Vacuum tubes

A basic introduction
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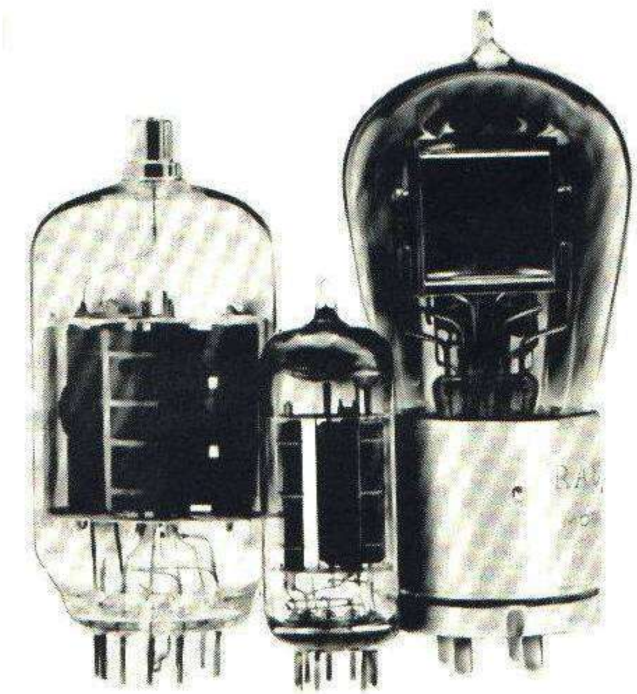
- The Basics
- Diodes
- Triodes
- Tetrodes
- Pentodes
- Applications in radio
- Amateur radio RF tubes
- Questions

The Basics

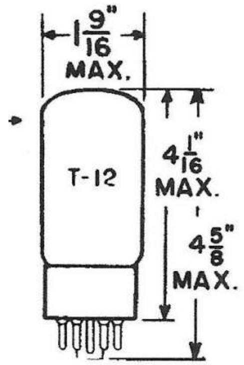
- In 1904 John Fleming invented the first diode.
- In 1907 Lee DeForest invented the Audion, the first triode and electronic device capable of amplification.
- Tube devices are called “Hollow State”.
- The earliest tubes evolved from the common light bulb.
- Tubes do not create power, they only control it.
- Tube equipment is virtually immune to ESD and EMP.
- All tubes work on the principle of thermionic emission.
- The black area on the tube is called the getter and is the result of RF induction flashing.
- Heat is created not only by the filament but also by electrons bombarding the plate.
- Power handling tubes can operate upwards of 400 F.
- There are two types of cathode systems; filament/cathode and heater/cathode

- Top cap connection reduces grid to plate capacitances, improves high frequency performance, keeps high plate voltages isolated from lower pin voltages, and helps avoid leakage resistance through the base (very important for high impedance grid input designs).
- Pinouts are always shown as a bottom view…pin 1 lower left.
- North American tube designation system is not always followed (ex: 12AX7)
- The highest capacity power tube is the Eimac 4CM2500KG which dissipates up to 2.5 megawatts. By way of comparison, the highest capacity transistor is the NXP MRFX1K80H which dissipates close to 2 KW.
- Some of these larger tubes are water cooled.
- The ENIAC computer had over 17,000 tubes and drew 150 KW. It averaged a tube burnout every two days.
- Many tubes are still in production today.
- Power supply specifics are designated as A, B, and sometimes C.
- An A supply is the voltage for the filaments only.
- A B supply is the high voltage, often called B+, that supplies the voltage for the tubes to function.
- A C supply was used to simply bias the grid. No current was drawn.

- The actual characteristics of a tube are measured by two factors. They are Amplification factor (Mu) and Transconductance (expressed in siemens as Mho or Gm).
- The Mu of a tube is equal to the ratio of a change in plate voltage to the change in grid voltage required to cause the same change in plate current.
- The Mho of a tube is a measure of the change in plate current to a change in grid voltage, with plate voltage being held constant.
- Tube testers are not always reliable in gauging a tube’s condition.
- The following two examples are abbreviated typical data sheets found for tubes. I selected one diode and one pentode often encountered.



DOUBLE DIODE



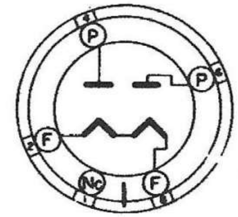
GLASS BULB

COATED FILAMENT

5.0 VOLTS 3.0 AMP.
AC OR DC

VERTICAL MOUNTING POSITION

HORIZONTAL OPERATION IS PERMITTED IF PINS 1 AND 4 ARE IN A VERTICAL PLANE. ←



BOTTOM VIEW
MEDIUM SHELL
5 PIN OCTAL
5T

THE 5U4GB IS A FILAMENTARY FULL-WAVE HIGH VACUUM RECTIFIER DESIGNED FOR USE IN THE POWER SUPPLY OF TELEVISION RECEIVERS AND OTHER EQUIPMENT WHICH HAS HIGH OUTPUT CURRENT REQUIREMENTS. IT IS A REPLACEMENT FOR THE 5U4G; HOWEVER, THE 5U4GB HAS A STRAIGHT SIDED T-12 ENVELOPE AND HAS HIGHER CURRENT RATINGS THAN THE 5U4G.

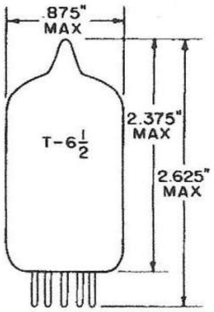
RATINGS

INTEPRETED ACCORDING TO DESIGN CENTER SYSTEM

RECTIFIER SERVICE[A]

FILAMENT VOLTAGE	5.0	VOLTS
MAXIMUM PEAK INVERSE PLATE VOLTAGE	1550	VOLTS
MAXIMUM PLATE SUPPLY VOLTAGE (EACH PLATE) RMS (SEE RATING CHART #1)	550	VOLTS
MAXIMUM DC OUTPUT CURRENT (SEE RATING CHART #1)	---	
MAXIMUM STEADY STATE PEAK PLATE CURRENT (EACH PLATE))SEE RATING CHART #2	1.0	AMP.
MAXIMUM TRANSIENT PEAK PLATE CURRENT (EACH PLATE) SEE RATING CHART #3	4.6	AMP
TUBE VOLTAGE DROP		
TUBE CONDUCTING: 225 MA. EACH PLATE	44	VOLTS
275 MA. EACH PLATE	50	VOLTS
300 MA. EACH PLATE	54	VOLTS

[A] FOR USE WITH SINUSOIDAL SUPPLY VOLTAGES WITHIN THE FREQUENCY RANGE OF 25 TO 1000 CYCLES PER SECOND.



GLASS BULB

MINIATURE BUTTON
9 PIN BASE E9-1
OUTLINE DRAWING
JEDEC 6-3

PENTODE

MINIATURE TYPE

COATED UNIPOTENTIAL CATHODE

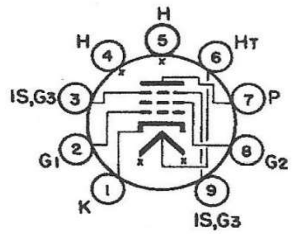
HEATER

SERIES	PARALLEL
12.6±1.3 VOLTS	6.3 VOLTS
300 MA	600±40 MA.

AC OR DC

ANY MOUNTING POSITION

FOR 12.6 VOLT OPERATION APPLY HEATER VOLTAGE BETWEEN PINS #5 AND #4. FOR 6.3 VOLT OPERATION APPLY HEATER VOLTAGE BETWEEN PIN #6 AND PINS #4 AND #5 CONNECTED TOGETHER.
CONTROL OF HEATER CHARACTERISTICS APPLIES ONLY TO 600 MA. HEATER CONNECTION.



BOTTOM VIEW

BASING DIAGRAM
JEDEC 9BF

THE 12BY7A IS A HIGH TRANSCONDUCTANCE PENTODE USING THE 9-PIN MINIATURE CONSTRUCTION. IT IS DESIGNED FOR SERVICE AS A VIDEO AMPLIFIER WHERE THE PLATE SUPPLY VOLTAGE IS LOW AND LARGE OUTPUT VOLTAGES ARE REQUIRED WITH LOW VALUE OF PLATE LOAD RESISTORS. THERMAL CHARACTERISTICS OF THE HEATER ARE CONTROLLED SUCH THAT HEATER VOLTAGE SURGES DURING THE WARM-UP CYCLE ARE MINIMIZED PROVIDED IT IS USED WITH OTHER TYPES WHICH ARE SIMILARLY CONTROLLED.

DIRECT INTERELECTRODE CAPACITANCES

WITH NO EXTERNAL SHIELD

GRID #1 TO PLATE: G_1 TO P	0.063	pf
INPUT: G_1 TO $(H+K+G_2+G_3\&IS)$	10.2	pf
OUTPUT: P TO $(H+K+G_2+G_3\&IS)$	3.5	pf

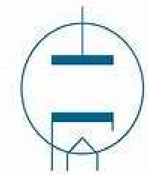
RATINGS

INTERPRETED ACCORDING TO DESIGN MAXIMUM SYSTEM

MAXIMUM HEATER—CATHODE VOLTAGE:			
HEATER NEGATIVE WITH RESPECT TO CATHODE			
TOTAL DC AND PEAK		200	VOLTS
HEATER POSITIVE WITH RESPECT TO CATHODE			
DC		100	VOLTS
TOTAL DC AND PEAK		200	VOLTS
MAXIMUM PLATE SUPPLY VOLTAGE	→	330	VOLTS
MAXIMUM NEGATIVE DC GRID #1 VOLTAGE	→	55	VOLTS
MAXIMUM POSITIVE DC GRID #1 VOLTAGE		0	VOLTS
MAXIMUM GRID #3 VOLTAGE		0	VOLTS
MAXIMUM GRID #2 VOLTAGE	→	190	VOLTS
MAXIMUM PLATE DISSIPATION	→	6.5	WATTS
MAXIMUM GRID #2 DISSIPATION	→	1.2	WATTS
MAXIMUM GRID #1 CIRCUIT RESISTANCE:		0.25	MEGOHM
MAFIXED BIAS OPERATION		0.25	MEGOHM
CATHODE BIAS OPERATION		1	MEGOHM
HEATER WARM-UP TIME (APPROX.).[A]		11.0	SECONDS

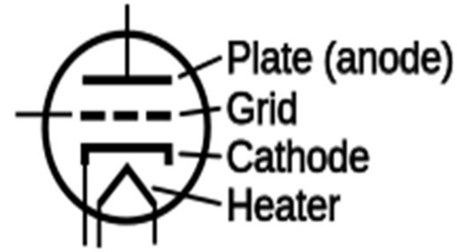
[A] HEATER WARM-UP TIME IS DEFINED AS THE TIME REQUIRED FOR THE VOLTAGE ACROSS THE HEATER TO REACH 80% OF ITS RATED VOLTAGE AFTER APPLYING 4 TIMES RATED HEATER VOLTAGE TO A CIRCUIT CONSISTING OF THE TUBE HEATER IN SERIES WITH A RESISTANCE OF VALUE 3 TIMES THE NOMINAL HEATER OPERATING RESISTANCE.

Diode



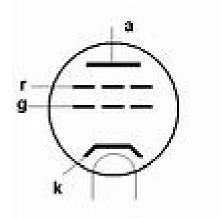
- When heated, the cathode releases electrons (thermionic emission) into the vacuum. The plate will attract them if it is at a more positive charge, resulting in a flow. Electrons cannot flow in reverse as the plate is not heated.
- Immune to voltage spikes.
- High reverse breakdown voltage.
- High forward voltage drop.
- Usually run hot and can consume a high amount of filament power.
- Most rectifier tube failures are by shorting.
- Sometimes done, it is unwise to replace a rectifier tube with a modern silicone diode. This is due to instant B+ being imposed on the circuit as well as higher B+ due to low forward voltage drop and unloaded transformer windings.
- Tube diodes are not limited to rectifier applications, they are also extensively used as detectors and in AVC circuits.

Triode



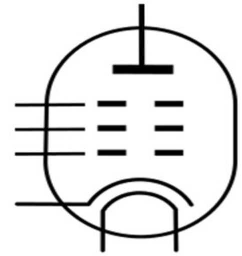
- Adds a control grid between the cathode and the plate.
- This is considered the first field effect device. The modern JFET most emulates it.
- The control grid controls electron flow from the cathode to the plate. (think of it as a water spigot).
- The more negative the control grid voltage is relative to the plate, the more the current is inhibited. Conversely, the more positive the voltage on the control grid is, the more electrons will flow to the plate.
- A few volts difference at the grid can make a large change in plate current and could lead to a much larger voltage change at the plate. (Voltage and power amplification).
- Triodes tend to oscillate unless gain is limited due to the Miller effect (parasitic capacitance between plate and control grid).
- Neutralization is usually necessary. Early TRF radios had this issue.
- Non-linear characteristics of the triode can cause harmonic distortions.

Tetrode



- Also known as screen grid tubes.
- Developed in 1915 by Walter Shottky in response to the triode's tendency to oscillate.
- A positive voltage slightly lower than plate voltage is applied to the screen grid.
- This tended to decouple the plate and control grid, reducing parasitic capacitance. This design helped make the heterodyne radio a possibility.
- Higher voltage gains became possible.
- A new problem arose called secondary emission where the electrons struck the plate hard enough to cause electrons to leave its surface.
- These emissions can be captured by the screen grid, reducing amplification (Mu) and resulting in instability in mild cases or destruction of the screen grid if enough current flows.
- This tube works well in IF stages but is not suitable for audio output designs.

Pentode



- Developed in 1926 as a response to the issue of secondary emission with the tetrode.
- A third grid called a suppressor was added.
- This grid was normally at the same voltage as the cathode, so its negative voltage repelled secondary emissions.
- The result was increased efficiency and lowered screen current.
- Mostly replaced tetrodes.
- Pentodes are almost unaffected by changes in supply voltage, they can operate well with poorly regulated power supplies.
- Tube mismatch can be a major issue in push-pull or parallel configurations due to interelectrode capacitance differences.
- The first beam power pentode was developed by RCA in 1936. It was the 6L6GT. Grids are not evenly spaced and plates are angled, both which focus the electron stream and further increase efficiency.
- Power pentodes (especially beam) tend to run hot.

Applications in radio

- Earlier models of consumer and amateur equipment used tubes as IF amps, detectors, diodes, AF output and RF output (in the case of hams).
- Tubes were known for their tendency to drift operating parameters until fully warmed up. “Fine tuning” controls were necessary and often used.
- Tubes were more economical than transistors when they first came out.
- Tubes were also preferred due to ease of replacement as early transistors could be unreliable and more difficult to replace.
- Most equipment was tube based until the mid 1960’s when transitioning to solid state became common.
- The last tube based television was made by GE in 1977.
- Amateur transceivers went hybrid, all solid state except the finals (up to around 1984), as no transistor at that time could handle the desired RF output power.
- Vacuum tube amplifiers, amateur and consumer stereo, are still being manufactured.

Amateur radio RF tubes

- Fall into two catagories; true RF transmit tubes and “sweep” tubes.
- Most often encountered: 6146B, 6883B, 6JS6C, 6KD6 & 6DQ5.
- Sweep tubes generally put out more power as the plates could be run at a higher voltage, but they could only be used in the HF range.
- Sweep tubes were designed for low frequency TV deflection service, operating between 15 to 20 Mhz. They were pressed into RF service as they were less expensive than true RF tubes.
- Sweep tubes are more fragile internally as they were designed for pulse service (pulse duration not to exceed 15% of one horizontal scanning cycle/10 microseconds), not continuous current (key down/continuous carrier mode). They are also far less forgiving of high SWR than true RF tubes.
- Two or more tubes in a transceiver are run in parallel, therefore the same brand must be used so that interelectrode capacitance may be matched. Neutralisation of the tubes internal capacitance is essential but cannot be done with differing brands being used.
- Mismatch is especially a problem with sweep tubes due to high transconductance ratings. Tubes will “run away”, go into oscillation, or over driven to the point of melting.

- As an example we will look at the 6JS6C sweep tube often used in amateur transceivers.
- Direct interelectrode capacitance:
  - Control grid to plate: .7 pf
  - Control grid to Cathode, Heater, Screen and Suppressor: 24pf
  - Plate to Cathode, Heater, Screen and Suppressor: 10 pf
- These are book values taken from both GE and RCA references. Real world values are different due to manufacturers using slightly different materials or construction techniques. It can make a difference!
- Transceiver manufacturers often listed brands to use for replacements. To use other brands required some modification of components.
- Yaesu, (FT-101 series) generally used the 6JS6C sweep tube up until the last year the series was made. Kenwood used the 6146B true RF tubes during the entire TS 500 production run. Motorola often used the 6883B in its commercial mobile applications.
- In most cases, a 12BY7A driver tube was required with hybrids.
- And as always, safety first! Vacuum tubes operate at high voltages no matter what they are used in. Always be careful and ask for advice if you are not sure.

Questions