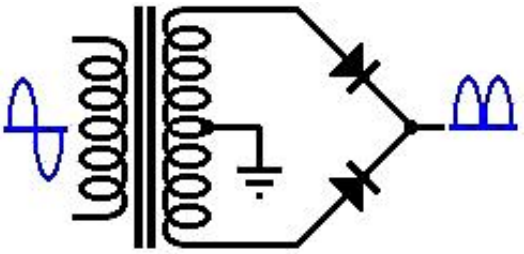
The Two-Phase, Full-Wave Rectifier

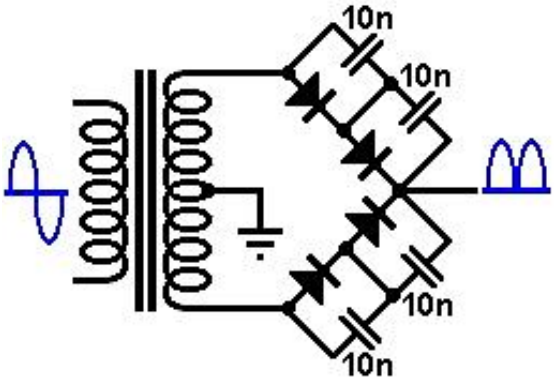
The two-phase, full-wave rectified power supply can be found in all early amplifier designs, before the advent of silicon rectifiers, and requires a centre-tapped transformer.



The centre tap is usually grounded directly to the chassis near the transformer. Every half cycle, one side of the transformer secondary passes current while the other side is 'off', then the whole thing reverses and the other side of the transformer secondary becomes active. Therefore each side of the transformer secondary only has to work half of the time. In other words, we have two half-wave rectifiers operating out-of-phase with each other.
Some transformer manufacturers quote the maximum current for the secondary *as a whole*, but because only half of it is ever active at one time, you can draw twice the rated current. You should check with the manufacturer whether they quote ratings in this way.

Using silicon rectifiers: Silicon rectifiers are small, cheap and efficient. As a rule of thumb; a power supply using silicon rectifiers will develop an HT voltage **under load** that is roughly 1.2 times the RMS voltage delivered by the transformer.

Minimum ratings: When using silicon rectifiers, they *must* have a peak inverse voltage (PIV) rating of 2.8 times (2 * root 2) the RMS voltage being delivered by the transformer. (This is a higher PIV rating than necessary with a bridge rectifier.)
For example; with a transformer rated at 300-0-300Vrms the diodes must be rated at:
2.8 * 300 = 849V PIV
For this reason, it is quite usual to place two or more diodes in series; their PIV ratings will sum, increasing the PIV of the rectifier as a whole.
(On modern data sheets, PIV may be listed as 'Reverse Repetitive Maximum' (Vrrm) instead). If diodes are used in series, a capacitor chould be placed in parallel with each one to ensure equal voltage sharing between each diode. Values of 10nF to 47nF (1kV or better) are common, and they will also act as snubbing capacitors to supress the voltage transients produced by the diodes switching.
The most popular silicon diode used is the 1N4007 (PIV = 1000V, 1A)

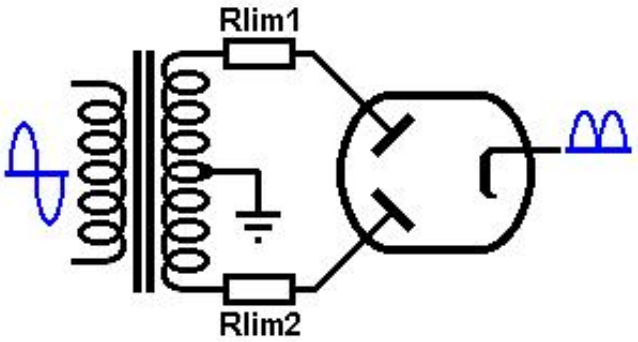


The diodes should have a current rating greater than the peak current you expect the amp to draw (ignoring ripple current). Thankfully, valve amps usually have fairly meager HT current demands, and 1A diodes are usually sufficient even for 100W amps. The maximum current value quoted on the data sheet already takes ripple current into account so this is not a major issue.

When not under load, the voltage after rectification will be close to the *peak* AC voltage, which is equal to the 1.4 times (root 2) the RMS voltage.
For example, with a transformer rated at 300-0-300Vrms, the DC voltage after rectification will be close to:
1.4 * 300 = 420Vdc
(There will be a couple of volts lost across the diodes, but we normally ignore this.)
We can expect this DC voltage to fall by 10% to 15% when we start drawing current, due to voltage being dropped across the transformer winding. So, we can realistically expect to achieve about 365Vdc of HT under load using this transformer.

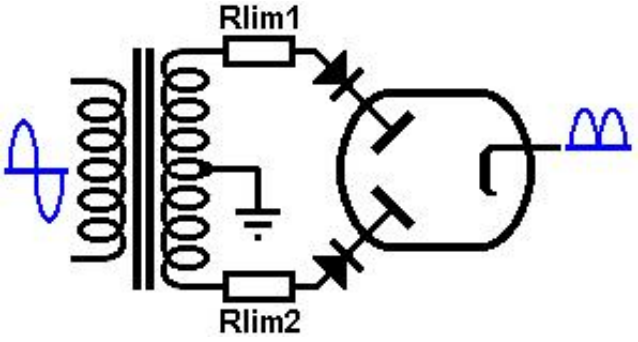
Using valve rectifiers: The main reasons for using a valve rectifier are to create 'sag' in a Class-AB amp, and/or to obtain a lower HT than silicon diodes would provide.

As a rule of thumb; a properly designed valve rectified power supply will develop an HT voltage (under load) that is roughly equal to the RMS voltage delivered by the transformer, although this is only an approximation. Both silicon diodes and valve rectifiers produce switching spikes, although those produced by valve rectifiers are less pronounced so snubbing capacitors are not required. Valve rectifiers also require a fairly high current heater supply, which may limit your choices.



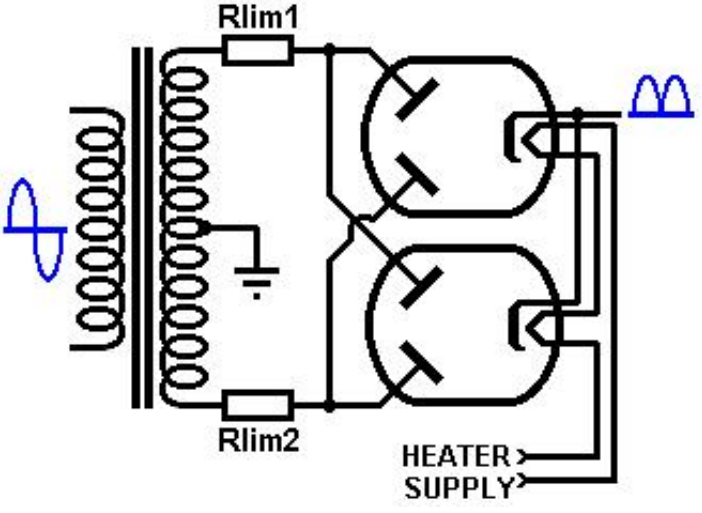
Because valve rectifiers were originally designed for use as full-wave rectifiers, the data sheet will specify a maximum anode supply voltage (Va(rms)) that is already appropriate for use in this configuration. This is NOT the same as the quoted PIV, which will be higher. For example, with a transformer rated at 250-0-250Vrms the common choices are:
GZ30 (Va(rms)max = 250V so this would be a risky choice)
EZ80 (Va(rms)max = 350V)
GZ34 (Va(rms)max = 550V)

If we were worried about running a valve rectifier too close to its maximum Va(rms), we could place one or more silicon diodes having a much higher PIV in series with each anode as protection elements. In theory the valve rectifier can then be used with supply voltages up to twice the rated Va(rms). The silicon diodes will have no adverse effects on the normal operation of the valve rectifier.



The valve type used will depend on the current you need to deliver, and the maximum ratings are given in a graph on the data sheet.
The EZ80 is rated at between 90mA at 350Vrms, to 104mA at 100Vrms
The GZ34 is rated at 250mA at all supply voltages.
This refers to the *average* anode current. The peak anode current will be higher but is only allowable for short current transients.

Rectifiers in parallel: If we need to draw more current than the rectifier is rated for, we can place two or more valves in parallel; the maximum current ratings will sum since each valves shares an equal portion of current, in theory! Remember that matched valves are rare, so don't run them very close to their maximum ratings as one valve may be working harder than the other!
If possible, the heaters should be run in series so that if one rectifier heater were to fail, the others would also shut down. Of course, the heater supply would need to provide the sum of the heater voltages, so would probably require a separate transformer.
Unfortunately, directly heated cathode rectifiers should not have their filaments run in series.



If two rectifiers are placed in parallel, the necessary series limiting resistance will be half the value for one. If three are used, it will be a third the value for one etc. [see below].

The DC voltage after rectification will be equal to 1.4 times (root 2) the RMS voltage from the transformer, minus the voltage dropped across the transformer coil under load, minus the voltage drop across the rectifier.
The voltage drop across the rectifier will be different depending on the valve type used, and will also increase as more current is drawn. The data sheet will provide a graph indicating either the voltage drop, or the DC voltage out for a given input voltage at a given current.
For example, with a transformer rated at 250-0-250Vrms, the DC voltage after rectification will be close

to:
1.4 * 250 = 350Vdc
We can expect this DC voltage to fall by 10% to 15% when we start drawing current making roughly 310Vdc.
If using an EZ80, the graph indicates that when drawing 90mA the voltage drop across the valve will be 25V, making 285Vdc. There will then be a *further*voltage drop across the limiting resistance [see below], in this case another 39V making a total HT of about 246Vdc. This is very close to the RMS voltage delivered by the transformer in the first place!

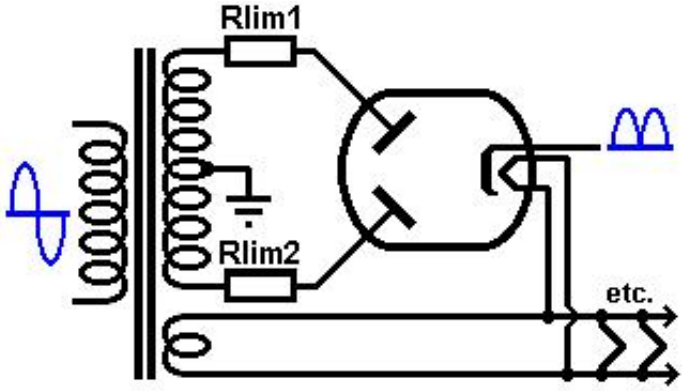
Minimum Limiting Resistance: A valve rectifiers *must* have a resistance in series with each anode. Many 'classic' amps do not include these when they ought to, and rectifier failure is common in these amps. The data sheet will provide a Minimum Limiting Resistance (Rlim(min)) for different supply voltages, although the limiting resistance can be decreased if the reservoir capacitor is also decreased proportionately. Part of the limitng resistance will be made up of unavoidable transformer resistance and reflected impedance, and this should be calculated first in order to find out whether any additonal resistance must be added.
For example, when supplied by a transformer rated at 300-0-300Vrms, the EZ80 specifies Rlim(min) = 215 ohms per anode. The total impedance presented to the rectifier by the transformer is given by:

Rt= Rs + (n^2)* Rp
Where:
Rs = DC resistance of *one half* of the transformer secondary winding.)
Rp = DC resistance of the transformer primary winding.
n = Secondary to primary turns ratio (equal to the secondary voltage divided by the primary supply voltage).

If we were using a mains transformer with a 240V; 80R primary and a 310-0-310V; 50R per half secondary:
Rt= 50 + (1.29^2)* 80 = 183R
The EZ80 requires at least 215 ohms, so an additonal 215 - 183 = 32 ohm resistor must be placed in series with each anode (so we would probably use 33 or 47 ohms).
Because the limiting resistors will have to carry the ripple current of the reservoir capacitor it is best to use high wattage resistors. Even 7W resistors will usually get quite warm. Remember that the voltage drop across the limiting resistors will cause the HT fall proportionately.
Alternatively, a single limiting resistor could be placed between the transformer centre tap and ground, although its power dissipation will be doubled.

Clearly your choice of rectifier has a huge effect on the HT you ultimately achieve. It is the voltage drop across the rectifier and series limiting resistance that causes 'sag' in Class-AB amps. When a loud sound is played and the amp suddenly draws more current the voltage dropped across the rectifier increases, lowering the HT and creating a compressing effect known as 'sag'. Class-A amps do not exhibit this effect since their current draw remains constant on average. Silicon diodes have a voltage drop (about 0.7V) that is constant with current so they do not produce sag, but it can be simulated simply be placing a resistor (roughly 100R to 330R) in series with the rectifier. But be sure to calculate the necessary power rating! A resistor in this position will usually need to be the biggest one in the amplifier, and may need to be rated at 10W or more.

Heater considerations: If the rectifier has an indirectly heated cathode (like the EZ80) then it can be run from the same heater supply as all the other valves in the amp, assuming the heater supply has sufficient current rating. However, be sure to check the data sheet for the maximum rated peak heater-to-cathode voltage (Vhk). If you are close to the maximum then you will need to elevate the heater supply to be within safe limits, although this is becoming fairly common practice anyway as it reduces hum [see the section on heater supplies]. Even better is to run the rectifier from a separate heater supply and connect it directly to the cathode, and run it like a directly heated cathode rectifier.



If the rectifier has a directly heated cathode or if the heater is internally connected to the cathode (like the GZ34), then it will need a separate filament supply. If the filament supply has a centre tap then the HT should be taken from there, which will help to reduce HT noise induced by the filament.

