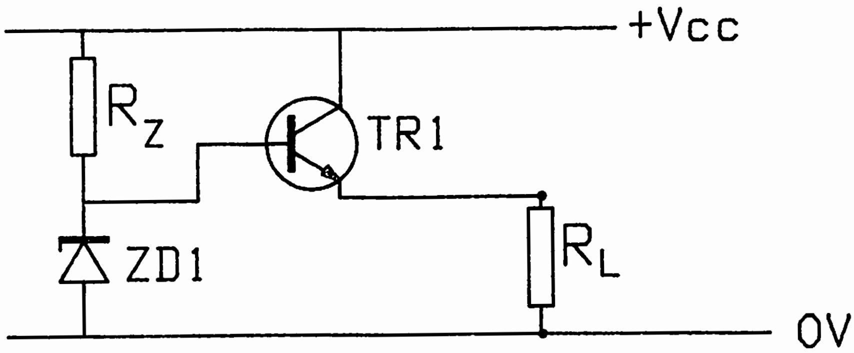


Fig. 9 P.S.U. Control Stage

Any variations in load current will be reflected as much smaller changes in base current (I_L reduced by h_{FE}) and hence zener current.

The changes can be reduced even more by effectively increasing the h_{FE} by using a Darlington Pair in the emitter follower.

Unfortunately in practice the 0.6 volts drop (V_{BE}) is not constant and depends on the emitter current. It can vary by as much as 0.2 volts over an emitter current range from 10 - 100mA. The effect of this variation of V_{BE} can be overcome by using negative feedback in conjunction with an Error Amplifier.

5. Feedback Stabilisation using an Error Amplifier

The error amplifier could be a single transistor stage with its inverting input (i.e. base) connected to a suitable tapping point across the load, and its non inverting input (i.e emitter) connected to the voltage reference. A signal proportional to the difference between these signals will be developed across its collector load, R_c . A typical circuit is shown in figure 10.

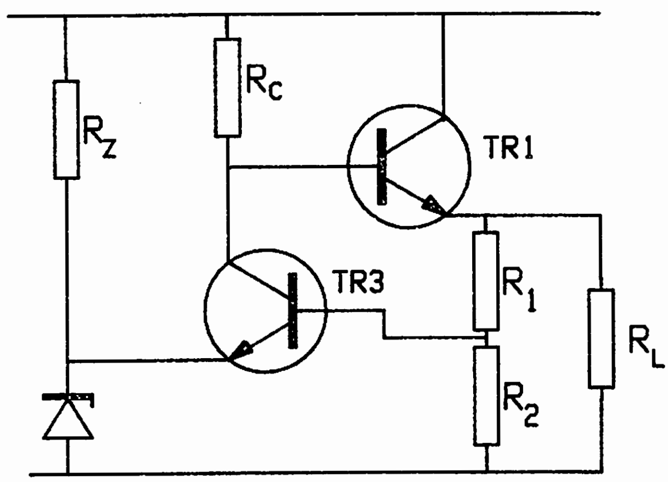


Fig. 10 Feedback Stabilisation Using an Error Amplifier

In this circuit, any reduction in output (or load) voltage will be sampled by TR3 base resulting in a reduction in its collector-emitter current. This reduction in curent will result in a smaller voltage drop across its collector load resistor and hence an increased collector voltage. This increase in voltage, which is also the output transistor base voltage, will be fed back to the output (via V_{BE1}) as compensation for the original voltage drop.

To achieve the best regulation (constant output voltage), the gain of the error amplifier should be maximised. Using the formula for a common emitter amplifier its gain can be calculated.

Gain of Error Amplifier, $A_v = \dfrac{g_m R_c}{1+g_m R_E}$

where R_E = slope resistance of the zener diode ($r_z \simeq 5\Omega$)

The gain will depend on the standing collector current, and can be maximised by selecting a suitable value of R_c . The optimum value is obtained when the collector current of TR3 is about equal to the base current of TR1.

The d.c. output voltage can be calculated as below if the component values are known.

$$V_{B3} = \frac{R_2}{R_1 + R_2} V_{out} = \beta V_{out}$$

$$V_{B3} = V_Z + V_{BE3} \simeq V_Z + 0.6V$$

$$V_{out} \simeq \frac{V_Z + 0.6V}{\beta}$$

The ripple voltage from the supply (v_r) is an a.c. signal which will be reduced by a factor of $1 + \beta A_3$, where β is the feedback fraction and A_3 is the gain of the error amplifier. β can be maximised to unity by bypassing R_1 to a.c. signals with a capacitor. A_3 can be maximised by selecting a suitable value of R_c, or alternatively by using a high gain Operational Amplifier instead of TR3.

6. **Current Limiting**

A fuse in series with the output cannot protect components against a current overload or short circuit with sufficient speed, so an electronic method of current limiting should be provided. If a resistor is connected in series with the output, its value can be selected such that if the output current exceedes a certain value, the voltage drop across this series resistor will exceed 0.6 volts. This voltage could then be used to switch a transistor on and reduce the output current either by

a) reducing the reference voltage, or

b) reducing the base voltage of the control transistor.

Circuits of these forms are shown in figure 11.

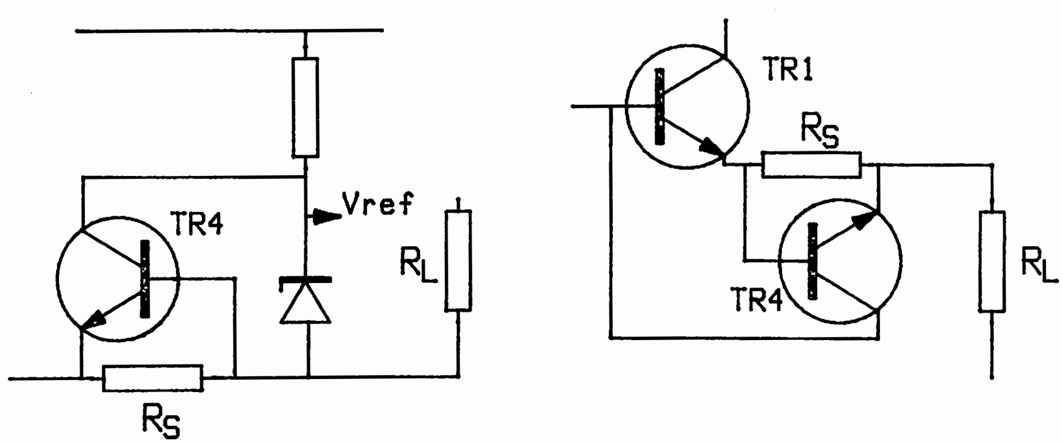


Fig. 11 Current Limiting Circuits

The method usually adopted is to reduce the base voltage of the control transistor. If the reference voltage method were used, the current limiting transisitor would have to have a high power rating to pass enough current to effectively short out the Zener diode.

Some power supplies incorporate a more complex circuit to provide Foldback Current Limiting. With this arrangement, once the maximum current value has been reached, any further reduction in load resistance will cause a reduction in output current resulting in a considerably reduced current in the event of a short circuit being placed across the load. This is shown in figure 12.

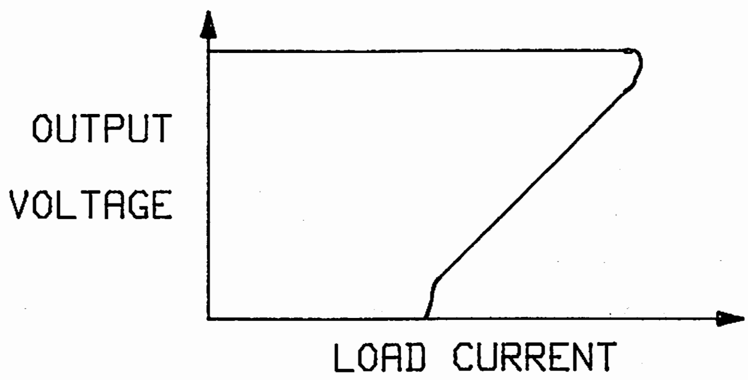


Fig. 12 Foldback Current Limiting

7. Overvoltage Protection

It is sometimes important to ensure that the output voltage does not exceed a specified voltage even in the event of a regulator failure. An overvoltage protection circuit will detect this and trigger a thyristor into conduction. This thyristor can then be used to either short the output voltage or apply a short to the unregulated supply. In either case, this 'Crowbar' action can only be removed by switching off the mains to the power supply. The Crowbar action relies on the output current limiting circuit operating or the supply fuse blowing. An overvoltage protection circuit is shown in figure 13.

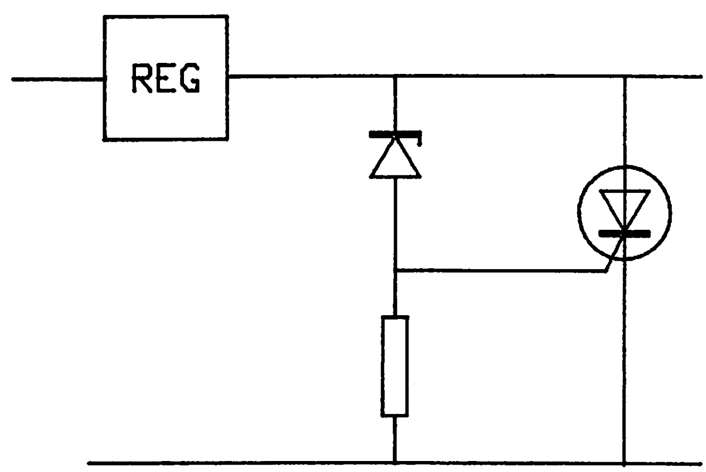


Fig. 13. Crowbar Overvoltage Protection

8. Complete Power Supply

The complete circuit for a typical stabilised power supply is shown in figure 14.

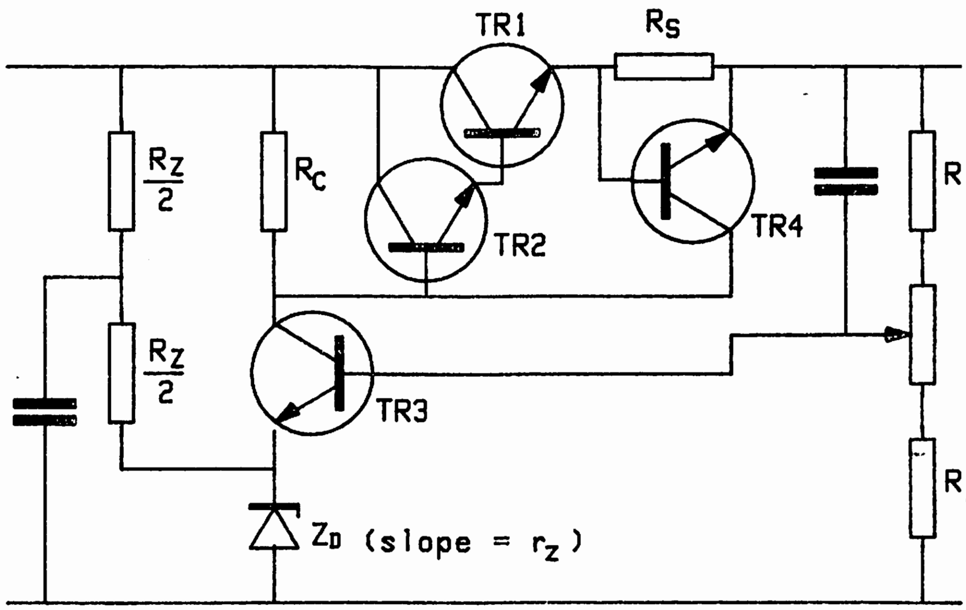


Fig. 14 Circuit Diagram of Complete P.S.U

Many, or even all, of these components may be incorporated on a single integrated circuit. A circuit of a 12V power supply using a LIC723 is shown in figure 15. Pin 4 on the I.C provide an internally stabilised output of 7V. This is fed as the reference to pin 3 where it is compared with a sample of the output on pin 2. The voltage drop across R_s (3.3Ω) limits the current to about 200mA.

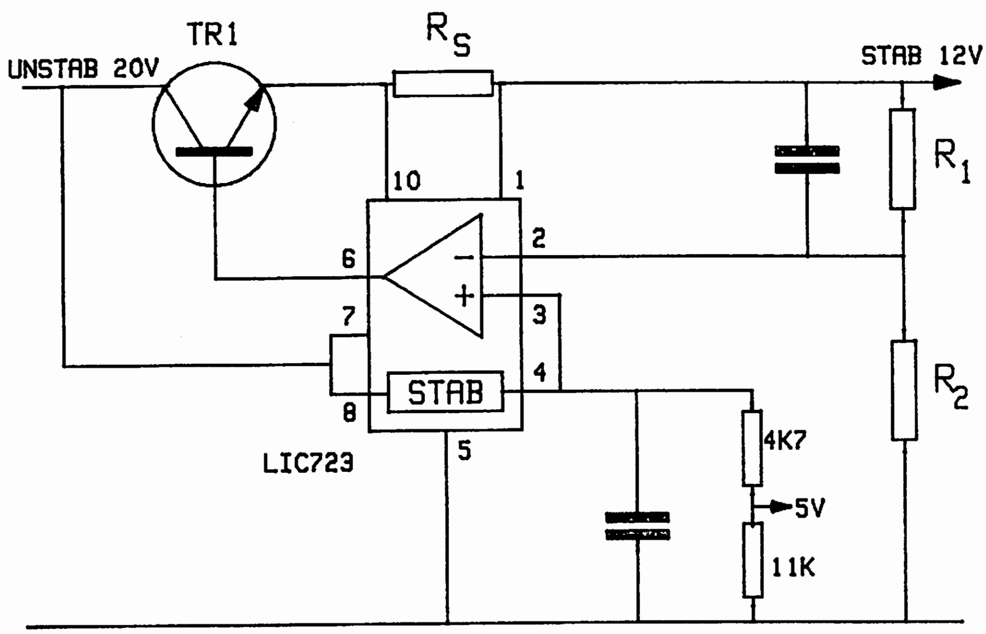


Fig. 15 An I.C. Voltage Regulator