Power Supplies and Circuits

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The power supply is an often neglected important item for any electronics experimenter. No one seems to get very excited about mundane items such as power supplies. Often, it is tempting to use whatever may be at hand, such as a surplus or scavenged "wall wart", or some batteries that have maybe seen better days. The wrong type of power supply can cause all sorts of problems, from annoying glitches to severe destruction of components, and even a fire or explosion. Most experimenter circuits will use a 5, 6, 9 or 12 volt source, and these voltages can be obtained from many different sources. Ideally, a supply should be adjustable, and produce relatively pure DC, and have good regulation. Additional features are metering of output voltage and current, and some form of current limiting to protect against excessive current flow.

Power supplies take many forms, and the kinds used for experimentation generally take their input power from the AC mains (120 or 240 volts AC) and use a transformer and rectifier assembly to produce DC powr. This is then used as is, or fed to a regulator circuit to remove AC residual components, and control the DC output voltage, maintaining a given level under varying loads. We will discuss a few basic circuits and show examples of simple supplies that can be built by the average experimenter, either as stand alone or as part of a project. A transformer is used to step the 120 or 240 volt AC line voltage down to a much lower voltage generally 6 to 30 volts, depending on the DC voltage needed. The secondary winding may have taps to give various output voltages, and in many cases contains two identical windings, which may be series or parallel connected to yield two different voltages. A popular combination is two 12 volt 1 ampere windings. In parallel this gives 12 volts at twice the current of one winding, or 2 amperes. In series, 24 volts is obtained, but at the maximum current of one ampere. The total power (resistive load) is 24 watts in either case. Transformers for the 50 or 60 Hz power line frequencies are heavy. There is a way around this problem. In switching type power supplies, a circuit converts the AC line power to a much higher frequency, generally 10 to 100 KHz. Transformers for these frequencies are much smaller and lighter, with fewer turns of wire. This enables a much smaller and lighter power supply. However, the high frequencies and fast waveforms encountered in these circuits can generate harmonics and noise (Radio Frequency Interference or "RFI") well into the RF spectrum. This can preclude their use in applications where very low level signals are present, such as in radio communications equipment. However, they find wide use in computers and in many other general electronics applications where the somr residual RFI will not be a problem. They are also very cost effective and greatly reduce size and weight compared to conventional 50-60 Hz supplies. Switching supplies are big topic, and will not be considered this time. For the 5 or 10 watt power levels required by experimenters, conventional AC transformers are not too bulky and are relatively cheap.

Rectifier circuits are used to obtain direct current from an alternating current supply. The half wave rectifier (Fig 1) is the simplest. This is a simple series diode which only allows current to flow one way. The output waveform is a series of sinusoidal pulses. The average DC voltage of a waveform such as this is ($1/\pi$) of the peak value. ($\pi = 3.14159$ approximately so $1/\pi$ is about 0.318). For a 12 volt RMS (root-mean square) input, the peak value is $12\sqrt{2}$ or about 16.97 volts. This would yield an average of 16.97 x (0.318) or 5.4 volts. A large 50-60 Hz AC component is also present. Note that there is a DC current flow in the transformer winding since it is in series with the diode. This acts to bias the core magnetically, and in order to avoid core saturation and overheating, a larger core must be used in the transformer. Also note that during the negative half cycles, the instantaneous output voltage is zero. Things can be improved by connecting a large capacitor across the DC output. The capacitor will charge to the peak value of the AC voltage (minus any diode voltage drop, about 0.3 to 0.6 volts). Now under no load conditions about 16 volts DC will be present. With a load, the capacitor will charge to the peak AC input voltage, less any diode and resistive voltage drops (transformer winding resistance, etc.), but as the AC input goes negative, the capacitor will discharge into the load until the AC input voltage exceeds the instantaneous load voltage plus diode drop at that time. Note that at worst case, a voltage twice the peak value of the AC input appears across the diode. This occurs when the capacitor is charged to the peak value of the AC waveform (about 16.97 volts) and the AC waveform is at its negative peak (about –16.97 volts). This is approximately 34 volts. The diode must withstand this voltage and this is called the peak inverse volts (PIV).A rule of thumb here is to use a diode with a PIV rating of at least 3 and better 4 times the RMS AC input voltage. The closest practical rating would be a 50 volt diode. Nowadays, this is pretty lousy 60 Hz rectifier diode, as silicon diodes having a PIV or reverse breakdown voltage of 600 to 1000 volts can be had for pennies. An example is the 1N4000 through 1N4007 series 1 amp diodes. The 1N4007 is good for 1000V and is very cheap. However, at higher frequencies used in switching supplies, faster diodes are required and cost quite a bit more. The rectifier output is a DC voltage across the load with a sawtooth shaped ripple component. This can be reduced with a larger capacitor value. However, also note that the capacitor must be recharged quickly during AC voltage peaks, producing high peak charging currents through the transformer and rectifier. This causes heating and loss. For any power level over about a few watts this is an inefficient way to get DC.

A full wave rectifier uses both halves of the AC waveform. There are two full wave circuits that are commonly used. Fig 2 uses two diodes and needs a center tapped transformer. The circuit of Fig 3 is a full wave bridge and uses four diodes, but no center tapped supply is needed. Fig 2 was popular in the tube days, when 250 to 400 volt DC supplies were used in tube circuits. A vacuum tube diode requires a filament, and the circuit of Fig 3 would require separate isolated filament supplies, which could become unwieldy. A popular tube approach used a diode with two separate plates and a common filament. These tubes such as the type 80, 5U4GB, 5Y3GT, 5R4GY were staple items. There were also separate cathode types such as the 6AX5, 6Y6, and 6X5 types, and others. With a 600 volt center tapped transformer and a few 20 to 50 mfd. 450 volt filter capacitors, a supply of 250 to 400 VDC at up to 300 ma DC was obtained. Radios, TV sets, amplifiers, as well as other electronic devices all needed these DC voltage levels. However, with todays solid state electronics needing low voltages generally less than 50 volts but at much higher currents, and the availability of very cheap silicon diodes, this circuit is used less often. The circuit basically uses the diodes as half wave rectifiers, one for each half of the cycle. A transformer having a 24 volt center tapped winding is needed. The resultant DC currents in the transformer secondary are in opposite directions so the

magnetization of the core tends to cancel. The output voltage is still a series of sinusoidal pulses, but there is no gap as in the half wave rectifier. The average value is now (2/π) or 0.636 times the peak value, or 10.8 volts DC. A smaller filter capacitor can be used, since the ripple component is now 100 or 120 Hz, for 50 and 60 Hz respectively. Each winding of the transformer is used for only half of the cycle and carries half the average load current, so although two windings are needed, smaller wire can be used in the transformer windings. The PIV across the rectifier is still twice the peak value of the AC input of 12 volts to each rectifier, about 34 volts. This circuit only needs two diodes, but the center tapped transformer adds to the cost of the circuit.

There is a way to get full wave rectification without a center tapped transformer. Four diodes are used in a circuit shown in Fig 3. Since solid state diodes are very cheap, the extra cost and complexity is not a problem, as it would be with vacuum tubes. This rectifier circuit is called a full wave bridge (FWB) rectifier. Examining the circuit, when the instantaneous AC voltage across the transformer secondary is such that the upper lead is positive, current flows out through the upper right diode, through the load, and returns through the lower left diode. We are using the standard convention that current flows from positive to negative. On the reverse half of the cycle, when the top lead is negative current flows through the lower right diode, through the load, and back through the upper left diode. The nonconducting diodes are reverse biased so no current flows through them. Each diode must be able to withstand the the peak voltage of the AC wave, or about 17 volts. However, since four diodes are needed, the load current must flow through two diodes during each half cycle. This means a drop of about 1.4 volts versus 0.7 volts in the previous examples. This voltage loss may be significant with low voltage inputs (less than 10 volts) since it limits the available output voltage. As before, a capacitor can be used to filter the DC output. One problem with the FWB is that, unlike the previous two circuits, the DC output and AC input are unable to share a common ground reference. Examining Fig 3, If either DC output terminal is grounded and one side of the AC input is grounded, the rectifier will be shorted out. This makes for problems where one is forced to use a grounded AC supply, such as the 120 or 240 volt household AC mains, as the DC output will have both terminals “hot” with respect to ground. Many solid state TV sets use this approach, and it makes use of an isolation transformer a necessity for servicing. For this reason, most FWB circuits are used in conjunction with a transformer, enabling one terminal of the DC output to be grounded, since the secondary winding can be left “floating”.

There is a circuit to produce a higher DC output voltage than the AC input would normally produce in the previous circuits. This is called a half wave voltage doubler. A circuit is shown in Fig 4. A series input capacitor C1 is used in this circuit. When an AC voltage is applied D1 conducts when the cycle goes negative, charging C1 to the peak AC line voltage. This is around 170 or 340 volts DC for 120 or 240 volt lines respectively. Note that this DC voltage will be in series with the AC line voltage. Neglecting any diode drop (This is OK for the normal line voltages of 120 or 240), the voltage across D1 and also that applied to D2 will swing between 0 and +340 volts (680 if 240V line). Therefore, C2 will charge up to this peak voltage, and a DC voltage of 340 or 680 volts will appear across C2. This voltage will have a 50 or 60 Hz ripple component. Note that diode D1 and D2 must withstand the full peak to peak line voltage, and C1 must be rated for at least the peak AC line voltage, while C2 must have a DC working voltage equal to the peak to peak line voltage. The negative DC terminal here is also connected to one side of the AC line. Tf line isolation is needed a transformer can be used. In practice, this circuit is used more for 120 volt applications than for 240, since a simple half wave rectifier can produce voltage over 300 directly from a 240 volt line. However, it is also used in some high voltage power supplies for high power RF amplifiers used in amateur and commercial service. This circuit and its relatives allow use of a relatively low voltage transformer to produce high voltages. As an example, the author has a ham radio linear RF amplifier using an 800 volt AC transformer delivering 1.5 amps AC to a voltage doubler. This produces the +2000 volt DC voltage required for the RF amplifier tubes, with up to 600 ma current. An 800 volt transformer at 1.5 amps is less difficult to make than a 1600 volt one, or a 3200 volt center tapped one, as insulation requirements are less and there are fewer turns required. Transformers with smaller turns ratios also tend to have a little better voltage regulation than those with large turns ratios, and the ability to ground one side of the 800 volt winding reduces stress on insulation and reduces the likelihood of flashover and breakdown. The capacitor C1 carries the full AC line input current and must be suitably rated for this service. This circuit is also handy for certain low voltage applications, where a small amount of DC power is needed at a higher voltage than the rest of the circuitry normally requires. If the diodes and capacitor polarities are all reversed, a negative polarity voltage can be obtained. This circuit has been used in older vacuum tube hybrid equipment, to obtain 12-15 volts DC for the transistor portion from the 6.3 volt AC vacuum tube filament supply, eliminating the need for a separate transformer or other source.

A full wave voltage doubler uses two half wave rectifier circuits, one producing a positive output, and one a negative output, with the common leads tied together. Note that if a grounded DC output is needed at the full DC output voltage, the AC supply must be isolsted from ground. This requires a transformer to be used if the AC source has one side grounded. See Fig 5

Naturally, you do not get something for nothing with voltage doubling circuits. Regulation tends to be poorer, and the demand on the components with regard to peak current capability is greater. The circuit is best used for relatively light loads, although with a large value of C2, loads with large peak to average current demands can be handled relatively easily. Examples of these kinds of loads are SSB linear amplifiers, photoflash power supplies, and audio power amplifiers where peaks are encountered. The AC line should also have good regulation (low impedance) for best results.

The voltage doubler can be turned into a tripler by adding another diode and capacitor as shown in Fig 6. In this circuit, the AC voltage component present across D1 is coupled to D3, which is connected to the voltage doubler positive output terminal. D3 acts as a half wave rectifier, and charges to the peak AC line voltage of 170 or 340 volts, respectively. This charges C4 to up to almost 3 times the peak line voltage, less diode drops. This circuit will produce over 500 or 1000 volts from a 120 or 240 volt input. Extending this concept further, a voltage quadrupler (4x) can be produced as in Fig 7. The sequence can be repeated indefinitely in theory, but a practical limit for most uses is probably 10 or 15 stages. The regulation becomes poorer as the multiplication is increased. Note however that relatively low voltage components may be used in many places,

since only the output capacitor sees the full output voltage across it. Triplers, quadruplers, and higher order multipliers find application mainly when a high voltage low current supply is needed, as for CRT second anode supplies, geiger counter tubes, some laser work, and high voltage experimentation. The chief advantage is that the voltage multiplier allows use of a relatively low voltage AC source to produce a high voltage DC output. Conventional half and full wave rectifier circuits would need a large and expensive high voltage transformer

The best way to understand these circuits is to build them and experiment. A 12 volt 1 amp transformer, four 1N4000 series diodes, and a few electrolytic capacitors of 100, 470, or 1000 mfd at 25 to 50 volts or better are all you need. Suitable loads can be low value 5 or 10 watt resistors (25-100 ohms, etc) or you can use small 12 volt automotive lamps, such as the #53, #57, and #194. There are 24 or 36 volt lamps available such as the #313, 1822, or 1829, and these can be used also. LEDS can be used but they do not draw much current, so you will need a lot of them. In this case a combination of LEDs and load resistors is more practical. A DVM can show how DC output voltage varies with load. And if you have access to a scope, you can also examine the waveforms. Lamps can give a visual indication via their brightness. If you cannot get parts, (also if you are inept at using tools and soldering, or otherwise too lazy) you can also plug these circuits into a SPICE simulator program on your PC and demonstrate their workings as well, but there is no substitute for the “real” thing. You will learn better by doing, rather than merely watching a monitor display. Also, many lower cost simulator programs used by experimenters do not take into account certain second and third order effects that may prove to be limiting factors that affect actual performance. Again, there is no substitute for the “real” thing.

DO NOT USE THE 120 OR 240 VOLT AC LINE VOLTAGE WITHOUT A STEP DOWN TRANSFORMER. Severe fire, shock and electrocution hazards are present. You could easily kill yourself and maybe someone else, and also start a fire. 6, 12 or 24 volts will work just as well, suitable parts are much cheaper, and it is a lot safer. You can use a wall wart (AC output only type), bell transformer from the hardware store, or a toy train transformer as an alternative to a 12V power type transformer. Any voltage from 6 to 24 volts will do. Higher voltages than 24 volts may present a shock hazard, especially when experimenting with voltage multiplier circuits. It would be a good idea to place a 1 amp. fuse in series with the transformer secondary. Many low voltage transformers have built in thermal fuses whose sole duty is to prevent a fire should the transformer overheat. They are placed inside the windings of the transformer and are incccessible unless you can disassemble it. These fuses usually take several seconds or more to self-destruct, and are not replaceable, so your transformer becomes a rather ugly paperweight. The extra 1 amp fuse, however, will fail first, protecting your transformer and components.

The next part will discuss voltage regulators and how to build a regulated adjustable power supply circuit that will be useable as a source to power experimental circuits.

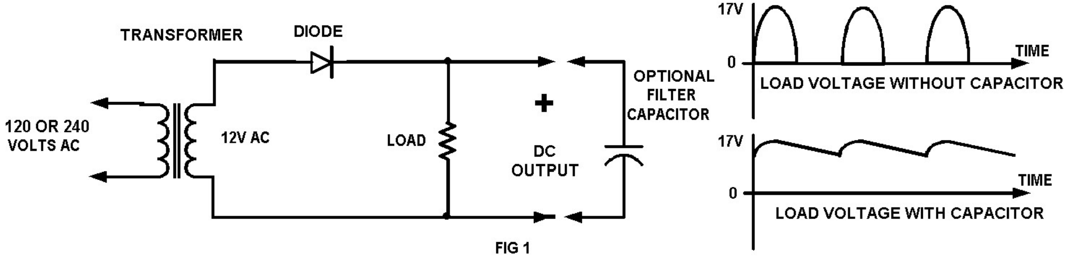


FIG 1

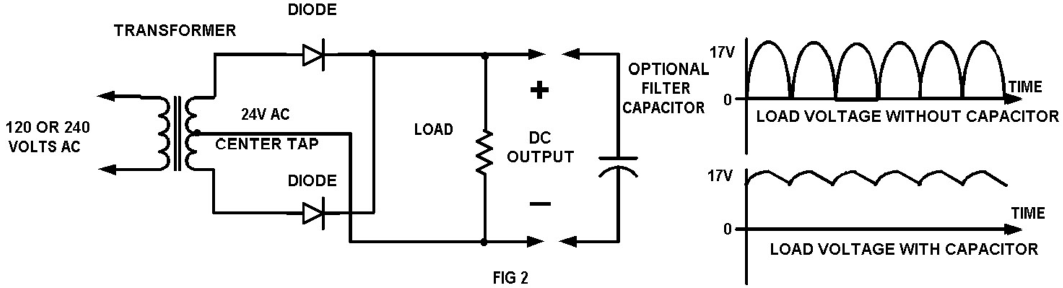


FIG 2

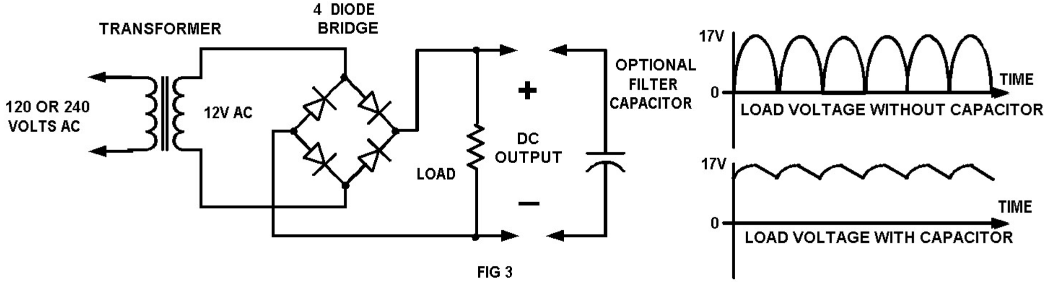


FIG 3

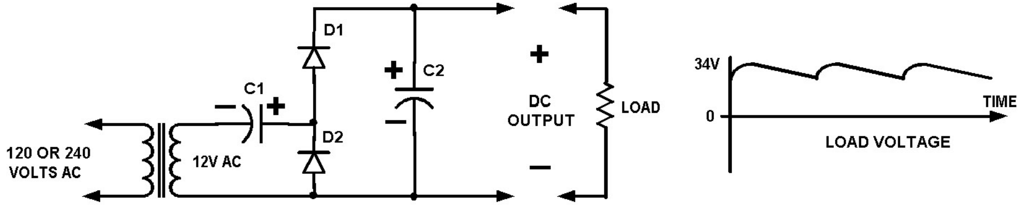
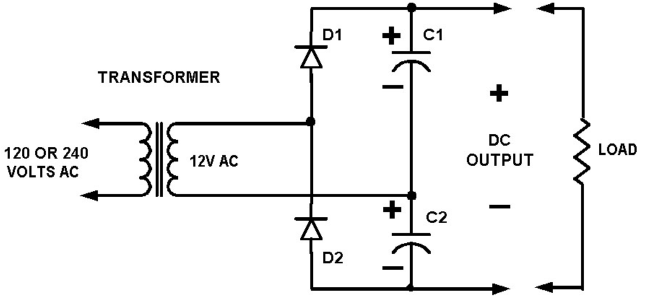
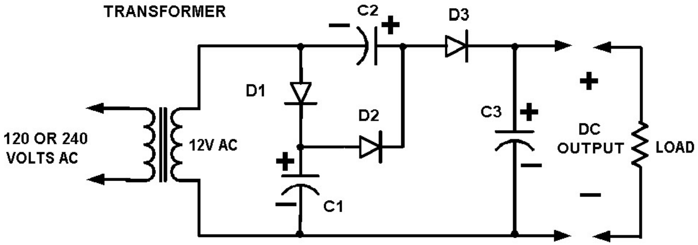


FIG 4



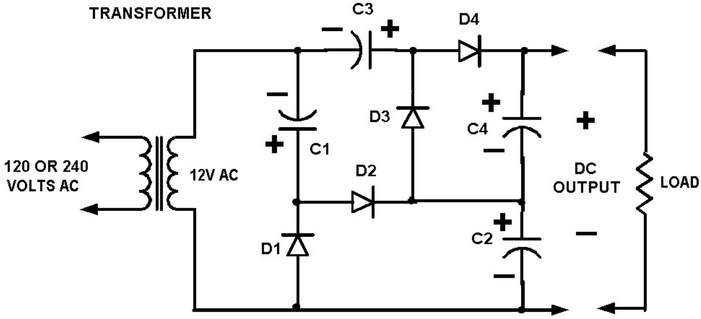
FULL WAVE VOLTAGE DOUBLER

FIG 5



VOLTAGE TRIPLER

FIG 6



VOLTAGE QUADRUPLER

FIG 7