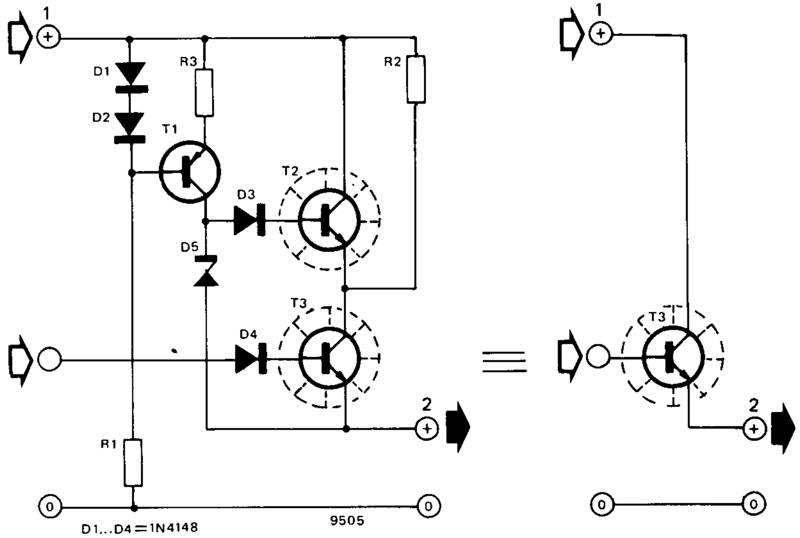
80 Nearly all stabilised power supplies use a series regulator transistor. The dissipation in this transistor increases with increasing load current and with increasing voltage across it. This means that it is often necessary to use several transistors in parallel for the series regulator and to incorporate a large heatsink – certainly if the power supply is to have a variable output voltage at high output currents (lab power supply).
It is cheaper to dissipate as much as possible of the excess heat in a resistor, provided some way can be found to do this without interfering with the voltage stabilisation.
The circuit shows a replacement for the original series transistor, consisting of

two power transistors, a power resistor (R2) and a few extra components. The single complete circuit is equivalent to a single NPN power transistor. The 'collector', 'base' and 'emitter' are marked with arrows.
The interesting point about this circuit is that the maximum dissipation in the two power transistors is only about one quarter of the maximum total dissipation; the rest (three quarters) is dissipated in the resistor R2.
The circuit operates as follows. T1, D1, D2, R1 and R3 form a current source, which biases the zener diode D5. At low output currents, the voltage at the collector of T3 will be higher than the voltage at the collector of T1. This



means that T2 must be cut off. The voltage at the collector of T3 is equal to the input voltage '+1' minus the voltage drop across R2. In this situation, the circuit behaves like a normal single transistor series regulator (T3) with a series resistor (R2). The maximum dissipation in T3 occurs when half the voltage difference between '+1' and '+2' is dropped across it; the load current is then:

$$I_L = \frac{\text{`+1'} - \text{`+2'}}{2R2}.$$

As the current increases further, the voltage drop across the resistor increases, and the drop across T3 decreases. At a certain output current (twice the value found above) the voltage drop across T3 would be zero, i.e. the transistor would be in saturation – and that would be the limit of the stabilisation range. However, the zener voltage of D5 is chosen in such a way that T2 will start to conduct just before T3 goes into saturation. At higher load currents T2 forms a variable shunt across R2, maintaining a voltage drop across T3 that is just sufficient to keep this transistor out of saturation so that it will still work as a series regulator.

In this 'second leg' of the series regulator operation, the dissipation in T2 will increase progressively. However, the dissipation in T3 is now very low, and the dissipation in T2 will reach the same maximum found earlier for T3. For this reason, both transistors can be mounted on a common heatsink (provided insulating washers are used); the heatsink must be designed for one quarter of the maximum total dissipation.

The formula for calculating the value of R2 is:

$$R_2 = \frac{\text{`+1'}}{I_{max}},$$

where '+1' is the DC input voltage and I_{max} is the maximum output current, limited by a fuse or a current limiter circuit in the power supply. The maximum dissipation in R2 equals:

$$P_{R2,max} = \frac{\text{`+1'}^2}{R2}.$$

This type of power resistor is used in the electrical system of some makes of car.

The value of R1 is chosen so that a few milliamps pass through D1 and D2. R3 determines the collector current of

T1; this current must be sufficient to bias D5, even when T2 requires base drive in the second leg of the regulator. Bear in mind that this current through D5 flows into the output, so that at very low loads it may have an effect on the regulation. In this case, an extra load resistor may be needed across the output.