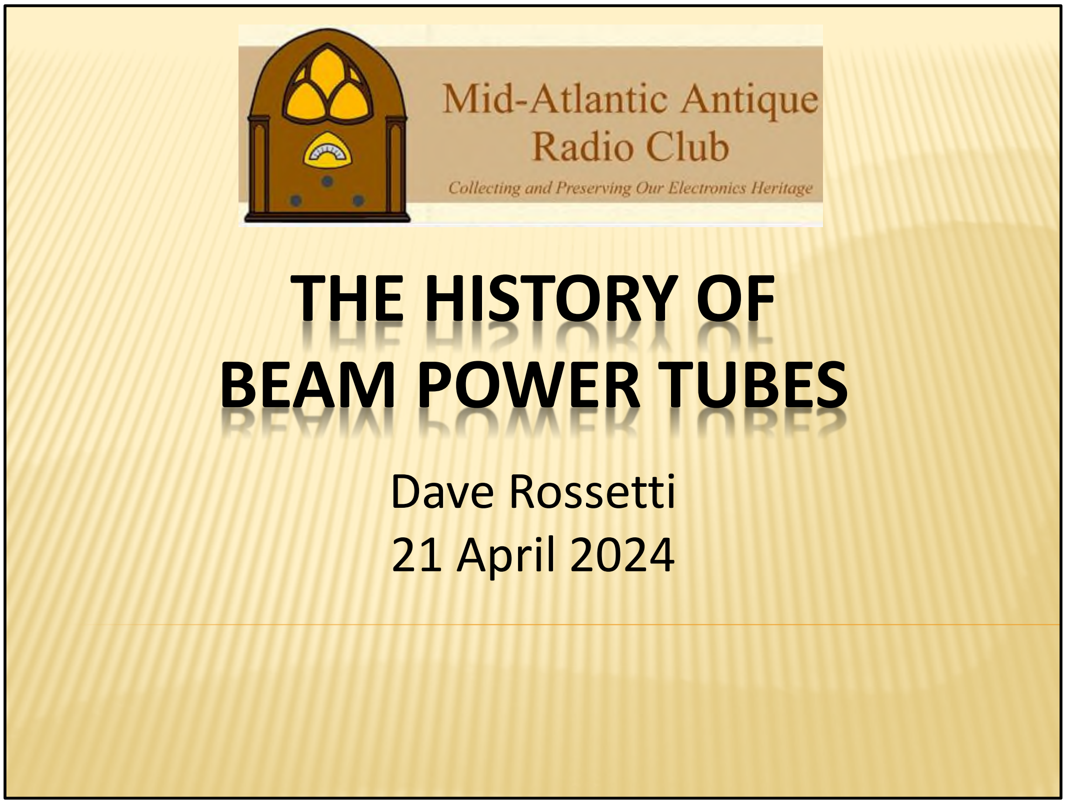
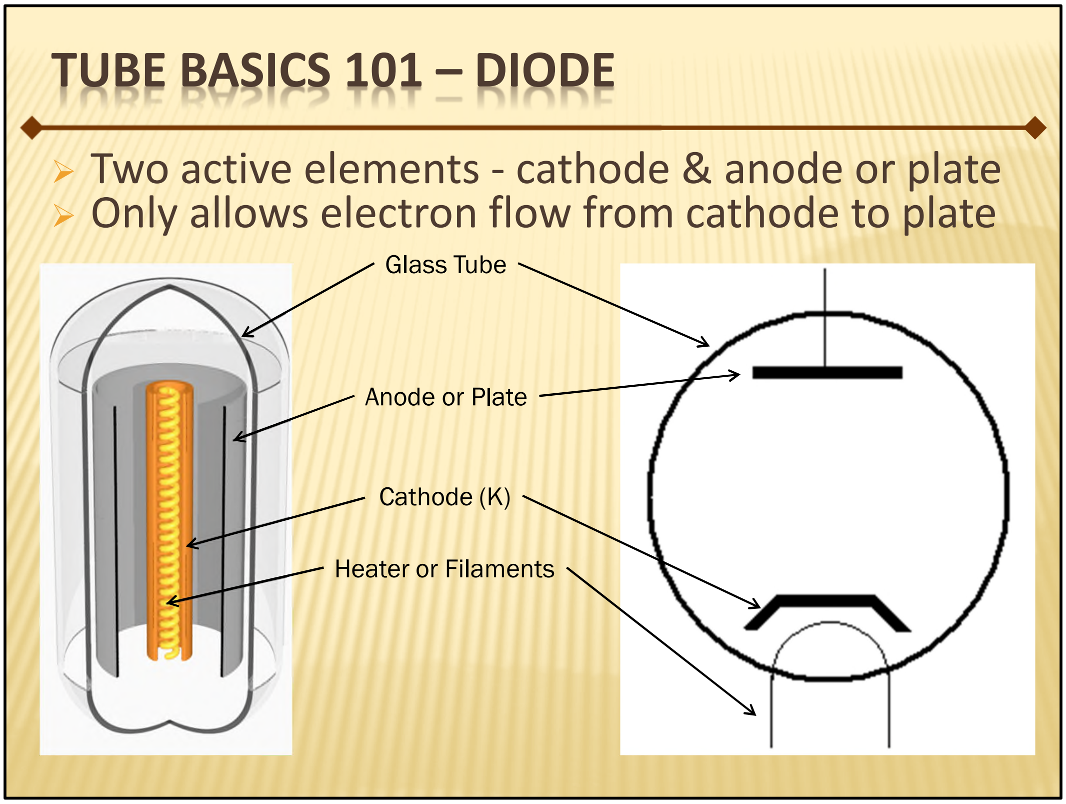


This presentation came out of a conversation I had with Randy Warren regarding beam power tubes in general, and the 6L6 tube, its direct decedent's, and its current day use in audio applications.

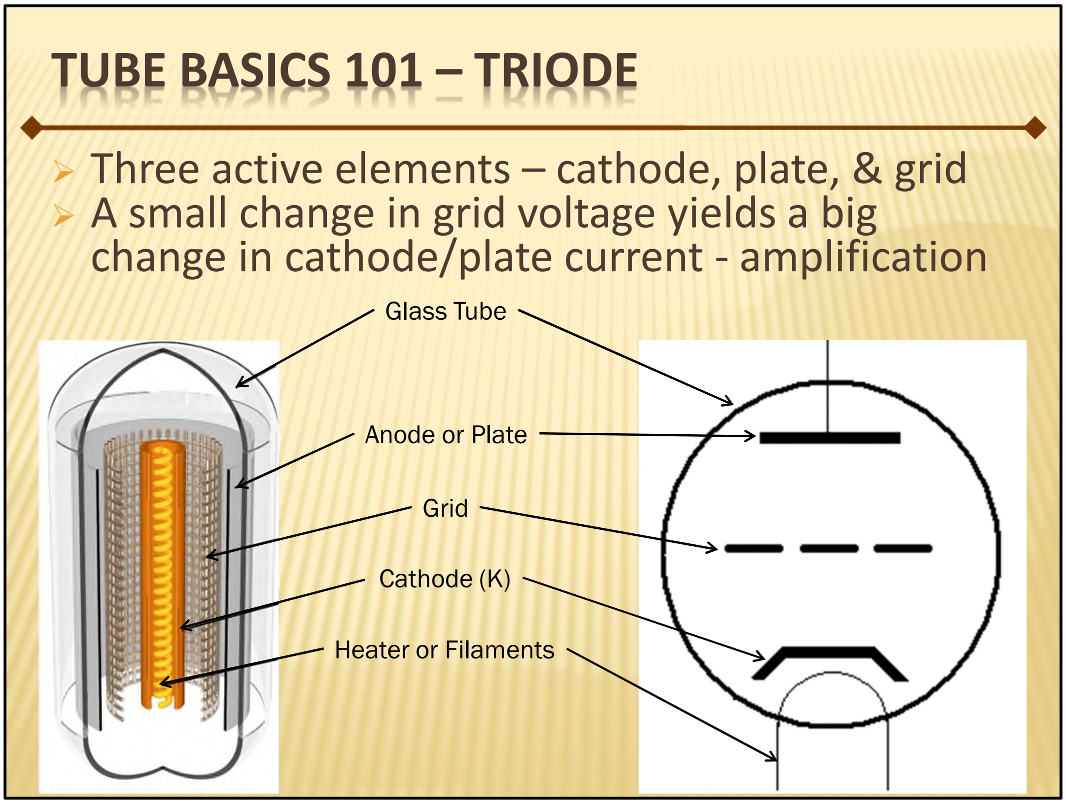
Beam Power Tubes are very much alive, being produced and used in many modern-day tube-based audio and guitar amplifiers.



To start things off, lets talk a bit about vacuum tubes in general.

The first and simplest vacuum tube was the diode. Invented in 1904 by John Ambrose Fleming, the diode or Fleming valve contains only a heated electron-emitting cathode (K) and an anode (or Plate).

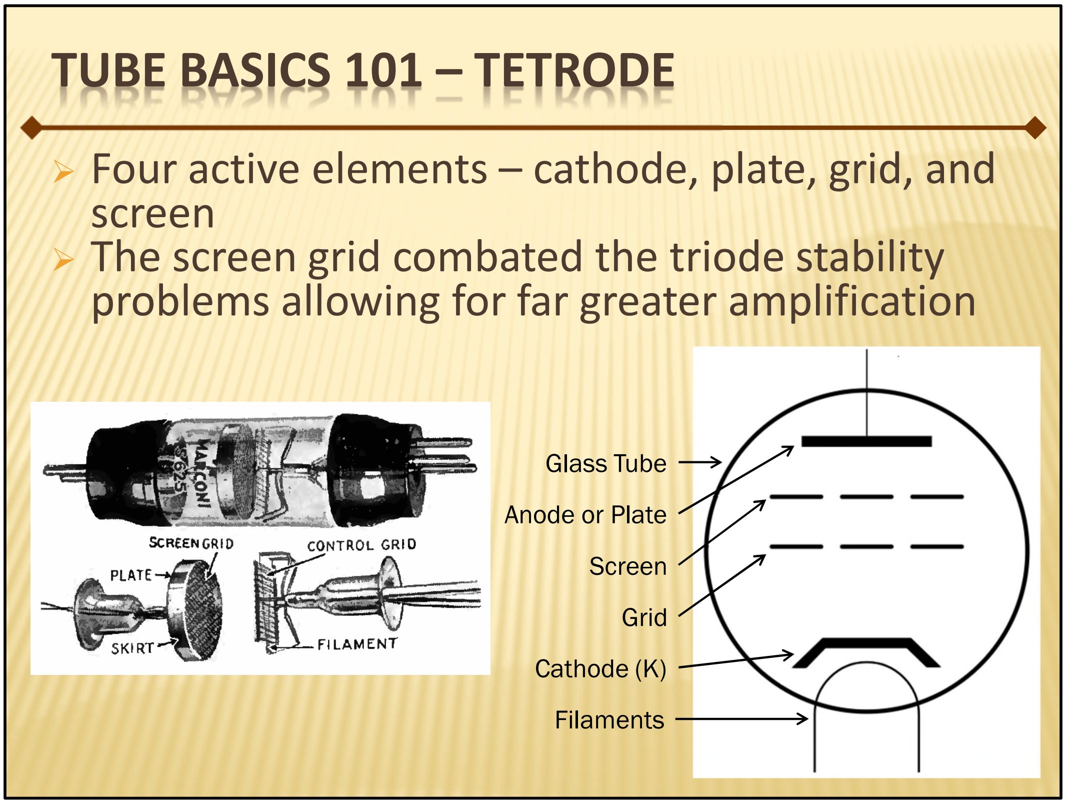
Diodes only allow electrons to flow in one direction from the cathode to the plate, which is also known as rectification, ergo a rectifier.



Lee de Forest invented the triode tube in 1907 while experimenting to improve his original Audion diode. Placing an additional electrode between the cathode and plate, he discovered the ability of the resulting device to amplify signals. As the voltage applied to the grid was lowered below that of the cathode, the current from the filament to the plate was reduced or even stopped.

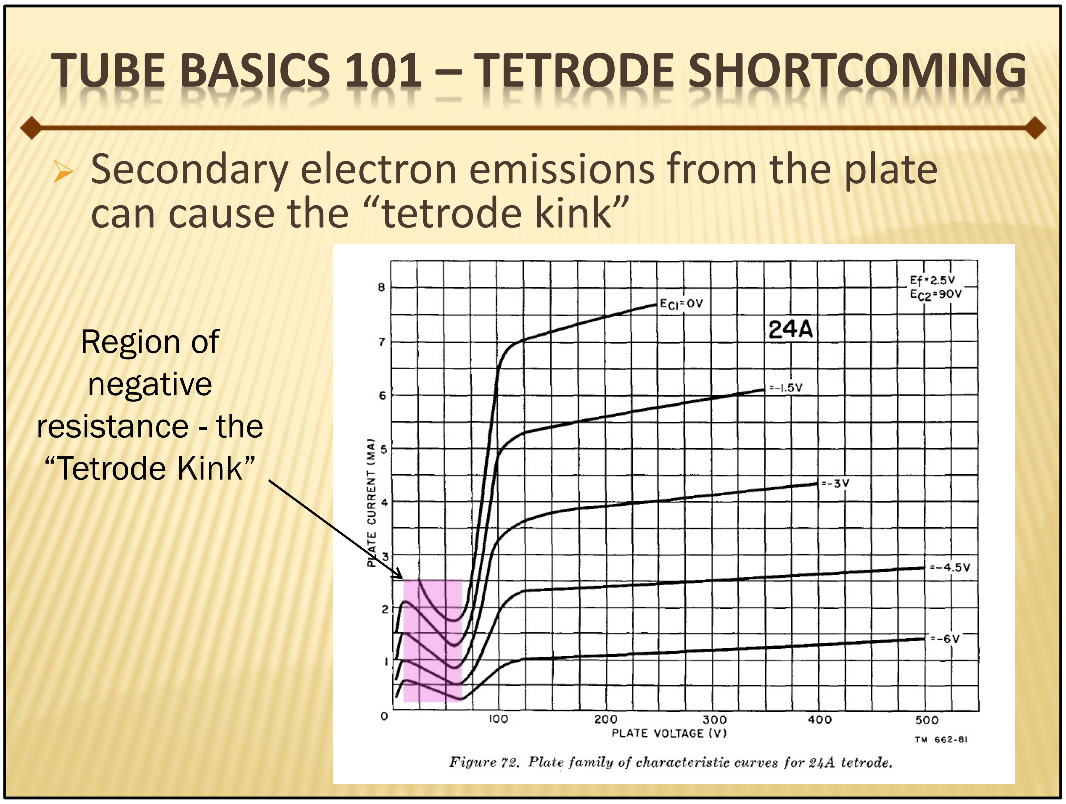
Thus a change of voltage applied to the grid, requiring very little power input to the grid, could make a much larger change in the plate current and lead to a much larger voltage change at the plate; the result was voltage and power amplification.

When triodes were used in radio transmitters and receivers, it was found that tuned amplification stages had a tendency to oscillate unless their gain was very limited. This was due to the parasitic capacitance between the plate (the amplifier's output) and the control grid (the amplifier's input).



To combat the triode stability problems due to grid-to-plate capacitance, physicist Walter Schottky invented the tetrode or screen grid tube in 1919. The addition of an electrostatic shield between the control grid and the plate solved the triode capacitance problem.

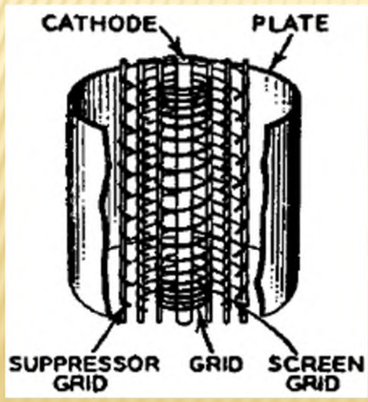
The added grid became known as the screen grid. It operated at a positive voltage significantly less than the plate voltage and was bypassed to ground with a capacitor of low impedance at the frequencies to be amplified. This decoupled the plate and the control grid. It also reduced the influence of the plate voltage on the space charge near the cathode, permitting the tetrode to produce greater voltage gain than the triode. Triodes typically have amplification factors from below 10 to around 100, tetrode amplification factors of 500 were common. The cutaway is that of the first commercially produced screen grid tube, the Marconi-Osram Valve (MOV) S625. Screen grid tubes were marketed by late 1927.

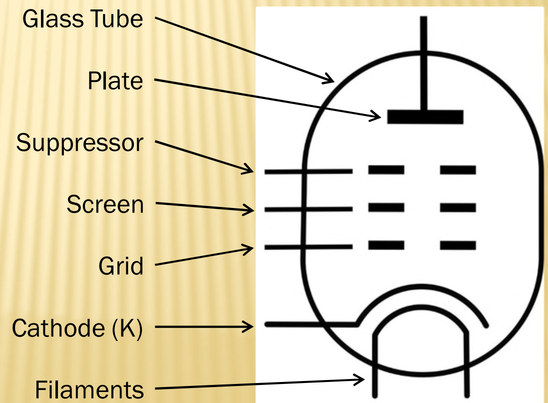


In any tube, electrons can strike the plate with sufficient energy to cause the emission of electrons from its surface. In a triode this secondary emission of electrons is not important since they are simply re-captured by the plate. But in a tetrode they can be captured by the screen grid since it is also at a positive voltage, robbing them from the plate current and reducing the amplification of the tube. Since secondary electrons can outnumber the primary electrons over a certain range of plate voltages, the plate current can decrease with increasing plate voltage. This tetrode kink is an example of negative resistance which can cause instability. Another undesirable consequence of secondary emission is that screen current is increased, which may cause the screen to exceed its power rating. Therefore, the useful region of operation of the screen grid tube as an amplifier was limited to plate voltages greater than the screen grid voltage, due to secondary emission from the plate.

TUBE BASICS 101 – PENTODE

- Five active elements – cathode, plate, grid, screen, and suppressor
- The pentode's suppressor grid combated the tetrode's instabilities caused by secondary electron emissions



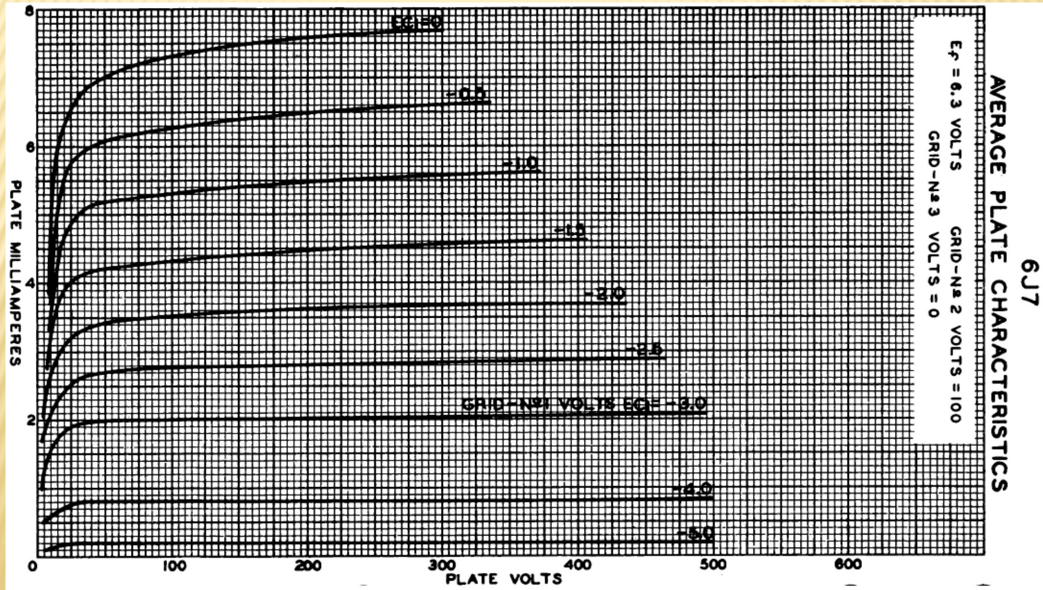


The term pentode means the tube has five electrodes.
It was invented in 1926 by Bernard D. H. Tellegen and rapidly became favored over the simple tetrode.
The Pentode eliminated the secondary electron emission issues of the tetrode by adding a suppressor grid between the screen grid and the plate.
The suppressor grid of the pentode was usually connected to the cathode and its negative voltage relative to the anode repelled secondary electrons so that they would be collected by the plate instead

of the screen grid.

TUBE BASICS 101 – PENTODE ADVANTAGE

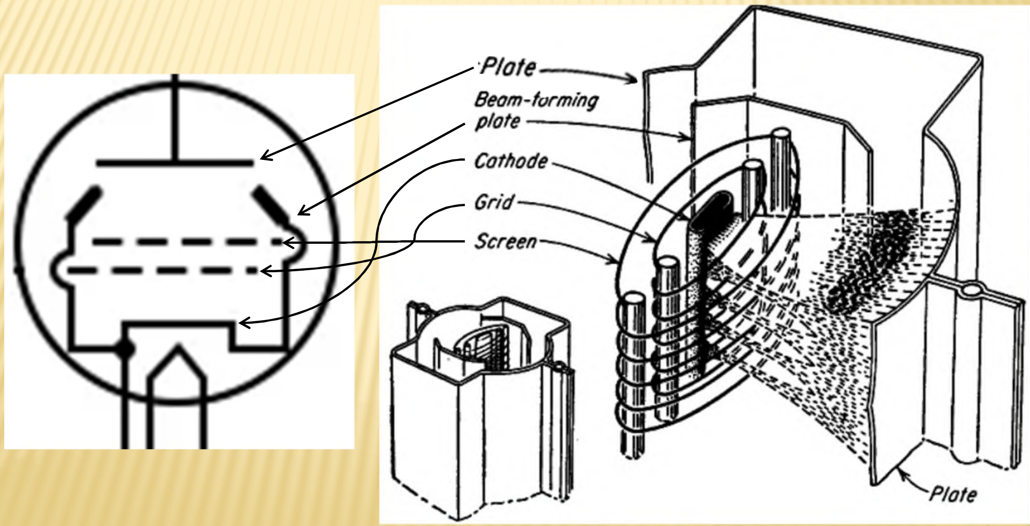
- No “Tetrode Kink”



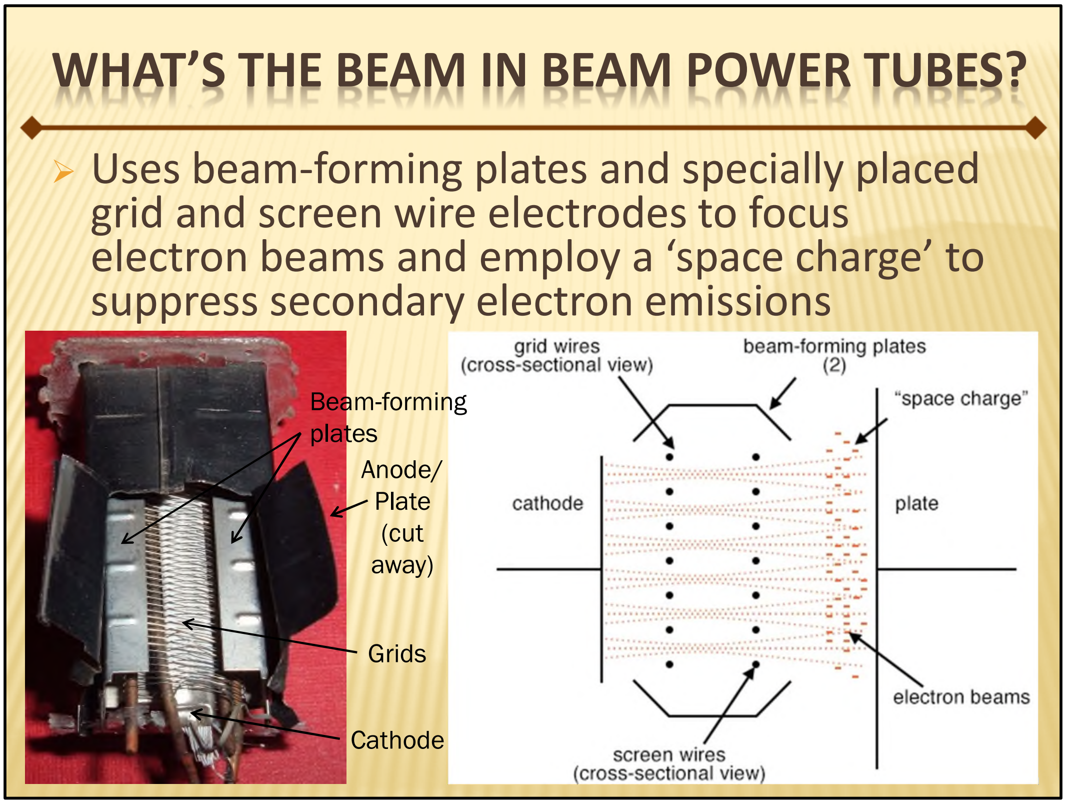
The tetrode kink region of the screen grid tube was eliminated by adding the suppressor grid. The addition of the suppressor grid permitted much greater output signal amplitude to be obtained from the plate of the pentode in amplifier operation than from the plate of the screen-grid tube at the same plate supply voltage. Pentodes, therefore, can have even higher current outputs and a wider output voltage swing than the tetrode. The anode/plate can even be at a lower voltage than the screen grid yet still amplify well.

TUBE BASICS 101 – BEAM POWER TUBE

- Four active elements – cathode, plate, grid, and screen, plus beam forming plates



A beam power tube is typically a tetrode in which directed electron beams are used to substantially increase tube's power-handling capability. .



In the beam power tube, the basic four-element structure of the tetrode was maintained, but the grid and screen wires were carefully arranged along with a pair of auxiliary plates to create an interesting effect: focused beams or "sheets" of electrons traveling from the cathode to plate. These electron beams formed a stationary "cloud" of electrons between the screen and plate (called a "space charge") which acted to repel secondary electrons emitted from the plate back to the plate. A set of "beam-forming" plates, each connected to the cathode, were added to help maintain proper electron beam focus. Grid and screen wire coils were arranged in such a way that each turn or wrap of the screen fell directly behind a wrap of the grid, which placed the screen wires in the “shadow” formed by the grid. This precise alignment enabled the screen to still perform its shielding function with low screen-grid current and minimal interference to the passage of electrons from the cathode to the plate.

The inventors realized they were playing with electron optics and were forming electrostatic lenses able to focus electron beams rather intensely, beams that could melt the screen wires in an instant if allowed to focus there. For the same reason it was important to collect all the electrons in the beams on the massive plate and not let them continue past the plate to hit the glass of the tube envelope, else a hole could be bored in the glass.

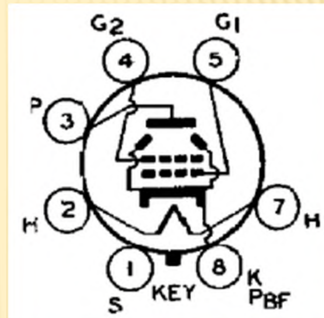
FEATURES OF BEAM POWER TUBES

- No triode parasitic capacitance issues
- No secondary electron emission “tetrode kink” issues
- Produced more output power (transconductance) than a similar power pentode
- Plate resistance lower than a similar power pentode
- Screen grid current 5–10% of the anode current compared with about 20% for the pentode, thus the beam tetrode is more power-efficient
- Produces less third-harmonic distortion in class A operation than a comparable power pentode

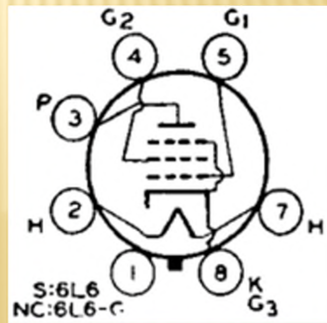
Because of the effective suppressor action provided by the space charge and because of the low current drawn by the screen grid, the beam power tube has the advantages of high-power output or transconductance, high power sensitivity, and high efficiency over other tube types. They also offer lower third harmonic distortion over comparable power pentodes.

ARE THEY TETRODES OR PENTODES?

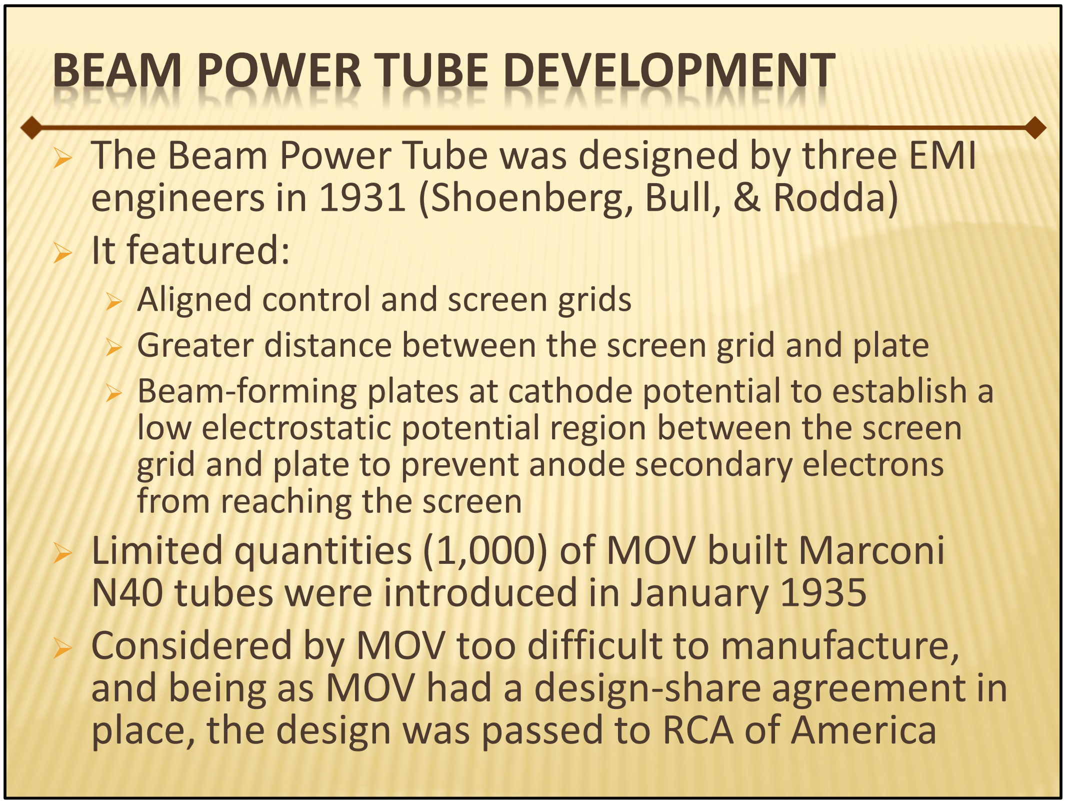
- 1940 RCA Receiving Tube Manual (RC-14) 6L6 Schematic



- 1947 RCA Receiving Tube Manual (RC-15) 6L6 Schematic



Manufacturer's data sheets often use the terms beam pentode or beam power pentode instead of beam power tube and use a pentode graphic symbol instead of a graphic symbol showing beam forming plates. After the Phillips patent on the suppressor grid had expired, many beam tetrodes were referred to as "beam power pentodes". By example, the 1940 RCA Receiving Tube Manual (RC-14) shows the 6L6 with beam-forming plates but with no change in tube design or function, depicts the 6L6 as a pentode in the 1947 RCA Receiving Tube Manual (RC-15).



In the UK, three Electric and Musical Industries or EMI engineers (Isaac Shoenberg, Cabot Bull and Sidney Rodda) filed patents on an alternative tube design in 1933 and 1934. EMI was also referred to as EMI Records Ltd., a British transnational conglomerate founded in March 1931 in London. EMI later manufactured records for the Beatles. Their design had the following features:

- The apertures of the control and screen grids were aligned by winding the control and screen grids with the same pitch (the grids of the pentode used different pitches).
- Greater distance between the screen grid and the

plate/anode than an ordinary tetrode or pentode.

- An auxiliary electrode structure (beam-forming plates) at or near cathode potential and substantially outside of the electron stream, to establish a low electrostatic potential region between the screen grid and the plate/anode, limit the included angle of the beam, and prevent anode secondary electrons outside of the beam region from reaching the screen (the pentode has a suppressor grid in the electron stream).

The new tube was introduced at the Physical and Optical Societies' Exhibition in January 1935 as the Marconi N40. Around one thousand of the N40 output tetrodes were produced, but MOV (Marconi-Osram Valve) company, under the joint ownership of EMI and GEC, considered them too difficult to manufacture due to the need for good alignment of the control and screen grid wires. As MOV had a design-share agreement with RCA of America, the design was passed to that company. RCA had the resources to produce a workable design, which resulted in the...

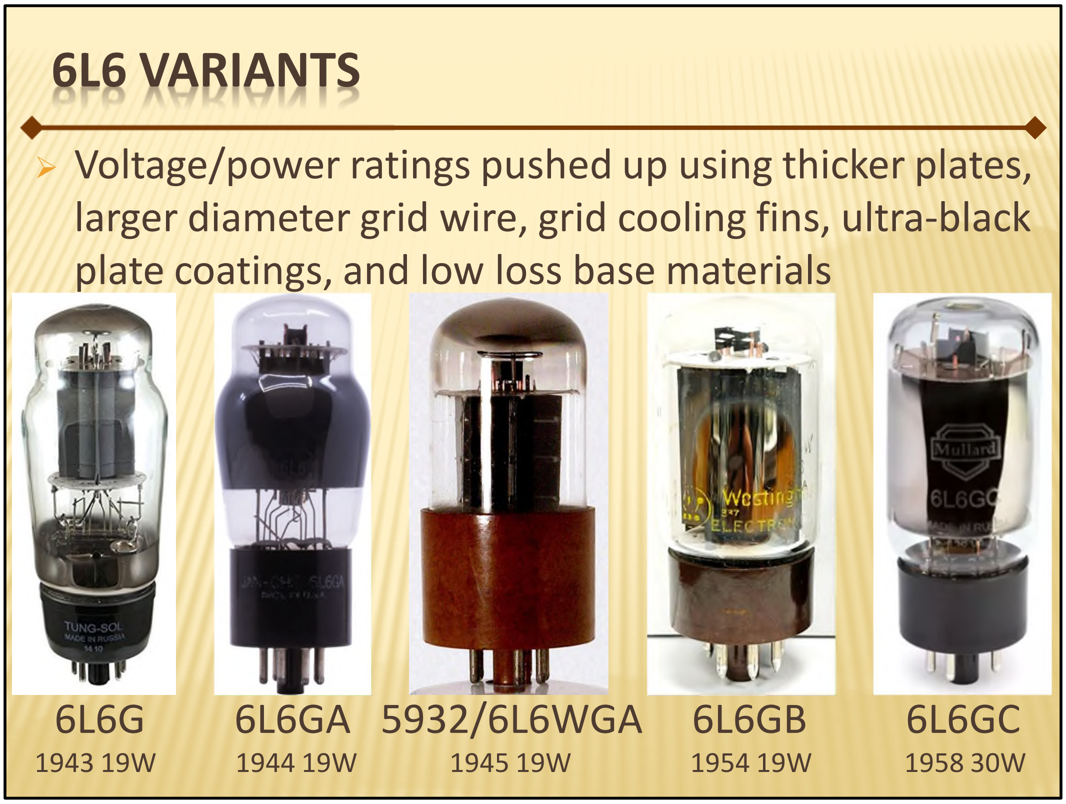
THE 6L6 BEAM POWER TUBE

- Grandfather of all U.S. beam power tubes
- One of the first metal tubes, it had the recently developed octal base
- The 6L6 was rated at 19 watts
- 1614 variant - selected transmitter rated 6L6 that passed a special radio frequency test - used in RT-19/ARC-4 and early McIntosh audio amps
- 1622 variant - 6L6 selected for low noise in theater sound systems
- The 6L6 family has had one of the longest active lifetimes of any electronic component, more than 80 years

The Metal 6L6 tube was introduced by Radio Corporation of America (RCA) in April 1936 and marketed for application as a power amplifier for audio frequencies. The 6L6 was the first successfully marketed beam power tube. Variants of the 6L6 are still being manufactured and used in high-fidelity audio amplifiers and musical instrument amplifiers. The metal tube technology utilized for the 6L6 was developed by GE and introduced in April 1935, with RCA manufacturing the metal envelope tubes for GE at that time. Advantages of metal tube construction over glass envelope tubes were smaller size, ruggedness, electromagnetic shielding, and smaller interelectrode capacitance. The 6L6 used an octal base, which was introduced with the metal tubes. The 6L6 and variants of it became popular for use in public address amplifiers, musical instrument amplifiers, radio frequency applications, and audio stages of radio transmitters. 1614 variant - selected transmitter rated 6L6 that passed a special radio frequency test and used in low-level stages of the RT-19 / ARC-4 and early McIntosh audio amps. 95% of all 6L6 tubes tested passed this test.

1622 variant - 6L6 selected for low noise in theater sound systems

The 6L6 family has had one of the longest active lifetimes of any electronic component, more than 80 years. Variants of the 6L6 are still manufactured in Russia, China, and Slovakia.



The voltage and power ratings of the 6L6 series were gradually pushed upwards by such features as thicker plates, grids of larger diameter wire, grid cooling fins, ultra-black plate coatings, and low loss materials for the base. Variants of the 6L6 included the 6L6G, 6L6GX, 6L6GA, 6L6GAY, 6L6GB, 5932/6L6WGA and the 6L6GC. Popular amps using 6L6GC tubes include the McIntosh MC30, MC40, and MC240; EICO HF 22; and Heathkit W-4M.
All variants after the original 6L6 utilized glass envelopes. A "W" in the descriptor identified the tube as designed to withstand greater vibration and impact. A "Y" in the descriptor indicated that the

insulating material of the base was Micanol. The 1946 ENIAC computer used 4,200 6L6 tubes.

807 is a 6L6 derivative redesigned into a ST16 bulb w/a small plate cap, internal shielding, 5-pin ceramic (later Micanol) base, and 25 W output. This tube was developed by RCA in October 1936 and announced in the November 1936 issue of QST magazine. The 807 was a universal power tube. The WWII Navy QJB sonar used six of them. The 1946 ENIAC computer used 350 807s.
The 807 tube led to the 12 Volt 1625, used massively in WW II communication gear, and the 6BG6G, sweep tube used in "every" '40s TV set.

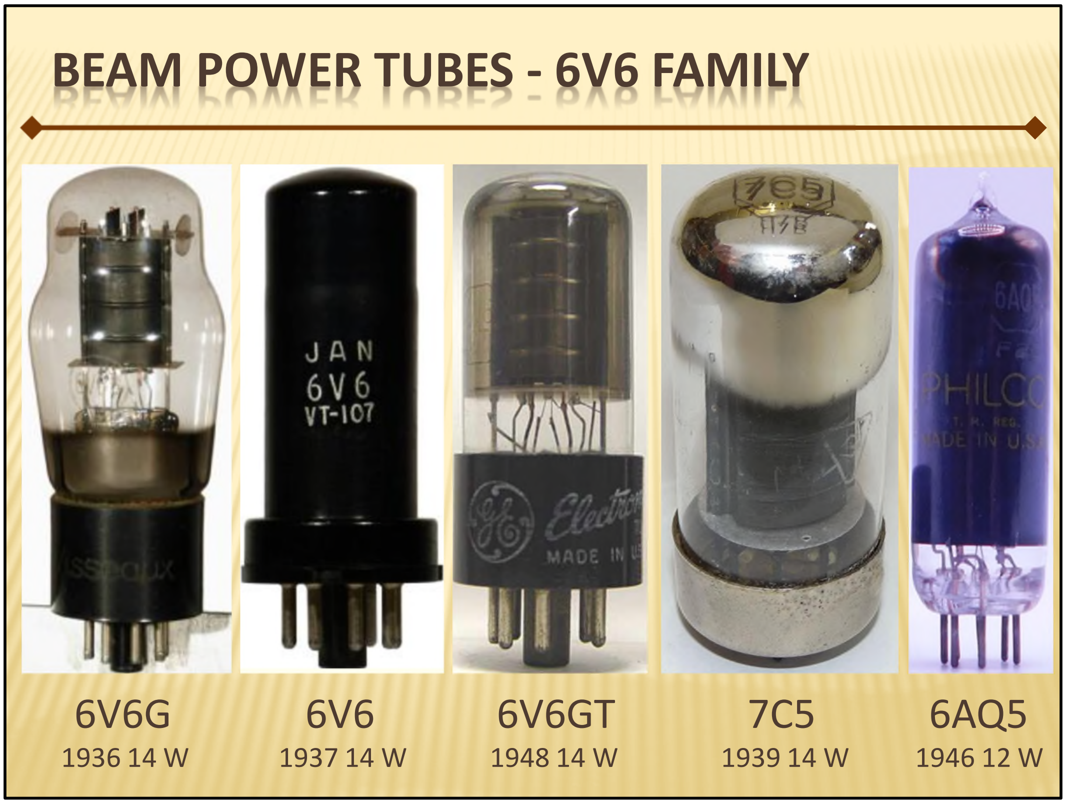
The 1625 beam power tube variant of the 807 used a medium 7-pin base with a plate cap and was introduced in 1943. It was common in WW II mobile transmitters including the SCR-274N, AN/ARC-2, and AN/ARC-5.

The 6BG6G came out in 1946 and was the first American television horizontal amplifier or "sweep" tube. A mass-market variant of 807, it was a repackaged 6L6G using a top plate cap and additional insulation for the plate to withstand the peak plate voltage required for the sweep function.

There are a number of popular audio tubes that use beam forming plates. Some of the most popular are the:

- GE designed 5881 (1950) electrically equivalent to 6L6WGB, 23 watt (Bell; Bogen; Heathkit WM-3 and WM-4; Fisher 70A; Fender Bassman)
- Tung-Sol designed 6550 (1954) 35 watt and 6550A (1962) 42 watt, (Altec 340A; McIntosh MC60; H.H. Scott LK-150; Harman-Kardon Citation II; Heathkit W-6M; Fisher 55A; Martshall, Sun, and Ampeg Amps)

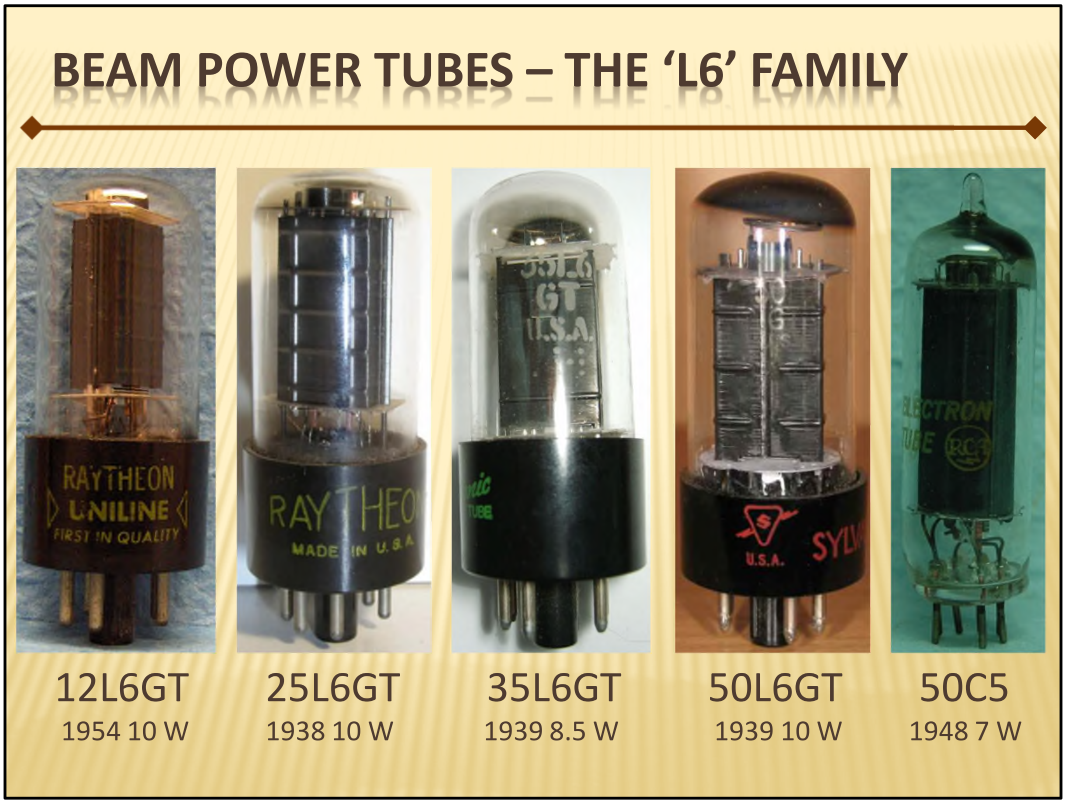
- GE designed 7581 (1959) 30 watt (Harman-Kardon Citation V)
- Westinghouse 7591 (1960) low cost, 19 watt (EICO ST40, ST70, 2050, and 2080; Fisher 500 B and C and 800 A-C; Harman-Kardon 7000; Heathkit 151; McIntosh MC225, MA230 and 1500; Scott 299C, 299D, LK-72, 340, 340B and 208)
- RCA 7868 (1961) – 7591 on Novar base (Fisher 400 receiver; Sherwood 7000 and 8000 receivers)



- 6V6G (1936), 6V6 (metal-1937), and 6V6GT (1948) octals – 14 watts (Fender Champ, Princeton, Harvard, Deluxe and early Tremolux; McIntosh 20W-2; Bogen; Electro-Voice; Fisher; Harman-Kardon; Knight-Kit; Lafayette; Pilot; Radio Craftsman; RCA; Realistic; Regency; E.H. Scott; H. H. Scott; Stromberg-Carlson; and Triad, to name a few). The 1946 ENIAC computer used 1,300 6V6 tubes.

- 7C5 Loctal 6V6

- 6AQ5/6005 – 12 watts (miniature 6V6)



- Not 6L6 tubes of different filament voltages

- 12L6, 25L6, 50L6 octals, 10 watts - Note, 35L6 a beam power tube of different design (8.5 watts)

- 35C5, 50C5 (miniature L6 derivatives)

➢All American made ‘sweep’ tubes where beam power tubes

➢Sweep tubes were intended for horizontal-amplifier use in TV sets. The arrival of large-screen color television in the early ‘60s caused the tube makers to develop new lines of sweep tubes, particularly in the all-glass novar and Compactron formats. They were essentially small transmitting tubes with continuous-duty dissipation ratings of 18 watts and up. At 40 watts, the 6LF6 was in the same class as the 6550 audio tube. Such powerful devices were needed to drive color picture tubes with their wide deflection angles and then low light-generating efficiency. These tubes also had to be linear to give undistorted pictures. Their mission was to deliver a linear sawtooth wave close to 16 kHz for North American television in continuous duty. The new generation of sweep tubes had strong appeal for use in single sideband linear amplifiers. Sweep tubes also adapted successfully' to high-end audio use but made no inroads into guitar amplifiers.

➢Key sweep tubes used in audio applications include:

➢6BQ6 – 1949,10 watt capped octal (Sansui 500A amp)

➢6GT5 – 1961, 17.5 watt single ended Novar (Grommes Precision G-101A amp)

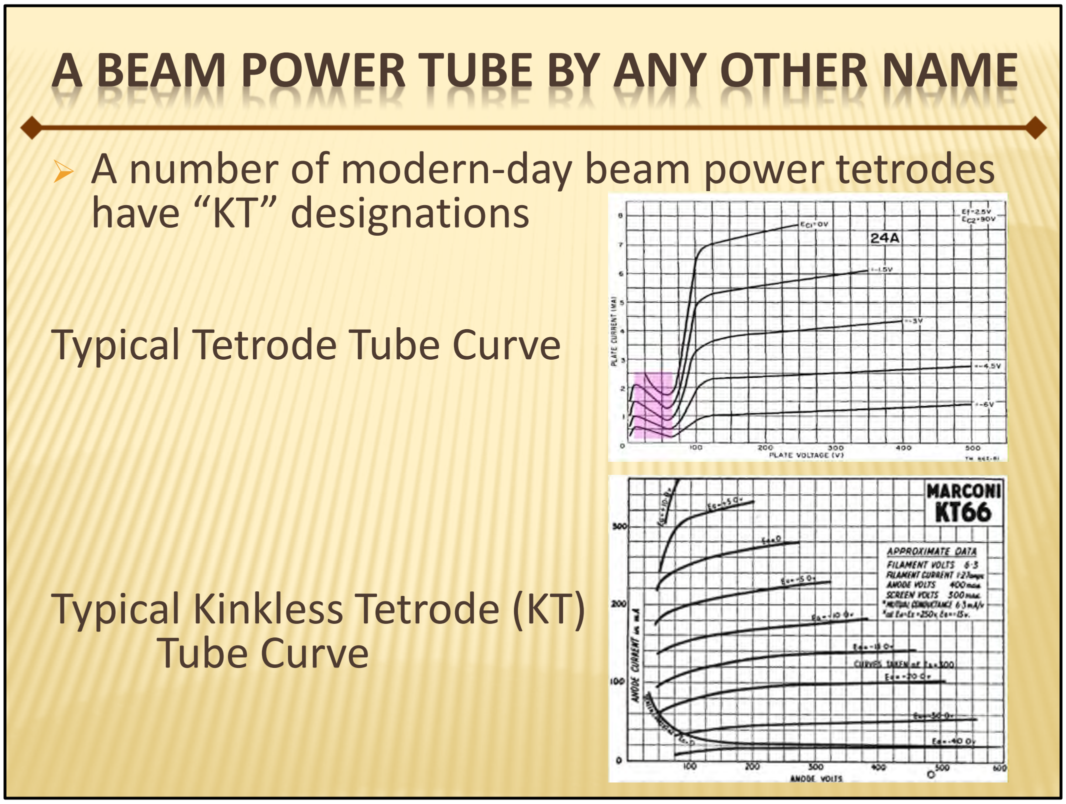
➢6HB5 – 1962, 18 watt single ended Compactron (Futterman H-3 amp)

➢6JE6 – 1962, 24 watt capped Novar (McIntosh MC3500 amp)

➢6JN6 – 1964, 17.5 watt single ended Compactron

(Berning EA-230 amp)

- 6LF6 – 1966, 40 watt capped Compactron (Counterpoint SA4 amp, Futterman H-3aa amp)
- 40KG6 – 1965, 34 watt Capped Magnoval (Esoteric amps)



The design is today known as the beam tetrode but historically was also known as a kinkless tetrode or KT, since it had the same number of grids as the conventional tetrode but without the negative resistance kink in the anode current vs anode voltage characteristic curves of a true tetrode.

- KT66 – 1937, electrically equivalent to the 6L6WGB and 5881 - 25 watts (Leak TL-12, TL25 and TL25+; Craftsmen 500A; Heathkit W-5M)

- KT77 – 1960, electrically equivalent to the 6CA7 – 32 watts (Acrosound UL-120; Marshall Amps)

- KT88 – 1956, AKA 6550 beam power tube – 42 watts (Leak TL50, Dyna Mark III, McIntosh MC75 and MC275, Marshall Major)

- KT90 – 1990, Replacement for KT88/6550 – 50 watts (Electronic Industry Amps)

- KT120 – 2010, Russian made Tung-Sol – 60 watts

DOUBLE BEAM POWER TUBES

- The major VHF push-pull tetrodes of WWII employed twin Beam Power Tubes

815
1945 20 W

829
1938 40 W

832
1943 15 W

815 and 829 were based on the 6L6
The 832 was a scaled-down 829

There were some examples of beam tetrodes designed to work in place of true pentodes.

The KT63 beam power tube (1937) is a substitute for the 6F6G power pentode (1936).

The 6BQ5 audio tube has had a diverse production background. Quoting Tube Lore II: RCA first purchased 6BQ5s, then developed their own {A40142} in 1958 as a true pentode. It appears in the RC-19 manual (1959) as a beam power tube. In the 1959 announcement letter; in all later RCs, and in the HB-3 manual; it was listed as a true pentode.

The Bill of Materials went through 17 issues from 1958 to 1960 with three grids; then 29 more issues with beam plates, then back to three grids in 1962, for three issues more. Then, in 1963, it was back to beam plates for five more issues; then, in 1964, return to grids for 40 more issues through 1974. This was an unusually unstable design.

The ubiquitous EL34, a true pentode manufactured by Mullard/Phillips and other European manufacturers, can be substituted as a drop-in replacement by the beam tetrode 6CA7 (manufactured by GE and Sylvania) or KT77 (made by Marconi-Osram Valve [MOV]). The 1946 ENIAC computer used 500 6AC6s.

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