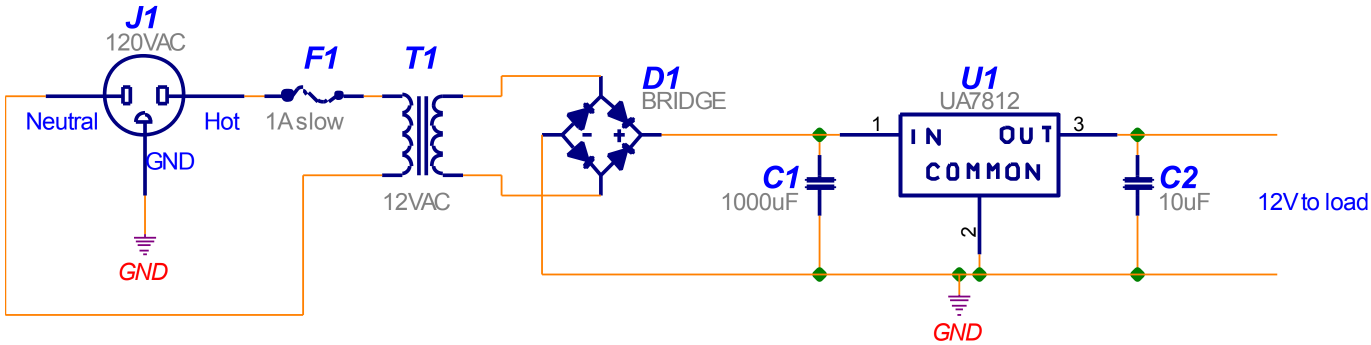
Linear power supply design:
To make a simple linear power supply, use a transformer to step down the 120VAC to a lower voltage. Next, send the low voltage AC through a rectifier to make it DC and use a capacitor to smooth out the ripples in the DC. Finally, add a voltage regulator to regulate the output voltage (i.e. keep it fixed even though the input voltage or the load current can change). An example is shown below.

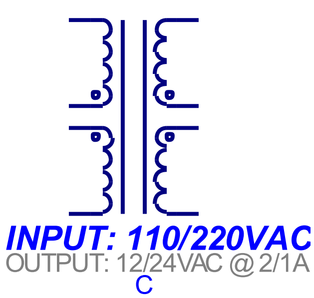


Explanation of how transformers work:
http://www.explainthatstuff.com/transformers.html

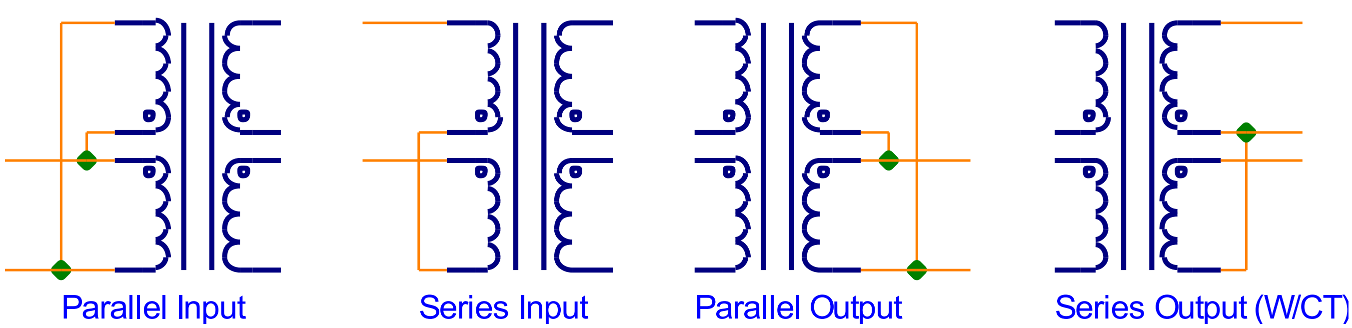
Different kinds of transformers:

The transformer in **Fig A** has a single input and a single output. The output will be rated for voltage and current (Ex: 12VAC @ 1A). Note: 12VAC is the RMS voltage. The peak voltage is 12*1.41 = 17V and the peak-to-peak voltage is 34V. The input will have a voltage rating (usually 120V for the US and 240V for Europe). The input current depends on the output current. Energy is conserved. Ex: with an output of 12V@1A a 120V input would draw 0.1A.

The transformer in **Fig B** has a center tap output. The output voltage is split evenly over each half of the output (Ex: 12VCT would have 6VAC from the center tap to the top wire and 6VAC from the center tap to the bottom wire. Center tap transformers are useful when making symmetrical positive and negative power supplies (since the center tap can be tied to ground).

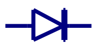


The transformer in **Fig C** can be wired for different input and output voltages and currents. If the two input coils are wired in parallel the input voltage will be half what it would be if the input coils are wired in series (i.e. 110/220V input). Similarly the output coils can be wired in parallel for more current or series for more voltage. Note: The dot marks the polarity. In parallel the wires with the dots are tied together. In series one wire with a dot is wired to the other coils wire without the dot. If wired incorrectly the transformer will get hot and possibly melt the windings.



Transformers aren't 100% efficient.
Voltage rating is at full load, will be higher at lower current.
Isolation, variac, impedance match transformers (600 ohm)
Add a fuse on the primary side for safety (circuit breaker, PPTC thermal reset)

Diodes:
Recall that a diode allows current to flow in only one direction (the direction of the arrow, current flows from the anode to cathode). When the anode voltage gets more than about 0.7V above the cathode voltage current can flow through the diode. This voltage drop is usually about 0.7 volts for silicon diodes and 0.4 for schottky diodes. Note: The voltage drop across the diode does increase slowly as the current increases but we will assume a fixed voltage drop of 0.7V when forward biased (i.e. conducting current). When reverse biased (i.e. the cathode voltage is higher than the anode voltage) there is only a small leakage current that flows. This current is usually in the nano-amp to micro-amp range and we will assume this leakage current is zero.

Current in (anode)  Current out (cathode)

The following link shows examples of how diodes and capacitors are used to convert AC to DC. Click on each of the three examples (half-wave, full-wave center-tap, and full wave bridge). Note: don't worry about the equations, just the shape of the waveforms and how the current flows in the bridge rectifier.
http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/rectifiers.html#c1

Filter capacitor selection (simplified ripple calculation):
Let's say you want to keep the rectifier ripple to 0.5V or less and the max current your power supply will deliver is 1A. If we assume a constant load current the voltage on the cap will decrease linearly **($\Delta V = I*\Delta t/C$)**. For a full wave rectifier the time between the peaks is 8.3ms (1/120Hz). So, to keep the rectifier ripple voltage to less than 0.5V at a 1A load you would need a 16,700uF or larger cap (1A*8.33ms/0.5V). 22,000uF electrolytic caps are available. Make sure you get one with a voltage rating above the max voltage you plan use. Also, if you plan to draw lots of power get a capacitor with a low internal resistance (ESR – equivalent series resistance). Some capacitor datasheets list maximum ripple current. The rated ripple current should be well above the current you plan to operate at since when delivering the rated ripple current the capacitor will be at it's maximum temperature (probably above 70C).

Mention Harmonics (pfc), decoupling, pulsed current, RMS vs. peak voltage, two diode drop in bridge.

How a linear voltage regulator works:
You can think of a linear voltage regulator as a magic resistor between the power supply and your circuit. The resistance changes to keep the output voltage constant independent of changes in the input voltage or the load (i.e. how much current is drawn from the output). It's actually a circuit which measures the output voltage and adjusts the voltage drop across a transistor but the concept is the same.

How to read a voltage regulator datasheet:
Pull up the datasheet for the LM78xx series voltage regulators:
https://www.fairchildsemi.com/datasheets/LM/LM7805.pdf

This is a simple three pin device (Vin, GND, and Vout). We'll be using the TO-220 package (The largest one with the metal tab). We'll be using the LM7812. It's an older voltage regulator but functionally equivalent to its replacement – LM340.

Output voltage:	For the LM7812 it's typically 12V with a min output of 11.5V and a max of 12.5V.
Line regulation:	How much the output voltage changes due to the input voltage changing. At 500ma output current the input voltage could vary between 14.5V and 30V and the output would typically change no more than 7.5mV (240mV max) Note: This is for slowly changing input voltages (also see ripple rejection below)
Load regulation:	How much the output voltage changes due to a change in the load. As the output current varies between 5ma and 1.5A the output voltage would typically change by no more than 1.6mV (240mV max). Note: This is for a slowly changing load.
Quiescent Current:	The current used by the regulator to operate (i.e. the current draw when the load current is zero). This regulator typically needs about 1mA to operate.
Output noise voltage:	Average rms noise present at the output of the regulator.
Ripple rejection:	How much the output voltage changes due to the input voltage changing at a given frequency. At 120Hz the ripple is typically decreased by 60dB. Note: dB in this case is $20\log(\Delta Vin/\Delta Vout)$ so 60 db is 1000 times less ripple on the output. Ex: If you have 1V of ripple (at 120Hz) on the input the output would typically have ~1mV of ripple. Note: Higher frequency ripples don't get cut down as much.
Dropout Voltage:	The voltage difference between the input and output required for the regulator to work properly (2V). For this 12V regulator the input should always be above 14V.

Power dissipation:
How much power is turned into heat (and must be dissipated) by the regulator. We will neglect the quiescent current because it's usually much smaller than the load current. We'll therefore assume the input and output currents are the same. The power dissipated in the regulator is $\Delta V*I = (Vin–Vout)*Iout$.
Ex: Vin = 18V, Vout = 12V, Iout = 200mA, so the regulator has to dissipate 6V*0.2A = 1.2W.

Temperature rise:
Page 1 of the datasheet states: The thermal resistance of the TO-220 package is typically 5°C/W junction to case and 65°C/W case to ambient. This means that for every watt that the regulator dissipates the temperature difference between the junction (the semiconductor circuitry inside the regulator) and the case (the metal tab) will go up by about 5°C/W. The 65°C/W case to ambient tells you how hot the part will get without an additional heat sink and without a fan to cool it (i.e. convection only). When calculating the temperature rise of the die you add the two thermal resistances (in this case you get 70°C/W).

Using the above example where we're dissipating 1.2W the regulator die temperature would be about 1.2W*70°C/W = 84°C above ambient. If used at room temperature (25°C) the die temperature would be about 25°C + 84°C = 109°C. Note: At the bottom of page one of the datasheet it states that the maximum junction temperature 150°C. So technically this is OK assuming the part is in the open allowing for sufficient airflow. In practice you want to keep the part cooler. The lifetime of the regulator (and many surrounding parts) depends on the temperature. The hotter it gets the sooner the part will fail. You could also burn yourself if you touch the regulator (the case temp would be 25°C + 65°C/W * 1.2W = 103°C

(217°F). Always design in a safety margin and don't assume the ambient temperature will be 25°C. Note: designing automotive electronics that have to operate under the hood of a car or other extreme conditions can be challenging.

Note: The regulator has internal thermal overload protection.

Heatsinks:
To lower the temperature of the regulator we can add a heatsink. Take a look at the following: http://www.digikey.com/product-detail/en/507302B00000G/HS115-ND/5849 We have similar heatsinks in the lab. Ex: This heatsink has a thermal resistance of 24°C/W. When this heatsink is properly attached to the regulator the thermal resistance of the heatsink replaces the thermal resistance of the regulator (case to ambient). The new thermal resistance (die to ambient) would be (5°C/W + 24°C/W = 29°C/W). Which would give us a new die temperature of 25°C + 29°C/W*1.2W = 59.8°C (about 43C cooler than before, not bad for a 41 cent piece of aluminum). Note: This is just an approximation but it's close. Use the graph on the datasheet for more precision.

Click on the datasheet for the above heat sink. As the temperature difference between the heatsink and ambient air decreases there will be less convection causing the thermal resistance to increase. Use the graph with the arrows pointing down and to the left (natural convection not forced air). At 1W the heatsink is about 28C above ambient. At 2W it's about 51C above ambient and at 3W it's about 71C above ambient. So it's thermal resistance would be about 28°C/W@1W, 25.5°C/W@2W, and 23.7°C/W@3W. Note: This manufacturer lists the thermal resistance for a 60°C temperature rise hence the 24°C/W.

The above example assumes that you're relying on thermal convection (not forced convection, i.e. fans). If you add fans you can decrease the temperature further or use a smaller heatsink (sometimes saving space, weight, and maybe money). One can use the thermal curve to estimate the thermal resistance at different flow rates. Ex: at 200lfm (linear feet/minute) the thermal resistance is about 10°C/W. At 600lfm the thermal resistance is about 5°C/W. A little airflow makes a big difference.

Attaching the heatsink to the regulator:
The regulator and heatsink should be relatively clean before starting. Apply a **thin** layer of thermal grease to the metal tab on the regulator. When pressed together the thermal grease fills in microscopic imperfections in the surfaces and increases the contact surface area. Use a machine screw, lock washer, and nut to secure the regulator to the heatsink. Note: Thermal grease does add to the overall thermal resistance but in low power applications the extra 0.1°C/W or so is usually neglected. When dealing with high power devices where heatsinks are on the order of 1°C/W or less the extra 0.1°C/W becomes more important. Better thermal grease is available (usually made with silver particles) that have lower thermal resistance. Note: For convection cooling heatsinks should be placed with the fins vertically to get the maximum airflow (to achieve the specified thermal resistance).

Safety note: On the LM7805 the metal tab is tied to the ground pin. When using transistors & FET's the metal tab will usually be tied to the collector or the drain and will not be at zero volts. Many times a thermally conductive electrical insulator is used to isolate the heatsink from the metal tab so the heatsink isn't at high voltages. These insulators can be Kapton pads that are used instead of thermal grease or a piece of Mica or film used with thermal grease. Note: You may need to use an insulating shoulder washer so the metal machine screw doesn't electrically connect the heatsink to the metal tab (see last link below).

Heatsink URL's (if interested):
Simplified explanation of how heatsinks work:
http://www.bcae1.com/heatsink.htm
How to select a heatsink (pages 9-11) (if interested, not required):
https://www.mouser.com/pdfdocs/Aavid-Board-Level-Heatsinks-Catalog.pdf
Example of thermal pad:
https://www.digikey.com/product-detail/en/bergquist/SP400-0.007-00-58/BER207-ND/529924
Heatsink mounting kits contain everything but thermal grease (electrically isolates the heatsink):
http://www.digikey.com/product-search/en?keywords=%09HS417-ND

Efficiency:
Efficiency is Pout/Pin = Iout*Vout/Iin*Vin. Since we're neglecting the small current used by the regulator the input and output currents are about the same. Therefore if your starting with 18V and regulating it down to 12V its 12V/18V = 66% efficient. The larger the difference between input and output voltage the worse the efficiency. Not only is this a lot of wasted power but it costs extra for larger heatsinks and possible fans required to dissipate this heat.

Switching Power Supplies:
Switching power supplies are more efficient than linear supplies. By cleverly switching the current in and out of inductors at high frequencies switching supplies can be over 90% efficient. Because they operate at higher frequencies they are much smaller than a similar sized linear power supply (switching supplies use small inductors at high frequency instead of large transformers at low frequency - 60Hz). An explanation of how a basic switching supply works is at: http://www.rason.org/Projects/swregdes/swregdes.htm
Note: Because switching supplies operate at higher frequencies (usually 50KHz-2MHz) the switching noise is harder to filter out (see ripple rejection or power supply rejection ratio (PSRR) in the datasheets). Sensitive equipment such as low noise amplifiers are usually powered by linear regulators because of the noise issues associated with switching supplies. Digital electronics (where all the voltages are either high or low, on or off) are less susceptible to noise and will usually use switching supplies. Your PC power supply is a switching supply.

Note: You can have a switching supply followed by a linear regulator.

Steps for Designing a Linear Power Supply:

1. Determine the output voltage and current needed (Ex: 15V@0.5A)
2. Pick a linear regulator with that can handle the required current (Ex: LM7815)
3. Pick a bridge rectifier that can handle the required current (Ex: DB102)
4. Pick filter capacitors that limit the rectifier ripple to a reasonable value
   (Ex: 0.25V ripple @ 0.5A requires > 16,700uF, use 22,000uF)
5. Pick a transformer with a secondary voltage rating to accommodate all the voltage drops
   (Ex: 15V output + 2V regulator dropout + 0.25V ripple + 1.5V diode drop = 18.75V)
   (18.75V peak = 13.26Vrms, add a safety margin, 14Vrms minimum @ 0.5A or more)
6. Add a fuse to the primary side of the transformer (and a heatsink if needed) for the rectifier
   and regulator.