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Vacuum Tube Amplifiers

Arguably the most important technological invention of the twentieth century was that of semiconductor or 'solid state' devices like the transistor. Prior to the invention of the transistor and the diode, vacuum tubes were used to design circuits for amplification and rectification. While tubes are impractical in most modern applications due to their size and non-idealities, they are still widely used in the design of high quality audio equipment because their desirable audio characteristics cannot be accurately replicated.

What is a Vacuum Tube?

Vacuum Tubes (sometimes called just "tubes" or "valves" in British English) are electronic components that control current by emitting electrons in an evacuated container. In the simplest design, electrons are emitted from the cathode, most often by thermionic emission, to the plate (or anode) which results in electrical current. To cause thermionic emission, the cathode must be heated. Some tubes use a directly heated filament as the cathode while others have a separate heat source inside that heats the cathode indirectly.

Example of different Vacuum Tubes *[pintrest.com]*

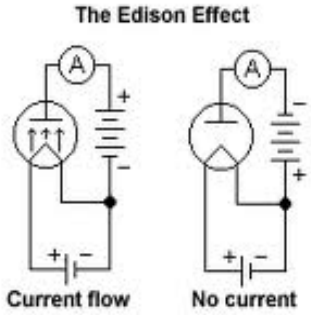
There are numerous types of vacuum tubes with additional parts for specific applications, but the most common ones used in audio amplifiers are diode, triode, and pentode tubes. A diode tube, like a semi-conductor diode, is used for rectification and only allows current flow in one direction. Triode and Pentode tubes function more similar to transistors and can be used for switching and amplification.

Types of Vacuum Tubes used in Audio Amplifiers

Rectification Tubes

The Diode Tube

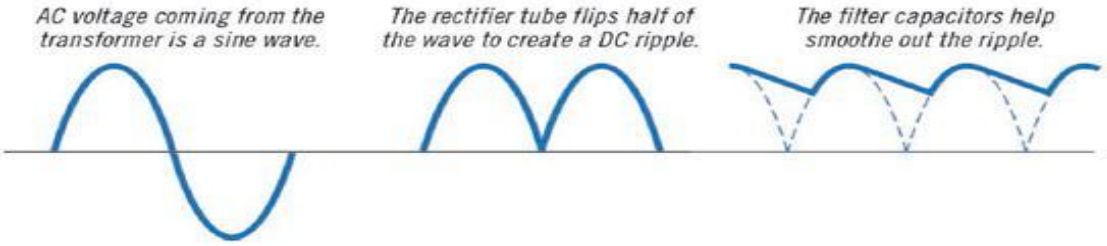
The diode vacuum tube utilizes electron emission to allow current flow in only one direction, preceding modern day semiconductor diodes. There are two terminals inside a basic diode tube: the plate (sometimes called the anode) and the cathode. If a positive voltage is applied to the plate, the electrons will naturally flow from the cathode to the higher potential at the plate after emission. On the other hand, electrons will not flow to a negatively biased cathode, preventing current flow in that direction. This phenomenon is known as the Edison Effect after the inventor of the Light Bulb, Thomas Edison.



A basic diode tube circuit, showing how current can only flow in one direction.
[www.hamslife.com/the-vacuum-tube-diode/]

The Rectification Process

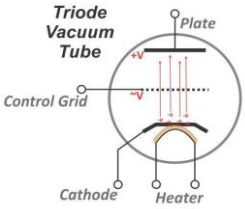
Diode tubes can be used in power supplies to rectify an AC input, beginning its conversion to DC. Most rectification circuits are designed to allow the positive part of the AC signal pass and then allow an inverted portion of the negative part pass, creating a bump-style waveform seen in the second picture below. This DC ripple is then filtered through additional circuitry to smooth it into a steady DC signal. While this process is used in nearly every device that plugs into a wall socket, most modern rectifiers are solid state. Audio applications use tube rectifiers for the non-ideal aspects of that will help produce desirable effects on the sound during the amplification stage.



The rectification process begins conversion of alternating current to direct current using diode tubes to only allow one direction of current to flow. *[www.robrobinette.com/How_Amps_Work]*

Amplification Tubes

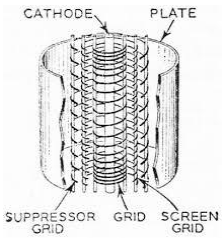
The Triode Tube



Schematic Diagram of a Standard Triode Tube
[www.hamradioschool.com/g6b10-vacuum-tubes]

Triode and Pentode Tubes both have the ability to provide amplification to an input signal, similar to the function of transistors. A triode tube has three terminals adding what is called a control grid to the plate and cathode of the diode tube. Physically placed in between the plate and the cathode, the control grid acts like gate for the emitted electrons. With a positive grid voltage, more electrons are drawn from the cathode to the plate, creating a gain. If the control grid has a varying voltage, it will create a varying current through the plate. This current through a resistor attached the plate shows a voltage gain from the input to the grid. The most common triodes used in audio amplifiers, specifically guitar amps, are the 12AX7 and 12AT7 tubes.

The Pentode Tube

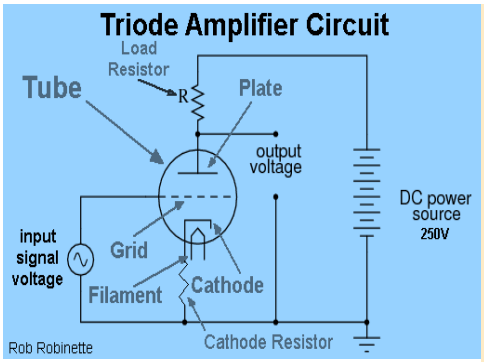


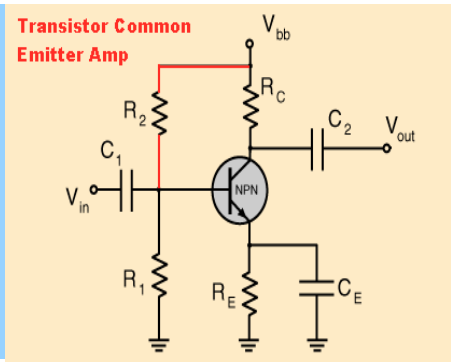
Inside of a Pentode Tube
[www.ampbooks.com]

Pentode tubes build off of the design of triode tubes, adding terminals for a screen grid and a suppressor grid. The screen grid is necessary to decrease the internal capacitance and the suppressor was added to prevent secondary emission, the process in which the kinetic energy of incoming electrons causes some secondary electrons in the plate to eject outwards. Without a suppressor grid, the secondary electrons could make it all the way to the screen grid, causing unwanted noise and oscillations. With a small applied voltage, the lower energy secondary electrons will be held back from reaching the screen grid while the electrons emitted from the cathode are able to pass through because of their higher energy. These added parts give the pentode greater amplification capabilities and better high frequency characteristics.

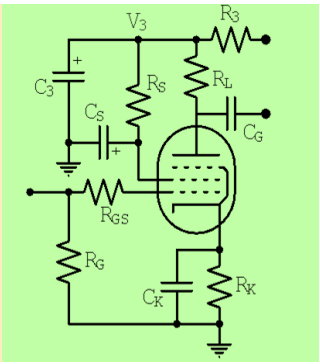
Tube Amplifier vs Solid State Amplifier Circuits

A simple amplifier circuit made using a triode tube is almost identical to that one using a bipolar junction transistor (BJT), the only difference being the addition of feedback resistor and some bypass capacitors. While not identical, the amplification characteristics of tubes and transistors are quite similar as their current vs voltage relationships closely resemble each other. A simple pentode circuit requires a more thorough design, but it can be used for specialized circuits that could not be created with a triode.





Comparison of Basic Triode and Transistor Amplifier Circuits
[www.robrobinette.com/How_Amps_Work]

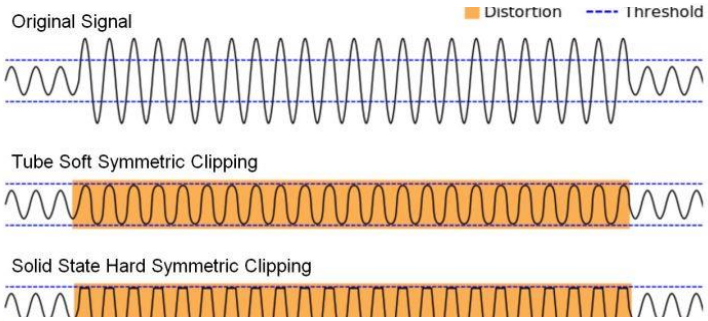


Simple Pentode Amplifier
[www.ampbooks.com]

Why Use Tubes in an Audio Amplifier?

In many amplification devices, the BJT and other transistors like the MOSFET and JFET have replaced triode (and pentode) tubes because of size, power and heat efficiency, and reliability. However, tubes and transistors affect certain aspects of an input signal differently, causing distinct advantages and disadvantages for both. Transistors last longer, can be made on an integrated circuit, and cost significantly less than their tube counterparts. On the other hand, tubes have a more linear response, require simpler circuits and cause much smoother clipping of a signal when compared to transistors. Although it is subjective, most guitarists prefer the soft clipping and specific frequency response of tubes, evidenced by the fact that a vast majority of high quality guitar amplifiers are made with vacuum tubes. For rock and blues guitarists especially, the distortion from clipping and the 'warm' tone of a tube's frequency response are essential to their sound. The same idea applies to recording equipment such as microphones and preamplifiers where the soft clipping gives a 'punchier' sound to a recording.

Fender Princeton Reverb Tube Guitar Amplifier
[www.topsound.fi/fender-65-princeton-reverb]



Comparison of Tube and Solid State Clipping
[www.robrobinette.com/How_Amps_Work]