Designing Power Supplies

Using this simple procedure, anyone can build a simple supply for almost any purpose.

THE POWER SUPPLY is one of the most fundamental circuits in all electronics. It is also one of the easiest circuits to design yourself, once you have the 'know how'. This article is intended to give you just that skill.

This month, we feature a simple regulated supply set at 12 volts, and capable of about 400 mA. We'll use it as an example to demonstrate how component values are calculated.

The Theory

Before you can begin to design a circuit, there is certain information that you must have at your fingertips. For power supplies, it is necessary to know the peak input voltage and the output voltage. The 'input' is the voltage delivered by the transformer to the rectifier. Unfortunately, this is not the voltage usually specified by transformer manufacturers, but it is easily obtained by multiplying the RMS voltage (which is specified) by 1.4 (see Figure 2). You might expect that this is the voltage delivered by the power supply — not so. Some voltage will be lost across the bridge rectifier. Most diodes produce a forward voltage drop (i.e. when they are conducting) of about 0V7 and, since there are always two diodes passing current in a bridge, the drop across the bridge will be roughly 1V4.

The makes of voltage regulator ICs always specify some minimum voltage input to their device and it is generally about 2V5 higher than the required output voltage (eg, a 5 V regulator needs 7V5). To be on the safe side, assume that the minimum is 3 V higher. Now we know the maximum voltage which we can expect from the bridge rectifier, V_{BRIDGE}, and the minimum voltage needed to drive the regulator IC. The next step is to calculate the value of the filter capacitor, C1, which is there to 'smooth' the rectified mains voltage for the regulator IC.

The effect of the smoothing capacitor is shown in Figure 3. It charges up with each voltage peak, then discharges slowly as the rectified voltage falls to zero. The discharge time is such that C1 will not discharge completely, however, so the voltage never falls below a certain level which (aha!) must be the regulator minimum input voltage. The difference between the voltage peaks and the regulator minimum is the ripple voltage, V_R. Obviously, the value of the smoothing capacitor must be chosen so that the input voltage to the regulator never falls below the specified minimum.

The diagram in Figure 3 shows cycles of the rectified mains voltage, enlarged. The quantity 'T' is the time (Period) between voltage peaks and it is equal to twice the line frequency of 60 Hz i.e. 120 Hz. Since the period, T, is the inverse of the frequency, T is 0.0083 seconds.

Now a capacitor in a circuit which has resistance (and every circuit will have at least some resistance) will take a definite time to discharge most of the voltage stored on its plates. This time is the familiar RC time constant:

$$t = RC,$$

where t is the time, in seconds; C is the capacitance in Farads, and R is the resistance in Ohms. Now from Ohm's Law, we also know that:

$$R = V/I,$$

therefore, substituting the second equation into the first, we get:

$$t = (CV)/I,$$

where I is the current required from the circuit; t is the time period over which the capacitor discharges and V is the voltage discharged in time t.

Now, since we don't want the capacitor voltage to drop below a certain minimum, V is the ripple voltage V_R, the difference between the rectified voltage peaks and the regulator minimum, and t is the period of the full-wave rectified mains.

For Example

The remainder of the procedure is best illustrated by a practical example. To choose a suitable transformer, select one which produces a slightly higher voltage than that required — usually the next one up in the range will do the trick, i.e., one with a 15 V winding. The current rating will be explained shortly.

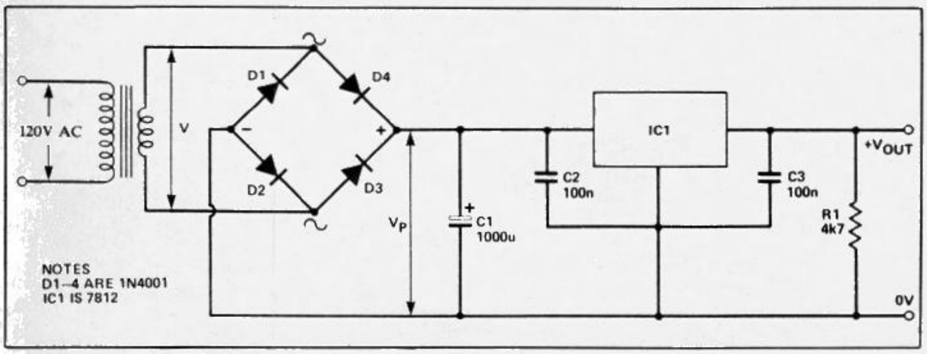


Figure 1. A simple regulated supply using one of the common three-terminal regulator ICs.

The next step is to calculate the voltage output from the bridge rectifier:

$$V_{BRIDGE} = Vp - 1.4$$
$$= (V_{RMS} \times 1.4) - 1.4$$
$$= (15 \times 1.4) - 1.4$$
$$= 19.6 \text{ volts}$$

The regulator IC needs at least 15 V, so we are on the safe side with 19V6. The difference is the ripple, V_R:

$$V_R = 19.6 - 15 = 4.6 \text{ V}$$

Now, using the formula for calculating the value of the smoothing capacitor C1, we have:

$$C = tI/V_R =$$

$$(0.0083 \times 400 \times 10^{-3})/4.6$$

$$= 725\ uF$$

This is not a preferred value, so use the next highest in the range, which is 1000 *u*F. It must cope with peak voltages of about 20 V, so use a 25 V working electrolytic type.

Now we come to the transformer current rating. Calculating the exact value required for the best efficiency is fairly complex, but there's an easy rule-of-thumb we can use.

Assume that we have 20 V on the unregulated output, i.e., across C1. This means that the transformer secondary will be supplying 20 x .400 = 8 Watts when the regulator is putting out its 400 mA. Allow a fudge factor for losses in the rectifier and transformer itself, and assume we need at least 10 Watts. The transformer current rating is then I = P/E, or 10/15, or 670 mA.

Another point to consider is that the bridge diodes must be able to handle both the current and the peak voltage; the popular 1N4001 diodes, rated at 50 V and 1 A, are quite suitable here.

Finally, there is the regulator IC. The one used for this supply is the common 7812 variety, a 12 V 1 A three-terminal device. The regulator dissipation is equal to the voltage across it times the current through it. Assume that the input voltage is on the high side at 20 V, and the current is 400 mA. The dissipation is then (20 - 15) x .4 = 2 W. The manufacturer's specification sheet says that the 7812 gains about 50 degrees Celsius for every watt dissipated without a heatsink, so the case temperature will be about 100 degrees. A further check on the sheet shows that the IC can still supply the required 400 mA at this temperature, so we can get away without a heatsink. However, the IC will be uncomfortably hot if you touch it, so you might want to bolt on a small finned heatsink, or mount it to the chassis with an insulating washer and nylon screws.

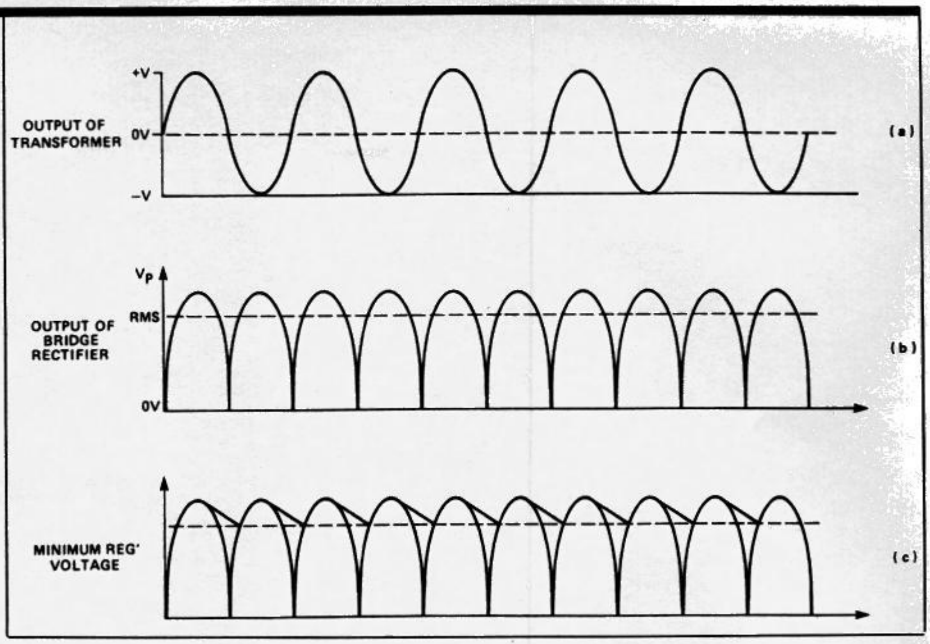


Figure 2. Power supply waveforms: (a) the output of the transformer; (b) output of the bridge rectifier; (c) input to the regulator IC.

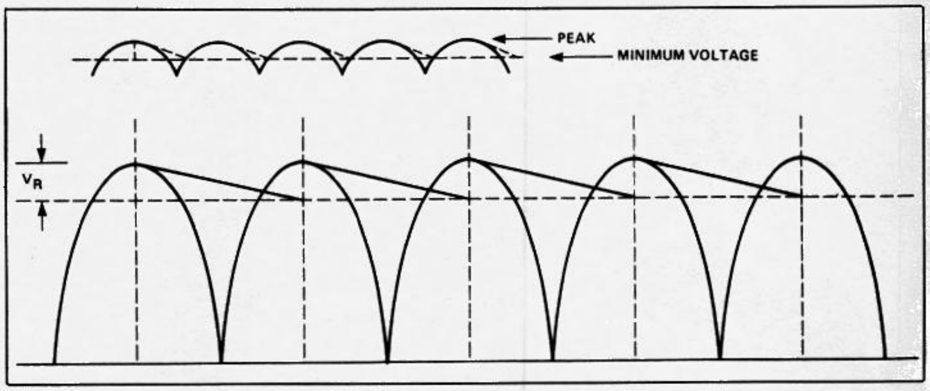


Figure 3. Power supply waveforms: (a) the output of the transformer; (b) output of the bridge rectifier; (c) input to the regulator IC.

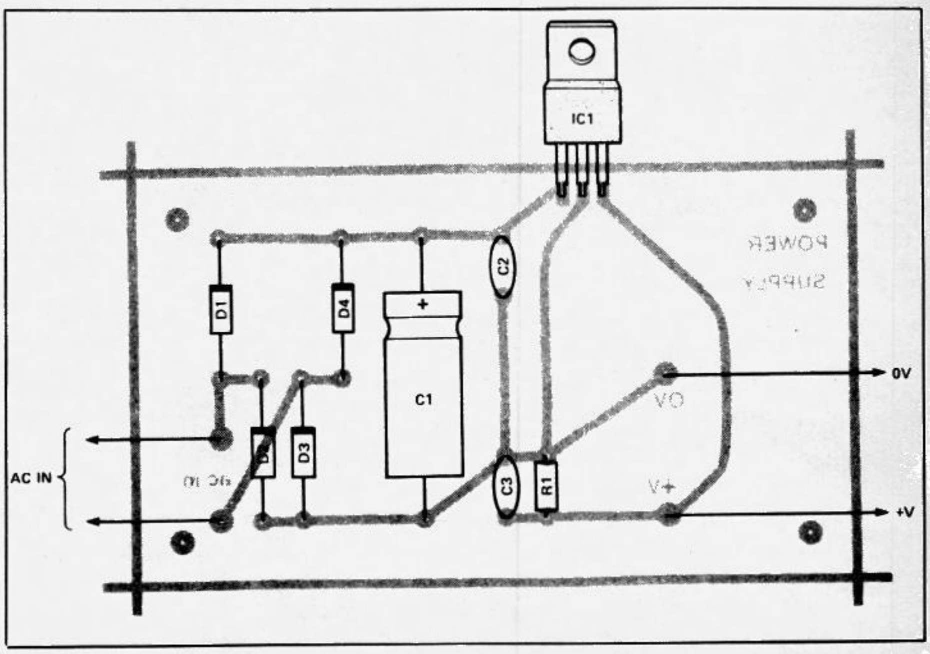
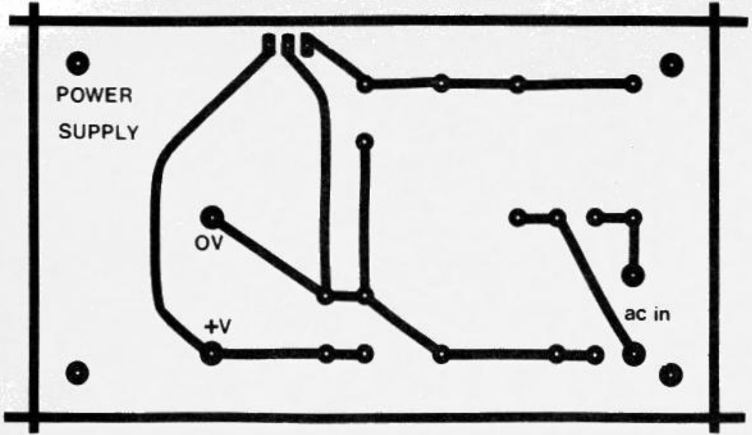


Figure 4. Component layout of the power supply.



Capacitors C2,3 are essential to prevent high frequency oscillations; the values are generally specified in the maker's data so they are not a problem; the point to note, however, is that they should be mounted as close to the IC as possible.

And that completes the circuit design — it's as easy as that! Although we have illustrated this procedure with a specific supply (12 V at 400 mA), it can be used with any three-terminal regulator IC to design a supply for any voltage and current. The next step is one you must make yourself!

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