Switching Plugpack

A switched-mode power supply that *can fit in a* ***plugpack;*** *the voltage can be set during* construction.

By Andrew Armstrong

THIS project is a small switched power supply to operate gadgets having a DC input socket, or you can mount it in an ordinary utility box with your choice of connectors. In its plugpack form, it operates from any 115VAC outlet, and its output voltage can be selected during construction.

Efficiency

The reason for using a switched mode supply in this application is that the efficiency is much higher than with a linear regulator. This means much less heat developed in the main pass transistor (Q1), and this in turn means that less power is required from the transformer, reducing its size.

This may even apply to using the power supply with equipment that has its own internal regulator. The number of milliamps drawn may be the same regardless of voltage over the range that the regulator can work. The useful aspect of a switched mode supply here is that as its output voltage is reduced, the available output current (for any given input current) is increased.

There is also a subsidiary advantage here. Equipment running from an unregulated supply must be able to operate even if the power line sags or else it will be unreliable in some areas. If this equipment has a high internal operating voltage to allow for this, the heat dissipation is unnecessarily high. Using an external regulator to send it the minimum required voltage minimizes this. The ZX81 is a case in point: its internal 5V regulator requires a minimum input of 7V for reliable operation, and to get around the problem of power line sag, the makers use an unregulated input of about 9V. By feeding the microcomputer from a preregulated 7V source, the internal dissipation can be reduced to about half.

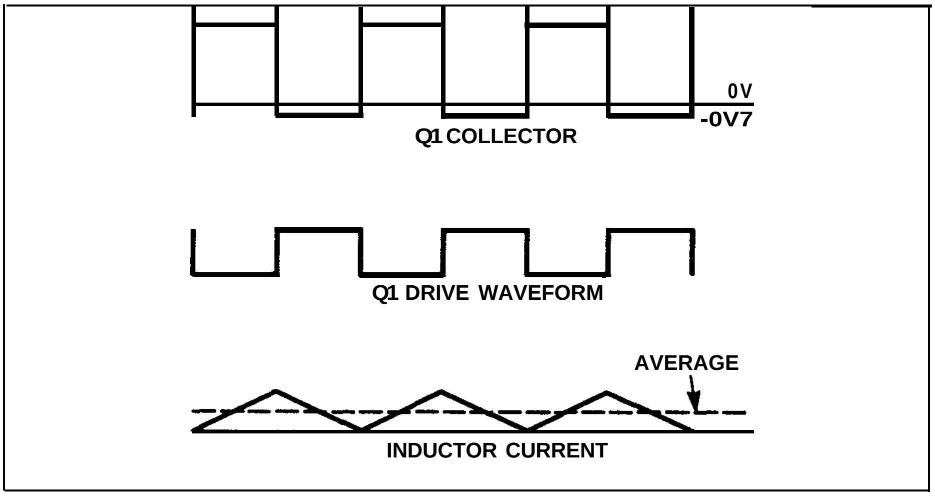


Figure 2a. Switching waveforms of the type found in the circuit in Figure 1.

Intermittent Rating

In practice, if a power transformer is overloaded, i.e., more load current than the permissible amount is drawn, then it will get too hot. Assuming that the overload is not severe and continues only for a short time, no harm is done, but the output voltage will fall below rated, and a linear regulator might not be able to function effectively under these circumstances.

Many loads draw heavy currents for short periods of time, such as LEDs or displays switching on and off. As long as the circuit is suitably fused and the average load somewhat inside the ratings, the transformer can be run at a slight overload for a few seconds at a time. This allows a smaller power transformer to be used for the projects.

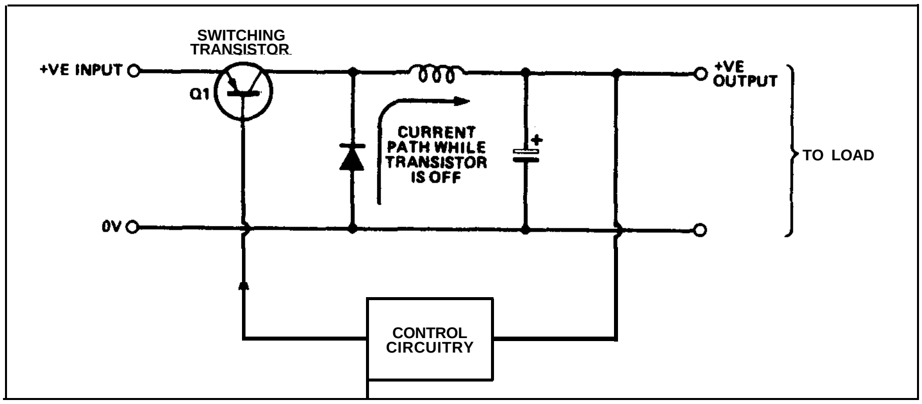


Figure 1. *A sample* circuit illustrating the series ***regulator principle.***

Primary Supply

This is the DC supply to the input of the regulator circuit. The selection of the main smoothing capacitor's voltage rating must allow for high line voltage and light loading. In this case, the capacitor DC voltage rises to the peak value of the AC input; this is equal to the AC RMS value times 1.414, or root 2. If we assume that the line voltage rises to 10% higher and no load is attached, then the capacitor voltage becomes 6.3 x 1.1 x 1.414, or 9.8V (note that the two-diode centre-tapped fullwave rectifier sees a 12.6V transformer as two 6.3V windings). A 10V capacitor will do; higher voltage ratings can be used if there's space in the box.

Circuit Principles

The circuit used is the series regulator type. The principle used is illustrated in

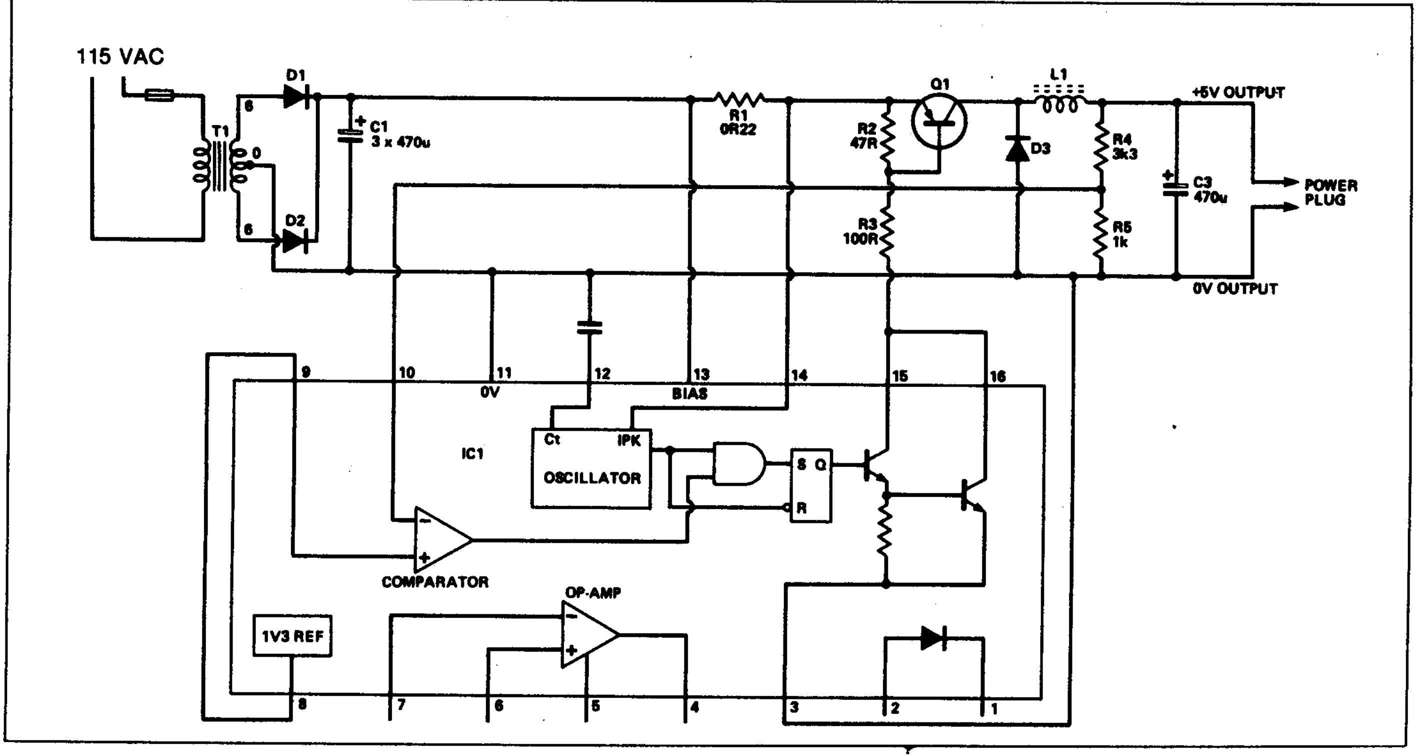


Figure 3. The circuit. Note that the lower part of the circuit illustrates the inside of the 78S40.

Fig. 1. The series pass transistor, Q1, is always switched on or off. When it is switched on, the current in the inductor rises, and the output voltage rises at the same time as energy is being stored in the inductor in the form of a magnetic field. When the on period of the internal oscillator expires, or when the current rises to its set point, the transistor is switched off.

The current continues to flow in the inductor, but it now flows via the diode once the transistor is turned off. The voltage across the inductor is now in the other direction, so the current declines steadily. The output voltage starts to fall once the current in the conductor has fallen below the load current. When the output voltage has fallen below the aiming point,the pass transistor is enabled to switch on at the start of the next cycle of the internal oscillator.

Once again the current rises and the cycle repeats itself. If the pass transistor is switched off due to the current sensing rather than due to the normal period of the oscillator, then current limiting is reached and no more load current can be supplied. Obviously, it is normal to choose this current limit so that a prolonged short circuit will not damage anything. The switching waveforms to be expected in this type of circuit are shown in **Fig. 2.**

The Circuit In Detail

The circuit used is shown in **Fig. 3.** The operation of the circuit is all controlled by the switchmode IC, the 78340. The internal circuit of this is shown to make the overall functioning clear. Not all the internal parts of the IC are used for this project; the op amp is not needed and the internal diode is not rated for a high enough current.

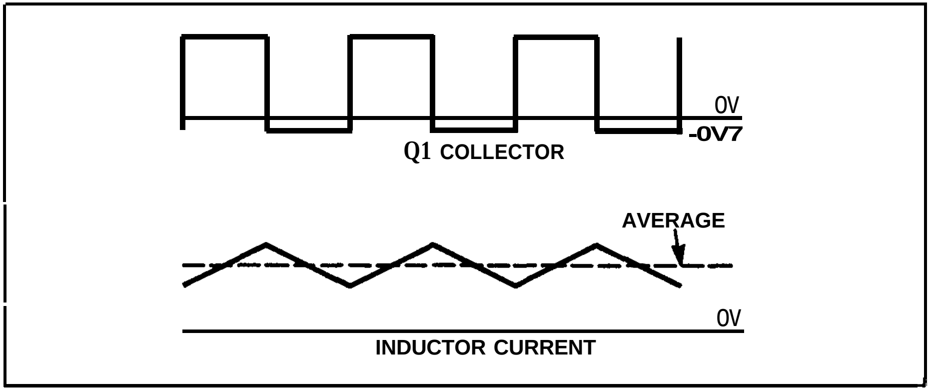


Figure 2b. A reduction in transistor peak current and output ripple voltage achieved by increasing the turns of the inductor.

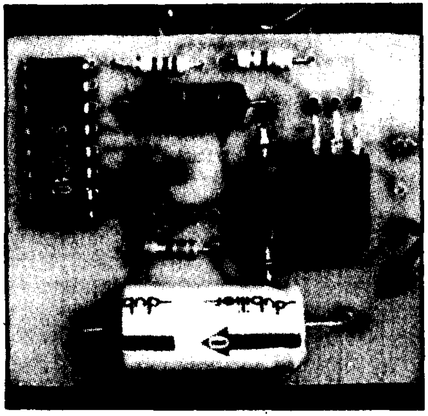
The basic operating frequency of the oscillator is set by the capacitor C2, and this controls the on-off times of the pass transistor. The off time is normally chosen to be greater than 10 microseconds so that the time that the transistor spends switching between the two states is not too high a proportion of the total time. The capacitor value may be calculated from the formula C = .00045 x Toff, where C is in farads and T in seconds.

This is not the whole story, of course, because there is an advantage in keeping the frequency high enough to minimize the ripple on the output for any given capacitor value. A good rule of thumb is that the total cycle time, at full load, should not exceed 50 microseconds. This corresponds to a frequency of 20kHz from the formula F = 1/T. It is necessary to have some estimate of how long the transistor should be on as compared to the off time in order to determine the total cycle time.

Disregarding resistive losses in the coil, the time for a given change of current (increase or decrease) is inversely proportional to the voltage across the inductor. For example, if the output voltage is 5V, and the input voltage is 10V, then there is 5V across the inductor whether it is charging or discharging. Only the direction changes. Therefore the on and off times will be about equal in this case.

If a 12.6V centre-tapped transformer

is used, the on time will be about 1.5 times the off time, while if an 18VCT transformer is used (with a 16V main capacitor) the times will be about equal, allowing for losses in the rectifier, capacitor voltage sag, etc. Therefore, an off time of 20 microseconds would seem reasonable. From the formula above (taken from the IC data), a capacitor of 9nF would be required. 10nF is close enough.



Energy Transfer

The control IC used in this project is designed on the basis that all the energy in the inductor should be transferred to the output during the off period. This means that there should be a change in the inductor current from the peak current to zero during the off time. This in turn means that the maximum load current is half the peak current in the inductor, because the average of a triangular waveform stating at zero is half its peak.

The peak current can be calculated from the maximum load current to be drawn, which can be 1A for this example. We now know that the peak current is 2A

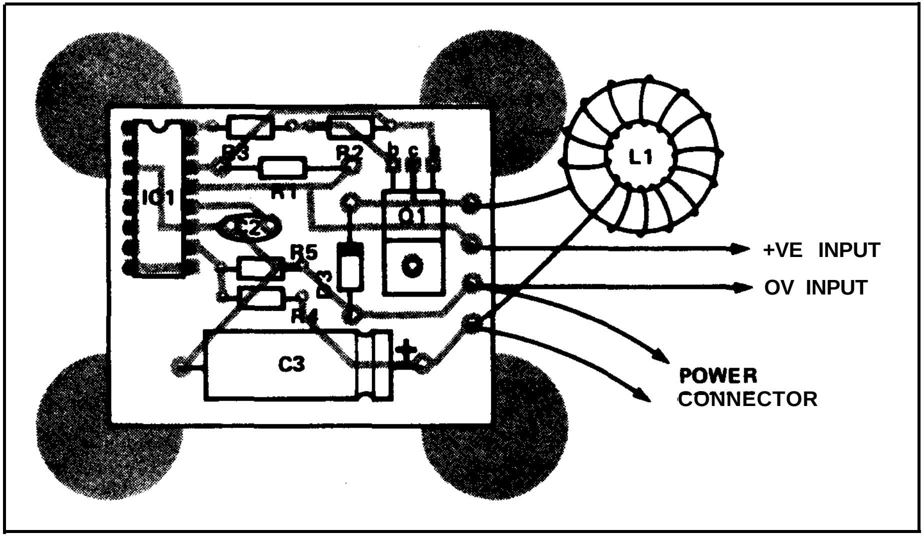


Figure 4. The components layout. Cl is off the board. Q1 lies flat.

and that the inductor must fall from 2A to zero in 20 microseconds. The rate of change of current in an inductor is proportional to the voltage across it, and inversely proportional to the inductance. Ignoring any resistive effects, the rate of change of current = V/L. The voltage across the inductor while it is discharging energy into the load is the output voltage plus the diode drop, say 5V5 in all. The rate of change of current is 2A in 2OµS, or 100,000 amps per second. Putting the figures into the formula, we have L = 5.5/100,000 = 55 microhenries.

Switching Inductor

The general design of the switching inductor is one of the most important aspects of the overall design. If this is far astray, the whole design is useless. One of the most likely problems in more powerful designs is the saturation of the inductor core at maximum currents. If the inductor begins to saturate, the current in the transistor rises more rapidly when it is on. The control circuitry cannot switch instantaneously, so the transistor will likely have to switch off more current than the designer bargained for, and in so doing it will get hotter than may have been expected.

It is better, if possible, to use a core which has a little in reserve. In fact, the core chosen has a lot in reserve and is not particularly large; it's a powdered iron toroid slightly over an inch in diameter.

PARTS LIST

Resistors
(minimum rating .25W, 5%)

Rl	OR22
R2	47R
R3	lOOR
R4	3k3
R5	1k

Capacitors
(**higher** voltages can be used if they fit)

Cl	3x470µF,lOV
C2	10n
C3	470µF, 10V

Semiconductors

Dl 2,3	lN4001
Q1	TIP34 or equiv.
IC1	78S40

Miscellaneous
12.6V centre-tapped power transformer (Hammond 166612 or larger), powdered iron toroid (Miller T-106-2 or equiv.), plugpack (Hammond 1593 P3 and 1593 BC2 or similar), pigtail fuse 100 to 250 mA, hookup wire, 0.5mm enamelled magnet wire, etc.

The 78S40 is available from Active Components, 4800 Dufferin St., Downsview. Ontario or their branch outlets. The Miller toroid and Hammond products are available from Electrosonic, 1100 Gordon Raker Rd., Willowdaie, Ontario.

The permeability of most magnetic materials (how much they concentrate the magnetic field) is such that they saturate very easily. When ferrite cores are used for switched mode supplies, they normally have an air gap between the two halves. This considerably lowers the effective permeability and raises the saturation point.

Powdered iron cores, as the name implies, have a built-in air gap between each of the tiny particles. This produces a nice predictable magnetic field which does not saturate easily and has low eddy current loss due to the small size of the particles. It is good both for switched-mode supplies and triac noise suppression.

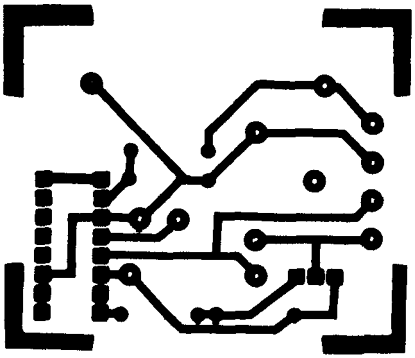


Figure 5. The printed circuit foil side.

Winding

The coil selected, a Miller T-106-2, requires only 40 turns for the required value of 55uH. However, if the inductance is increased somewhat, the peak current in the transistor is reduced, increasing the efficiency of the supply and prolonging its life. The output ripple is reduced as well. The effect is shown in Fig. **2b..**

A reasonable compromise between the improvement and the effect of putting extra turns on the core is to choose 50 turns. This raises the inductance to about 68µH. Fairly wide variations from this will still result in a working project.

One tedious thing which is important: fairly thick wire should be used. It makes the job more difficult, but gives lower resistive losses. 0.5mm wire is a good choice.

Transistor Switching

To achieve high efficiency, the transistor should switch on to saturation and off again as rapidly as possible; heat is generated as it passes from one state to another because the collector voltage and collector current are both at a fairly high value at the same time.

The rule of thumb for saturation says that the base current should be one-tenth of the collector current. However, this means that under some conditions more than a tenth will flow, wasting power by warming up resistors needlessly. A good compromise would be one-twentieth of the collector current.

The value for R3, which sets the base current, is calculated on the basis of the voltage on Cl sagging to 7V and the peak current being 1.4A. If a higher voltage transformer is used, the value for R3 can be increased proportionately.

R2 assists the transistor in turning off rapidly by draining charge carriers from the base region. Rl sets the short circuit current. The IC switches when the current sense voltage reaches OV3, which with a OR22 resistor gives a peak current of 1.4A. This peak current comes close to the output design figure of 1A.

Construction

Not all the parts mount on the PCB due to lack of space. Diodes Dl and D2 are mounted on the transformer pins, which is a PCB type. Capacitor Cl is actually three 470uF capacitors to better suit the case dimensions. Insulating tape should be wound over the inductor turns.

You can either rebuild an existing plugpack, buy the commercial plugpack listed in the Parts Lists, or build it into a utility box with a line cord and suitable output connectors.

Testing

First, see that there are 7 to 10 volts (positive) across Cl. The output should be 5V, though it can vary due to parts tolerances; if it's off, check R4 and R5. An output the same as the input indicates that Ql is probably shorted.

Finally..

Ql is not on a heatsink because it barely gets warm. A pot can be wired in place of R4 to provide variable output voltages; the output voltage is 1.3(1 + R4/R5). The output voltage should be about one volt less than the lowest input, and the voltage rating of C3 should allow for the highest output voltage. ■