Need DC Power? Try a PC/AT supply!

Modifications for non-standard output voltages

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Although the amount of power drawn by electronic circuits is steadily decreasing, there are still many devices that need a large amount of low-voltage power. Some examples are miniature (PCB) drills, model railways, vintage radios, safe low-voltage lighting and heating systems, battery chargers and so on. With a few modifications, a standard PC/AT supply is an excellent choice for the job.

When they need a low-voltage power supply, most hobbyists use the ‘classic’ transformer/bridge rectifier combination. This has many advantages, such as simple design, outstanding mains isolation, robustness and low interference levels. However, there are also a few serious disadvantages to this approach: the supply is large and heavy, it is difficult to efficiently obtain an adjustable voltage at high power levels, and it is fairly expensive.

Naturally, the alternative is a primary-switching converter (off-line switcher). For a hobbyist, designing such a power supply from scratch or copying an existing design is expensive, impractical and unsafe. It is expensive because in most cases, any error is punished by having the switching transistor go up in smoke; it is impractical because many of the necessary components are simply not available from retail sources; and it is unsafe because the primary side is directly connected to the mains. To this can be added an (unjustified) fear of everything composed of a core and a few turns of copper wire.

In this article, we describe an inexpensive solution to the above problem, based on using a standard PC/AT power supply. These are mass-production items that are available everywhere, and if necessary, one can be salvaged from a discarded PC or picked up for next to nothing at rallies and jumble sales. Everything you need to build a primary-switched supply is already there.

PC/AT supplies

The design of a PC/AT supply is quite conventional. It consists of a ‘half-bridge’ converter. The mains input voltage is directly rectified to generate a DC voltage of 320 V (**Figure 1**). Half of this DC voltage is applied to the primary winding of transformer T1 via a switching transistor. By alternately switching Q1 and Q2, the transformer is magnetised in both directions. This means that the energy transfer is very similar to that in a traditional transformer/rectifier design. On the secondary side, the windings have a common centre tap, and the voltages are full-wave rectified by two diodes for each output and then filtered. This is done by D1 and D2 for 12 V, and by D3 and D4 for 5 V. The four remaining diodes are used to generate the negative voltages. In most AT supplies, these negative voltages are completely unregulated, and they can be literally regarded as ‘extra’ voltages.

The base currents for the switching transistors flow via control transformer T2, so the secondary side is fully electrically isolated from the primary side. The primary side of the power supply is limited to the circuitry around transistors Q1 and Q2, capacitors C1 and C2, transformers T1 and T2 and so on. **Be careful – this portion of the supply is connected to the mains.** Also, bear in mind that Figure 1 is a basic schematic diagram, in which a number of networks have been omitted for the sake of clarity.

Even today, all of the drive signals for the switching transistors in a PC supply are provided by an IC dating from the early days of switching power supplies, the Texas Instruments TL494. Due to its age, this IC is not exactly the best choice for building a supply with the highest possible performance, but it results in a simple design that is ideal for our purposes, since it is easy to modify.

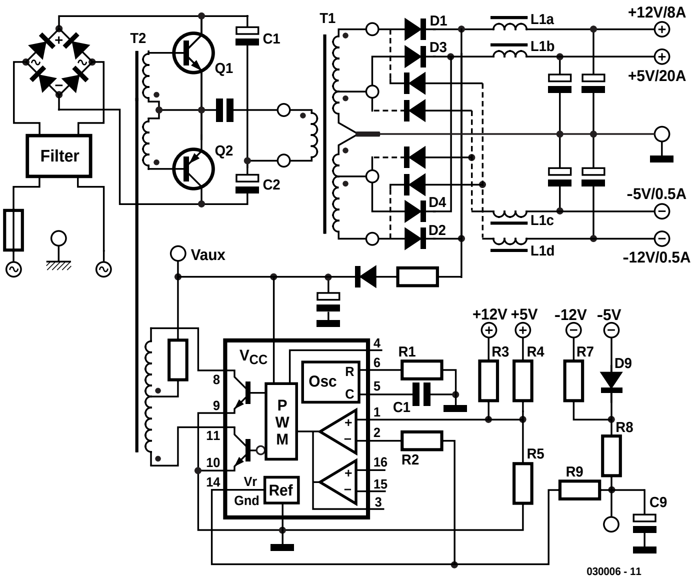

Figure 1. Basic schematic diagram of a PC/AT power supply.

The switching frequency is approximately 30 kHz, which is determined by the values of R1 and C1. The conduction time of Q1 and Q2 is continuously adjusted during each 33-μs period. This time ultimately determines the value of the output voltage, since the duty cycle of the square wave on the cathodes of the diodes (D1 and D2) depends on the conduction time (see trace 2 in **Figure 2**). The DC voltage at the output is (approximately) equal to the average value of the square wave. Via a voltage divider (R3–R5), the TL494 compares the voltages on the 5-V and 12-V outputs with its internal 5-V reference voltage. If the output voltage is too low, the conduction time of the switching transistors is increased, thus increasing the output voltage.

Modifications

A typical 200-W AT supply has the following output specifications:

+5 V,	3–22 A
+12 V,	0.5–8 A
–12 V,	0.5 A
–5 V,	0.5 A

This gives an idea of the loads that the components in the various secondary circuits can handle (transformer, diodes and filter choke). When modifying a supply to suit your purposes, you must keep within a number of limits, as follows:

- The total secondary power must never exceed 200 W. Transformer T1 and transistors Q1 and Q2 are specified for this value.
- The current through each of the 12-V windings must never be greater than 4 A. This is determined by the specifications of L1a, D1 and D2.
- The current through each of the 5-V windings must never be greater than 10 A. This is determined by L1b, D3 and D4.
- The transformer must be symmetrically loaded for the two magnetic polarisations. This means that full-wave rectification must always be used.
- The desired output voltage must be in the neighbourhood of ±5 V or ±12 V. This is because transformer T1 has a certain turns ratio that must be respected. Deviations of up to ±30% (3.5–6.5 V and 9–15 V) are certainly possible. However, the ratio of the output voltages always remains the same. If 6 V is generated on the 5-V output, the voltage on the 12-V output will be 14.4 V (6 × 12.5 ÷ 5).

Example 1: 6 V / 16 A

The desired value of 6 V is sufficiently close to 5 V. The desired current requires 8 A from each arm of the rectifier, which is less than the available amount of 10 A, and the total power is 96 W. This objective is thus feasible. The +12-V, –12-V and –5-V outputs are not necessary and can be deleted. This yields the circuit shown in **Figure 3**. D1 and D2 are only necessary to produce V$_{aux}$, which powers the TL494.

The output voltage is determined by R4 and R5. The TL494 regulates the output voltage such that the voltages on pins 1 and 2 are the same. The voltage on pin 2 is equal to the reference voltage (5 V), so the voltage on R5 is also 5 V. This means that there is 1 V on R4. The value of R4 is then:

$$R4 = (6\ \text{V} - 5\ \text{V}) \div (5\ \text{V}) \times R5$$

If we choose a value of 4k7 for R5 and 1k for R4, the output voltage will be 6.06 V.

Example 2: 24 V / 4 A

An output voltage of 24 V does not fall within the mandatory ±30% range. This means that we have to take a different approach in order to achieve this ‘high’ output voltage. A pos-

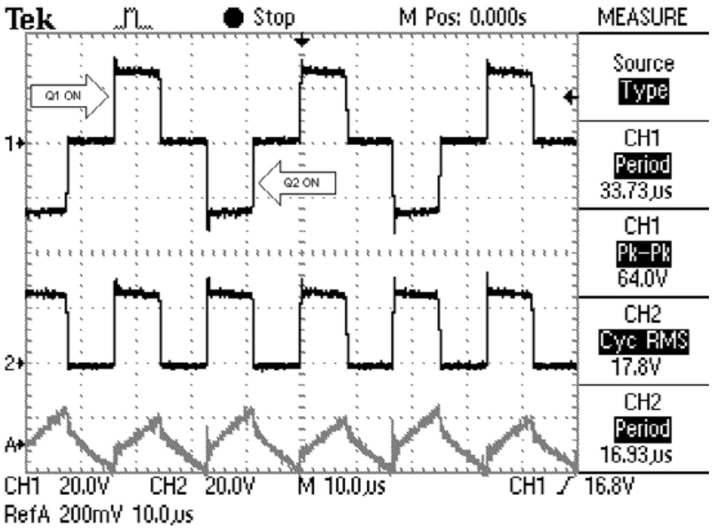

Figure 2. Typical secondary waveforms.

sible solution is shown in **Figure 4**.

Here diodes D5 and D6 have been added to the rectifier. These diodes must also be power diodes of the same type as D1 and D2 (which means they cannot be the diodes used to produce the –12 V / 0.5 A output in the original supply). The 24-V load is actually connected between the +12-V and –12-V outputs, which have been renamed to +24 V and 0 V. The output voltage is regulated using the +12-V output according to the formula:

R3 = (12 V – 5 V) ÷ (5 V) × R5

If R5 is 3k3, R3 becomes 4k7 and the output voltage is 24.2 V (2 × 12.1 V).

Although the –12-V circuit is not explicitly included in the control loop, in practice it will almost exactly track the positive output, due to the excellent coupling between the secondary windings of T1 and the coupled choke L1. The waveforms shown in Figure 2 were measured using this configuration with a 3-A load.

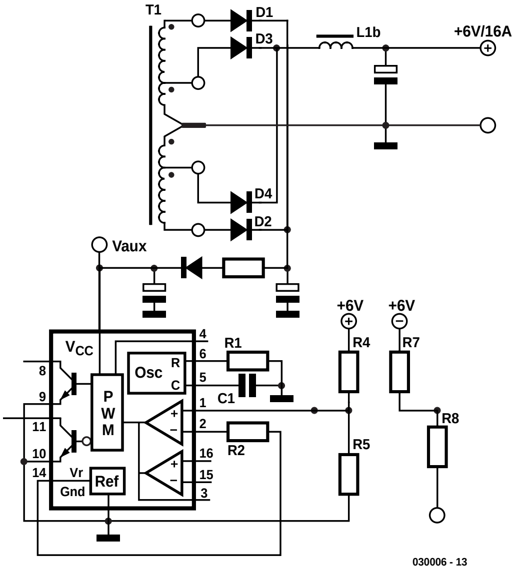

Figure 3. A configuration for 6 V / 16 A.

Other configurations

In some PC supplies, both secondary windings of T1 have the same wire diameter. This means that the maximum current load on the 12-V winding can also be as much as 10 A, as long as the total power of 200 W is not exceeded. With such a supply, the load on the 24-V output in Example 2 above could be as much as 8.3 A (200 W ÷ 24 V), assuming that the diodes and choke are modified accordingly.

If the 5-V winding is also used with the circuit configuration shown in Figure 4, 10 V / 10 A is also available, and so on. Naturally, the arrangement shown in Figure 4 can also be used if it is desired to have ±12 V / 2 × 4 A or ±5 V / 2 × 10 A. There are thus many different possibilities.

Component modifications

Filter choke L1

In an AT supply, choke L1 usually has five bifilar windings. Due to the large current flowing through L1b, two windings are used for this branch.

The five sections of L1 form a coupled inductor. This means that the turns ratio for the 5-V and 12-V windings is the same as the voltage ratio. The opposing directions of current flow for the positive and negative voltages must also result in balanced polarisation of the magnetic field. The choke sections on the negative side of the supply are thus connected in the opposite direction.

In Example 1, L1 can be used as is without any problems. In Example 2, this is not possible, since the original –12-V winding on the choke (L1d) is usually wound using thinner wire than L1a. If this is the case, L1d is probably only designed to handle the specified 0.5 A, which makes it unsuitable for the 4-A load of Example 2.

The solution to this problem is to rewind choke L1. First, remove all the windings while carefully noting the exact number of turns for each winding. After this, you can rewind the choke with only two windings, each of which has the same number of turns as L1a and a wire diameter at least as great as that of L1a, so that can be used with a 4-A load. The two windings must be wound bifilar (together) on the core. Spread the windings evenly over the entire core. When reconnecting the choke, make sure the polarities are correct.

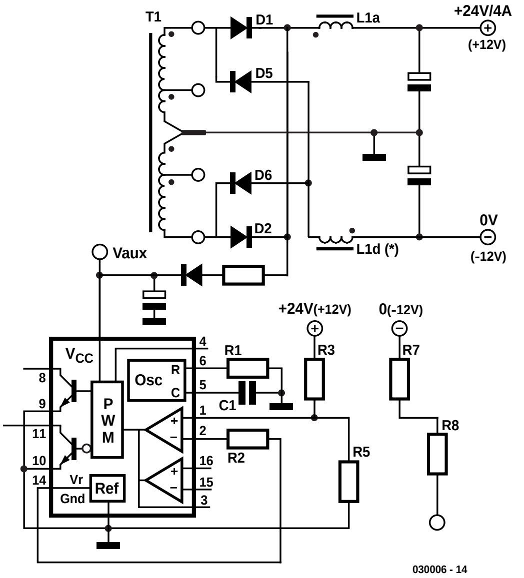

Figure 4. This arrangement allows the supply to provide 24 V / 4 A.

If you have to wind a new choke for a different output voltage, it's a good idea to adjust the number of turns. For example, for 15 V the number of turns should be increased by a factor of 1.25 (15 ÷ 12). Note that this is not strictly necessary. If the number of turns is too small, the ripple voltage on the output will be

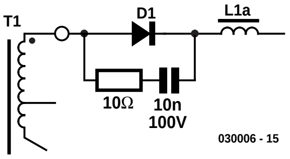

Figure 5. Diode snubber network for suppressing voltage spikes.

somewhat greater.

In Example 2, it is also possible to use the two sections of L1b (since each winding is suitable for 10A). Although this yields are relatively large ripple voltage (see trace RefA in Figure 2), it is ideal for a quick test.

Diodes

Fast Schottky diodes must be used for the rectifiers. These diodes are usually arranged in pairs in a TO220 package, with both cathodes connected to the middle pin. They can handle 'enormous' currents (2 × 25A is not exceptional), but they are somewhat less tolerant with regard to maximum reverse voltage (which is sometimes as low as 25 V). The measured signals in Figure 2 show that the peak-to-peak voltage on the 12-V winding is 64 V! This high voltage is applied to the reverse-biased diodes. To obtain a reasonable margin, it is necessary to ensure that these diodes have a reverse voltage rating of at least 90 V, even if the output voltage is only something like 10 V. This is because the voltage is controlled by adjusting the width of the pulse, rather than its amplitude. Reducing the voltage from 12 V to 10 V has almost no effect on the amplitude of the square-wave signal. For the 5-V winding, diodes with a reverse voltage rating of 40 V must be used.

In addition, it is advisable to connect an RC snubber network in parallel with each diode (see **Figure 5**). This reduces the values of the voltage spikes generated when the diode starts to conduct or stops conducting. Be sure to use a capacitor with an adequate working voltage!

The diodes in the 5-V circuit can be reused for almost all feasible configurations, since they are rated for 45 V / 2 × 10 A. The 6-V / 16 A supply of Example 1 thus presents no problems in this regard.

Things are different with the 12-V circuit. In some supplies, this circuit is fitted with PR3002 diodes, which are specified for 100 V / 3 A. Evidently, manufacturers of (inexpensive) power supplies assume that the maximum continuous current will never be greater than 6 A. If your configuration demands more, a better choice of diode is the Philips PBYR20100CP (100 V / 2 × 10 A), for example, or possibly the PBYR10100 (100 V / 10 A). Incidentally, these types can also be cooled better, thanks to their TO220 packages.

Capacitors

The electrolytic capacitors at the outputs have to handle the ripple currents. Due to the internal resistance of the capacitors (ESR), these currents produce a certain amount of ripple voltage at the outputs (trace RefA in Figure 2). The lower the ESR, the lower the ripple voltage and the lower the temperature of the capacitor. This means that only low-ESR types can be used here. A second consideration is the working voltage. The capacitors in the supply usually have values of 2200 µF / 10 V for the 5-V output and 1000 µF / 16 V for the 12-V output. If output voltages greater than 8 V or 14 V are desired, the capacitors must be replaced by low-ESR types with working voltages of 16 V and 25 V.

Transformer T1

The ground leads of the transformer windings, which form the centre tap, emerge from the transformer as a 'pigtail' and are thus not connected to a terminal. The ends of the windings are twisted together, and they can be easily separated to yield two independent windings with asymmetric 5-V taps. This makes it possible to build supplies having two electrically isolated outputs. However, note that the secondaries of T1 are wound bifilar, so the insulation voltage is limited and is only suitable for isolating low-voltage portions of circuits. It is not suitable for isolating the mains voltage, for example.

Ensure that the transformer is always symmetrically loaded for the two halves of the magnetisation waveform. This means that full-wave bridge rectification must always be used, since there is no longer a centre tap available (**Figure 6**). Only the voltage on the second output is regulated.

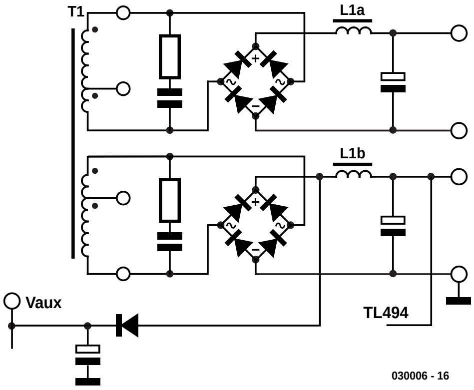

Figure 6. Two electrically isolated outputs.

A nominal voltage of 7 V is available on the winding between the 5-V and 12-V terminals (with the two loose ends of the pigtail not being used). This can be used to generate output voltages of around 7 V ± 30% (5–9 V or 10–18 V).

Other details

TL494 supply (Vaux)

Naturally, the switch-mode controller also needs a source of power. This is derived from the peak secondary voltage, which means that around 20 V is available. After modifying the supply, measure this voltage. The allowable working range for the TL494 is approximately 7–40 V.

Power Good detection

A PC supply has a 'Power Good' output. This output is high (+5 V) if all voltages are correct. If the supply is used in one of the configurations described above, the detection line will naturally indicate a fault. In this case, most supplies shut down the TL494 via pin 4. This means that this circuit must also be modified.

The detection circuit of just about all PC/AT supplies is based on a small network similar to the network formed by R7–R9, D9 and C9 in Figure 1. If everything is OK, the voltage on C9 is usually around 3 V. If you want to reproduce this situation without actually implementing a true Power Good function, you can simply remove R8 and connect an extra resistor across C9, with a value such that 3 V will be present at the junction. C9 must be left in the circuit, since it provides the soft-start function for the entire power supply.

This means that you will have to track down this network in the supply before removing any other items. It is easy to find, since it forms the only connection between the –5-V and –12-V outputs and the control circuit. Once you have located the network, use a multimeter to measure the voltage at the junction. **When making this measurement, avoid touching any components carrying mains voltage!**

Overload detection

Two different types of overload detection are commonly used in AT supplies. Older designs use a small current transformer in series with the primary winding of T1. After rectification and filtering, the signal bearing the information about the magnitude of the current is monitored by the second comparator of the TL494 (pins 15 & 16). In the event of an overload, the pulse-width drive to the switching transistors is reduced. This system is foolproof and provides secure overload protection.

Newer designs dispense with exact measurement and deduce the current from the duty cycle. If the duty cycle is too large, it is reduced by the second comparator. This makes it unnecessary to use a current transformer (thus reducing the cost of the supply). In most cases, the protection is adequate. However, if the transformer becomes (briefly) saturated for some reason, it cannot be detected using this method, although it can be detected using a current transformer.

Minimum load

If you examine Figure 2, it is clear that the output capacitors will charge to the peak value of the square-wave voltage on the cathodes of the diodes if no load is connected. Consequently, a certain minimum load is always necessary. You might want to use a nostalgic incandescent lamp for the power-on indicator instead of an LED, or you can connect a fan to the output. Of course, you can always simply connect a load resistor across the output terminals.

Temperature

The rectifier diodes become quite warm with currents of this magnitude. At 10 A, the voltage across a Schottky diode is 0.4–0.6 V, which yields a power dissipation of around 5 W (this is an approximation, since the diode does not conduct all the time, but there are still two diodes in a single package). A TO220 package has a thermal resistance of 50 °C/W (junction to ambient). If no heat sink is used, 5 W will thus cause a temperature rise of 250 °C. This means that a heat sink is imperative.

With the same TO220 package, the thermal resistance from the junction to the case is 1 °C/W. If the heat sink has a thermal resistance of 10 °C/W, for example, the total thermal resistance is 11 °C/W. At 5 W dissipation, this causes the temperature to rise by only 55 °C. If the ambient temperature is 30 °C, the junction temperature will be 85 °C, which is acceptable.

In accordance with the motto ‘if it’s warm, you have to blow’, it is naturally possible to use a fan. With a reasonable air flow (> 0.5 m/s), the original thermal resistance of the heat sink is reduced by factor of approximately 3. In our example, this gives a total of 4 °C/W. This yields a temperature rise of 20 °C instead of 55 °C, which is naturally better.

The switching transistors are also fitted to a heat sink, which is already adequate. **Lethal voltages are present on this heat sink,** so don’t just give it a quick finger test to see whether the temperature has become too high!

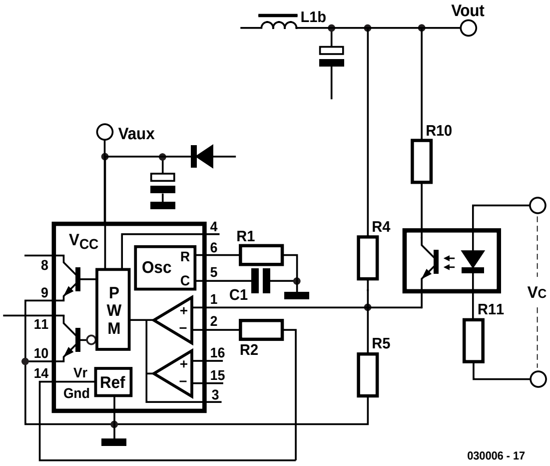

Figure 7. Output voltage adjustment can be obtained by adding R10 and an optocoupler.

Other uses

This type of supply is not especially suitable for use as an adjustable supply, but it is still possible to build in a certain amount of adjustment range by modifying the feedback loop for the TL494. In this way, the supply can be used to control the speed of a drill or the brightness of a string of lamps. As can be seen in **Figure 7**, R10 can be connected to modify the resistance of R4 in an adjustable manner. This affects the division ratio for the output voltage. The parallel resistance can controlled by a normal transistor or an optocoupler in series with R10. If the current through the LED of the optocoupler is increased, the output voltage will decrease.

Have a go!

As we have shown here, a PC/AT power supply can easily be modified to generate or control relatively large amounts of DC power.

Before you start making any changes, it’s a good idea to first trace the circuitry around the TL494 in order to locate the resistors for the feedback and Power Good networks. After this, in many cases you can use the suggestions presented here to build a power supply that provides the desired voltage and current.

Finally, we would like to warn all of you keen experimenters to be extremely careful when opening the enclosure of a PC power supply. **Mains voltage is present on a number of components, and that can have fatal consequences if you touch these components!**

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