Beyond Pentodes

Audio use of odd tubes

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ETF.24

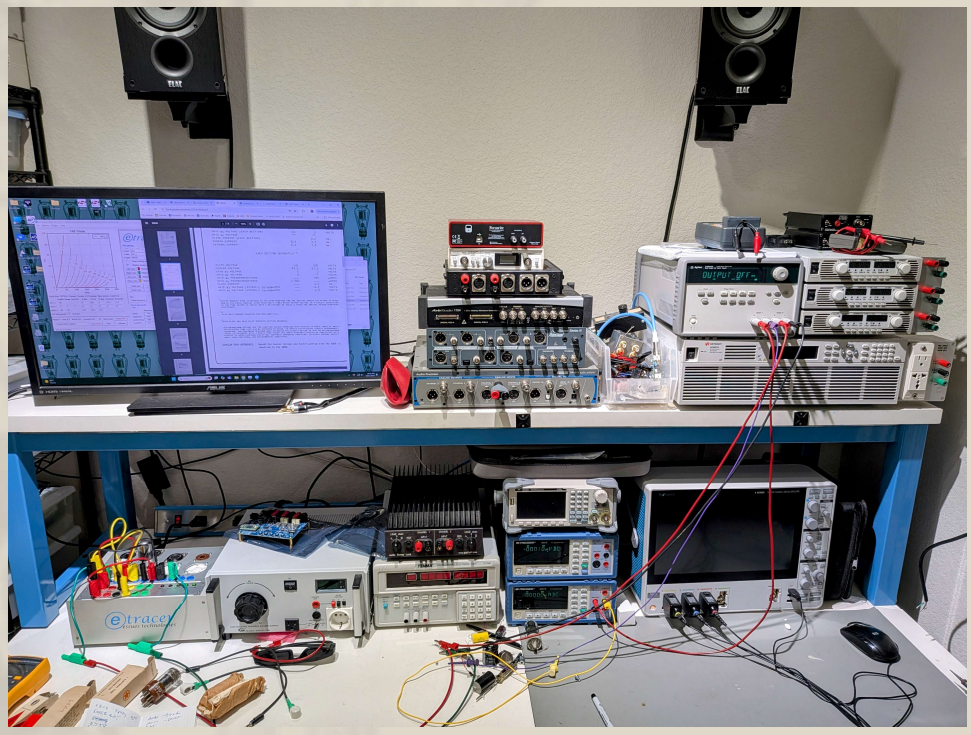
Agenda

- A little biography
- Why would I use non-traditional audio tubes?
- Beyond pentodes – heptodes, hexodes, octodes, nonodes
- Weird tubes – gated beam discriminators, sheet beam tubes…
- Odd high frequency triodes
- Multi-element tubes

Image credit to many sources online, especially the Valve Museum – www.r-type.org

Biography

- I've been coming to ETF since 2003
- I've been an Electrical Engineer for almost 40 years, live in Austin, TX and work from a lab in my home
- I was a board level hardware guy in consumer and computers, but I've spent the last 20 years working for semiconductor companies
- Have a hobby business doing DIY audio stuff



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Why bother with these odd (non-audio) tubes?

- All the “treasured” audio tubes have become scarce – and expensive!
  - A plain old 6SN7 or 12AX7 now sells for between €30 and €150 each – sometimes much more!
  - An NOS EF86 pentode sells for €100, and it often can be replaced by a lowly 6AU6/EF94 for less than €10
- Meanwhile, there are thousands of tube types that sell for €1 or less
  - For example, www.vacuumtubes.net has several hundred types listed for $0.75 – even less if you buy in quantity

Better performance!

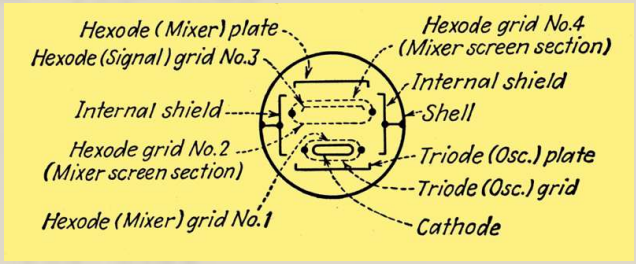
- Many of these odd tubes perform as well – or better – than the old standards
  - Often they contain the exact same internal structures as the expensive tubes
- Many tubes developed for non-audio use perform far better than typical audio tubes
  - Tube technology was at its peak when tubes were developed for color TVs before the transition to silicon
  - For example, lots of high-gm pentodes were made for color TV video amplifier use, some with gm over 20mA/V. These make awesome audio amplifiers
  - Triodes were developed for UHF use that have high gm and low noise
- Some have already been discovered, driving up the price
  - The D3a high gm pentode used to be cheap… now it sells for $50-100
  - But there are lots of others out there. Look up 6HM6… gm = 15mA/V, for $3. The only reason it is $3 is that it is “undiscovered” by audiophiles. (Did I just ruin that?)

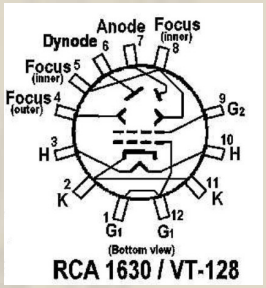
Multi-grid tubes

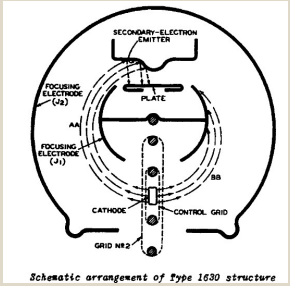
Hexodes, Heptodes, Octodes and more…

Hexodes

- A hexode has 4 grids
- Some hexodes are just pentodes with an extra grid inserted between G1 and G2
  - These are RF amplifiers like 6GU5 and 6FS5, which basically function the same as pentodes
  - The AH1 and RENS1224 are hexodes designed as a mixer
- Triode-hexode tubes contain a triode intermingled with a hexode
  - There are several “triode hexode” tubes, which combine a triode in the same envelope as a hexode, with a shared and cathode and two plates, and often a shared G1
  - ECH11, ECH35, ECH41, ECH81/6AJ8, ECH83, ECH84, and 6K8 are examples
  - These were used as oscillator/mixers, especially in Europe
- There are some unusual ones – like the 1630 orbital-beam amplifier
  - This was designed as a wideband UHF amplifier







Triode-hexode example: ECH81 / 6AJ8

- The ECH81 was a popular mixer tube for AM radios in Europe
  - It's pretty much a pentode and triode that share the cathode
  - If you ground the triode plate you should get more-or-less a beam pentode
    - But no regular curves in the datasheets
    - You can also triode connect it but it isn't very linear
  - The triode section is a separate, normal triode with gm 0f 3.2mA/V and mu of 19

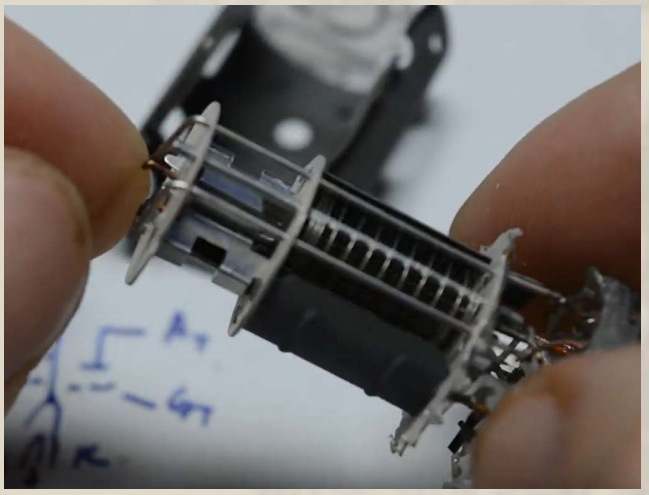
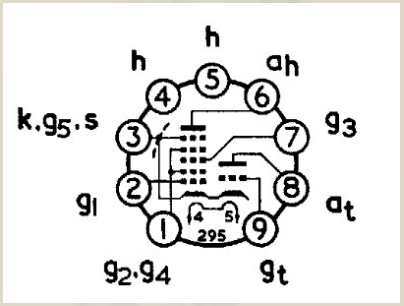
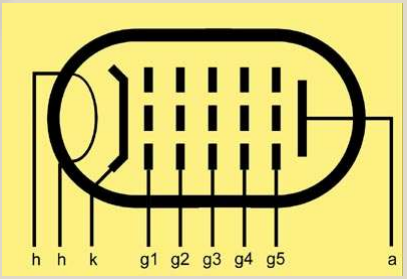


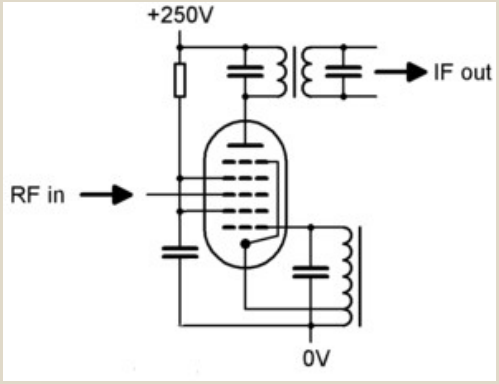
Image credit to Fesz on YouTube



Heptodes and pentagrid converters

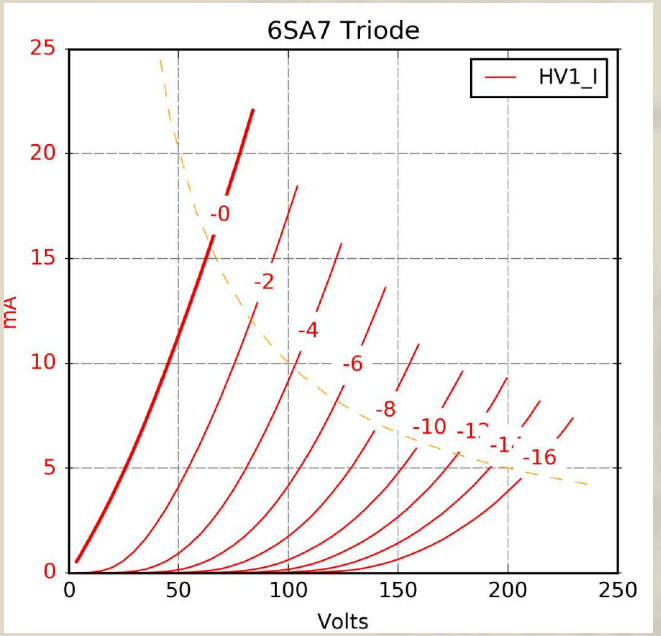
- A heptode, AKA pentagrid converter, has 5 grids
- They figured out you could add two grids to a pentode and make a combined oscillator and mixer for an AM radio, eliminating the oscillator tube
  - One of the grids acted as the oscillator plate
  - For transformerless “AA5” AM radios in the US, the 12SA7 and then the 12BE6 were common
  - There are many others – most are dirt cheap
- You can make these into triodes by connecting them similarly to how you would connect a pentode – hook all the grids except G1 to the plate
- You can also connect these as pentodes by using G2 and G4 as the screen and connecting G3 and G5 to the cathode

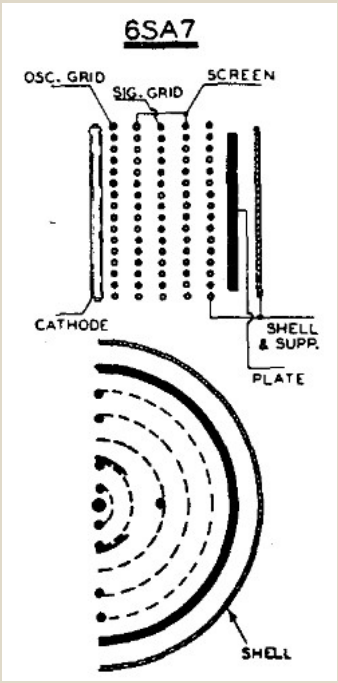




Pentagrid example: 6SA7 in triode mode

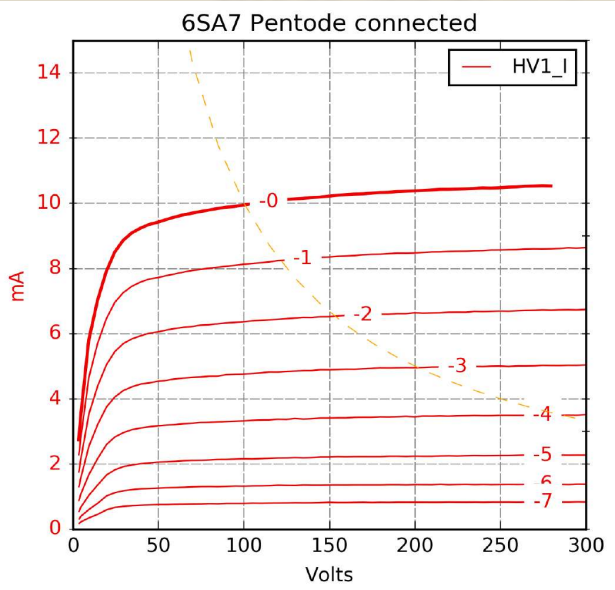
- The 6SA7 is an octal pentagrid converter. Connected with G2, G3, G4, and G5 connected to the plate, you get a decent low-mu triode with a gm of ~2.5 mA/V and a mu of 12.7

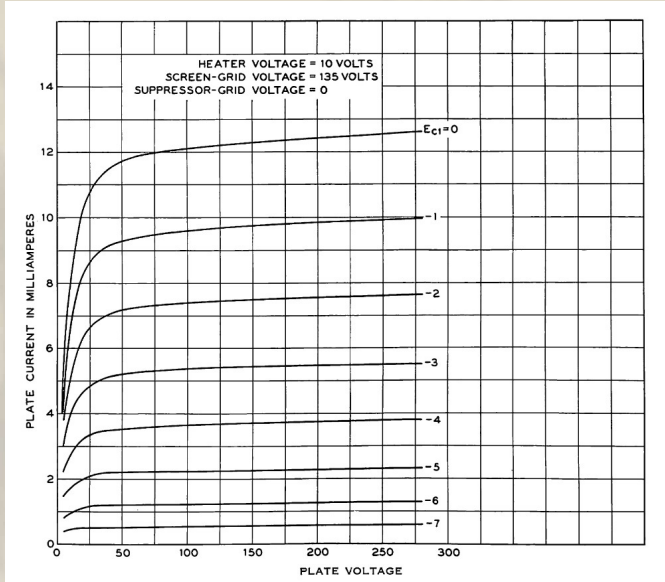




Pentagrid example: 6SA7 in pentode mode

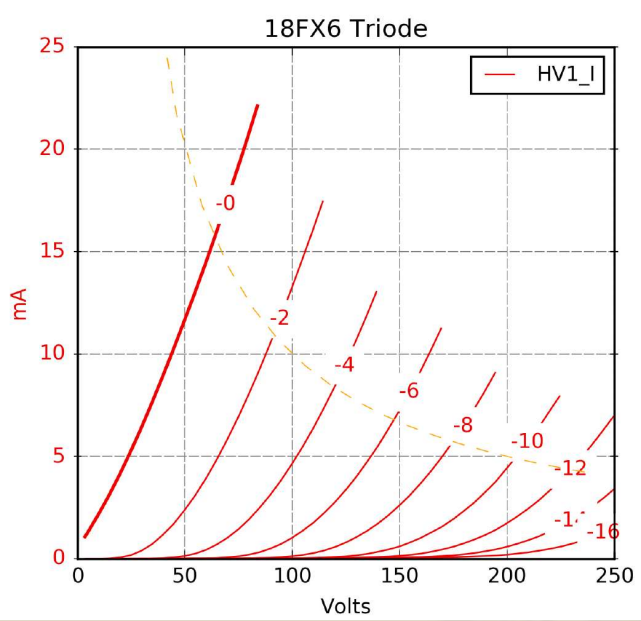
- To act as a pentode, G2 and G4 are the screen grid, and G3 and G5 are the suppressor
- This makes a pretty audio good pentode! Compare it to the ($100) WE310A:

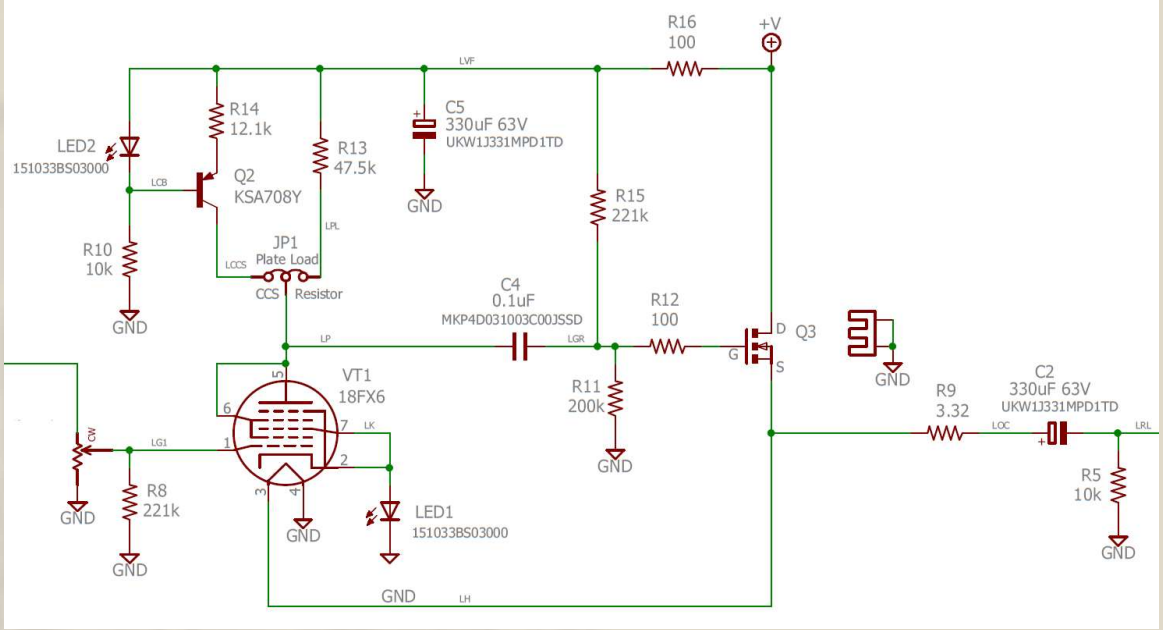




Pentagrid example: 12BE6 or 18FX6 in triode mode

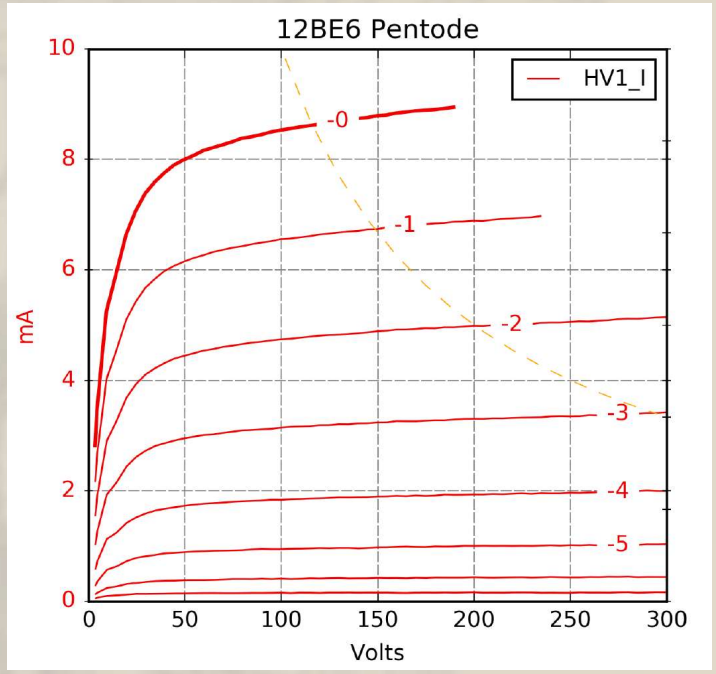
- The 12BE6 and 18FX6 are 7-pin-mini pentagrid converters. Connected with G2 and G4 connected to the plate, you get a medium-mu triode with a gm of ~4 mA/V and a mu of 18





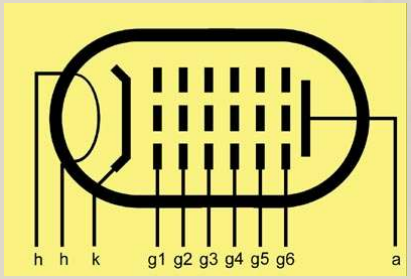
Pentagrid example: 12BE6 in pentode mode

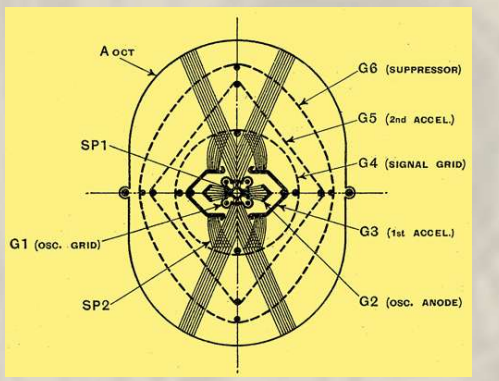
- G2 and G4 are the screen grid, and G3 and G5 are the suppressor

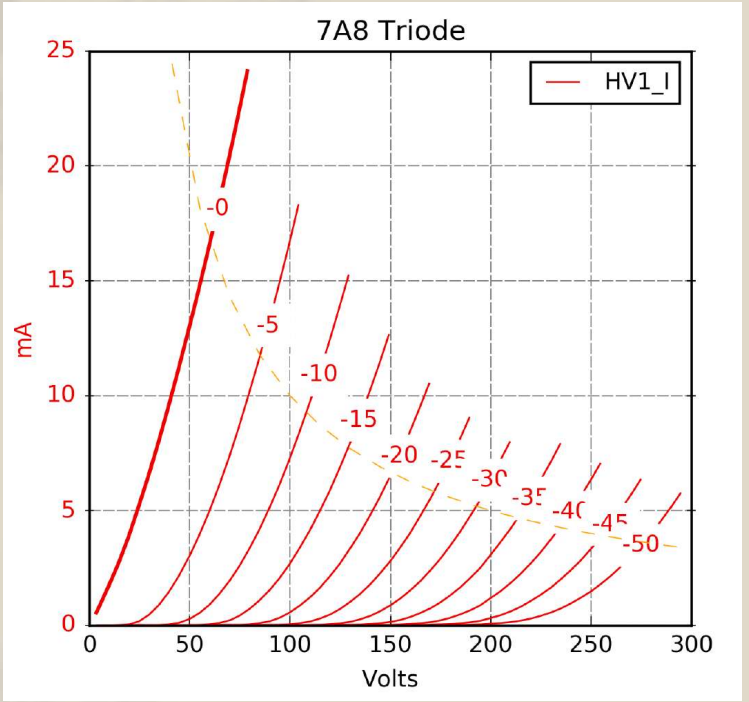


Octodes

- If you add one more suppressor grid to a heptode (for a total of 6 grids) you get an octode
  - These are also used as oscillator/mixers
- These are pretty uncommon
  - The US 7A8 and old EU EK3 are examples
- The 7A8 triode connected (G2 – G6 connected to plate) is similar to the pentagrids
  - gm 1.1 mA/V, mu 5.2

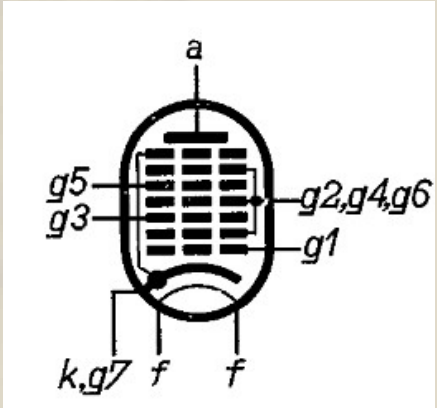


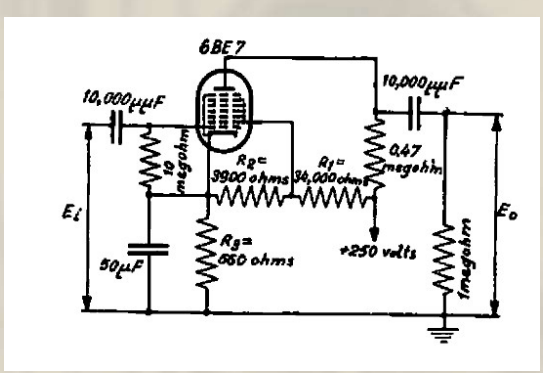




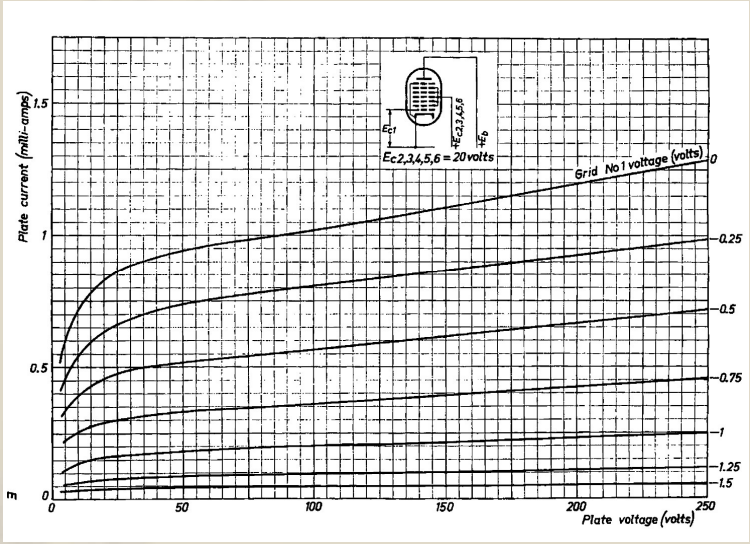
Nonodes (AKA Ennodes)

- A nonode (or ennode) has 7 grids (!)
- These are uncommon. The EQ80 / 6BE7 is about the only example I could find
  - Several grids are connected together inside the tube
- The EQ80 was used mostly as an FM detector
  - It makes a pretty good pentode with only 20V on the “screen”
  - Philips also published a circuit to use it as an audio amplifier
- It is cheap





Audio amp circuit



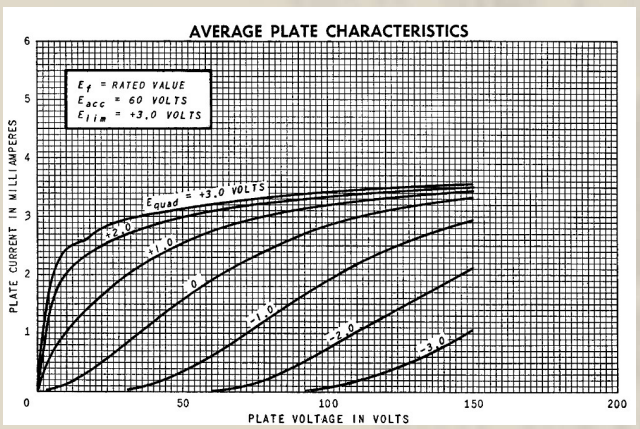
Pentode curves

The really weird stuff

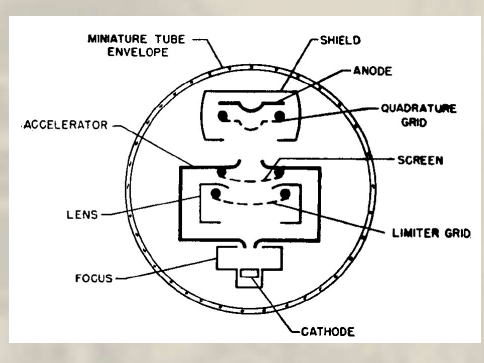
Surprisingly, some are useful

Gated beam discriminators (GBD)

- The gated beam discriminator was designed to be a detector in FM radios
  - It was also used in digital circuits
  - 6BN6 and 6KS6 are examples
- The plate curves are… curvy?
- I used the 6BN6 GBD in the “magic box” I made to demo even and odd distortion at ETF.04
  - Varying the quadrature grid (G3) voltage changes the shape of the G1 curves



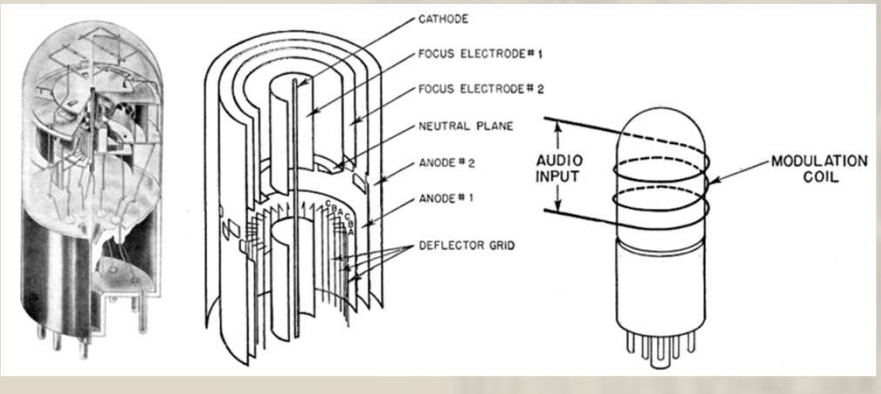
Quadrature characteristic



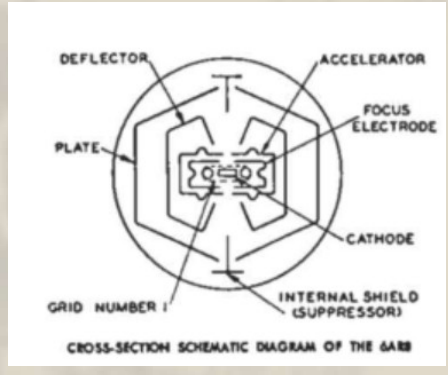
GBD cross section

Beam deflection tubes / sheet beam tubes

- Beam deflection tubes (BDTs) form an electron beam that can be steered between two (or more) plates
- The most common BDTs were used for SSB modulation (7360) and chroma demodulation in color TVs (6AR8/6JH8/6ME8)
- It gets weirder from there… like the GE “Phasitron”, an early FM modulator that uses a magnetic field to modulate the phase of a VHF carrier



GE Phasitron tube



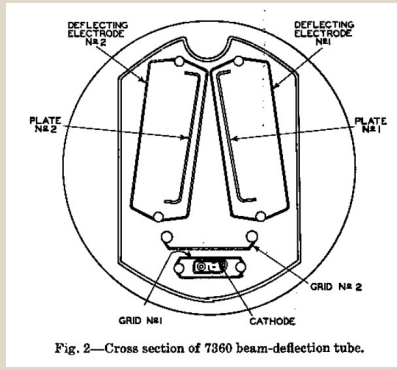
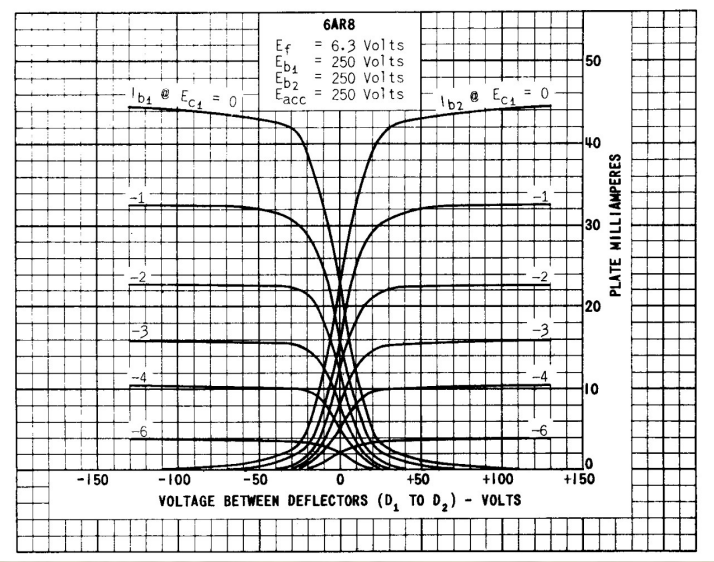


Fig. 2—Cross section of 7360 beam-deflection tube.

BDT cross sections

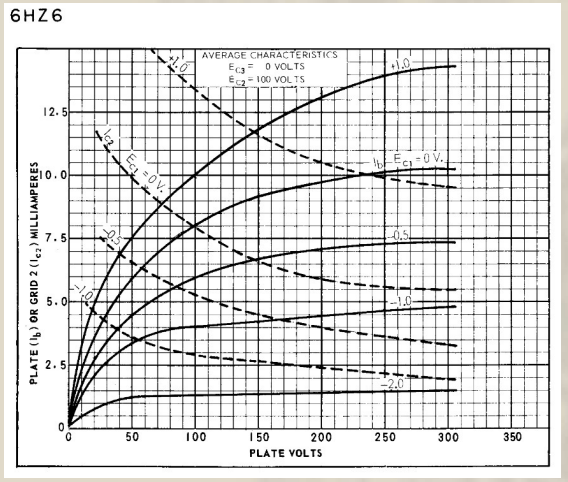
BDT audio applications

- The 6AR8 BDT actually has been used for some unique audio applications
  - JN Van Scoyoc published an article in 1959 suggesting audio applications of the 6AR8
  - You can make a variable gain amplifier by applying the audio input differentially to the deflectors
  - Varying the G1 voltage varies the gain (Van Scoyoc claims over an 80dB range!)
    - In the curves below, see how the slope changes with varying G1 voltage?
  - Using that principal you can also make compressors with a BDT

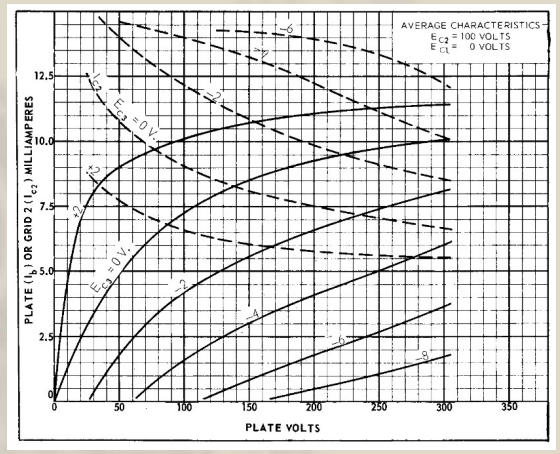


Dual control pentodes (DCPs)

- Dual control pentodes are pentodes where G3 is designed to be a control input, not just a suppressor grid
  - Dual control pentodes include 6DT6, 6HZ6, 6GY6, and 6GX6
  - These were primarily used as FM detectors in TVs
- Providing a positive DC bias to G3 varies the characteristics of the pentode
  - You can "square up" the G1 pentode curves by finding the optimal G3 DC voltage
  - Here are G1 and G3 curves for the 6HZ6



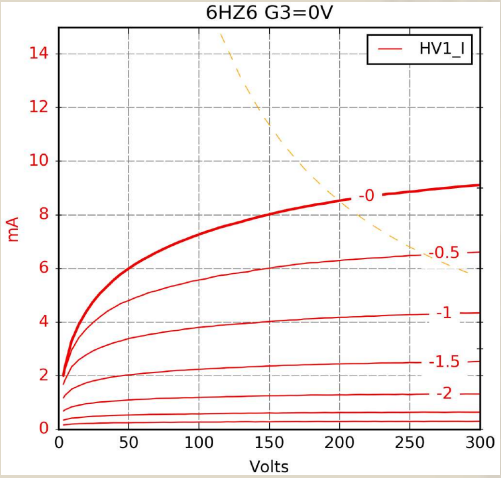
G1 characteristic curves

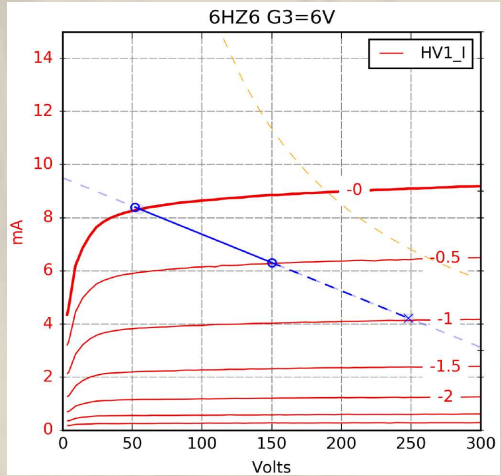


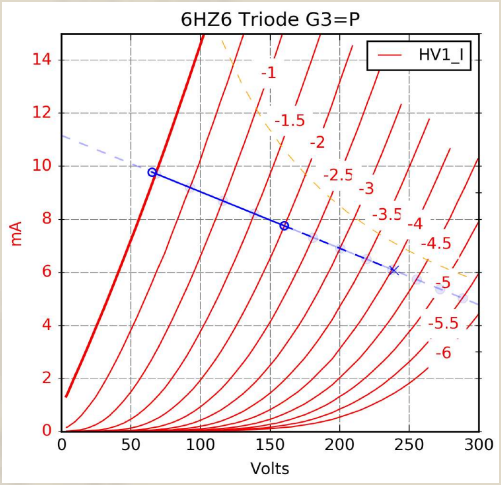
G3 characteristic curves

Details: the 6HZ6

- 6HZ6 is a typical dual control pentode designed for FM sound detector use
- The 6HZ6 sells for $0.75 and can make a fine audio tube
- As a pentode, with G3=6V, it's quite linear
  - With a 47k load, you get a gain of 200 Triode connected (all grids to plate), it has a gm of 7mA/V, rp of 7k, and mu of 52
  - With a 47k load, you can get a gain around 48

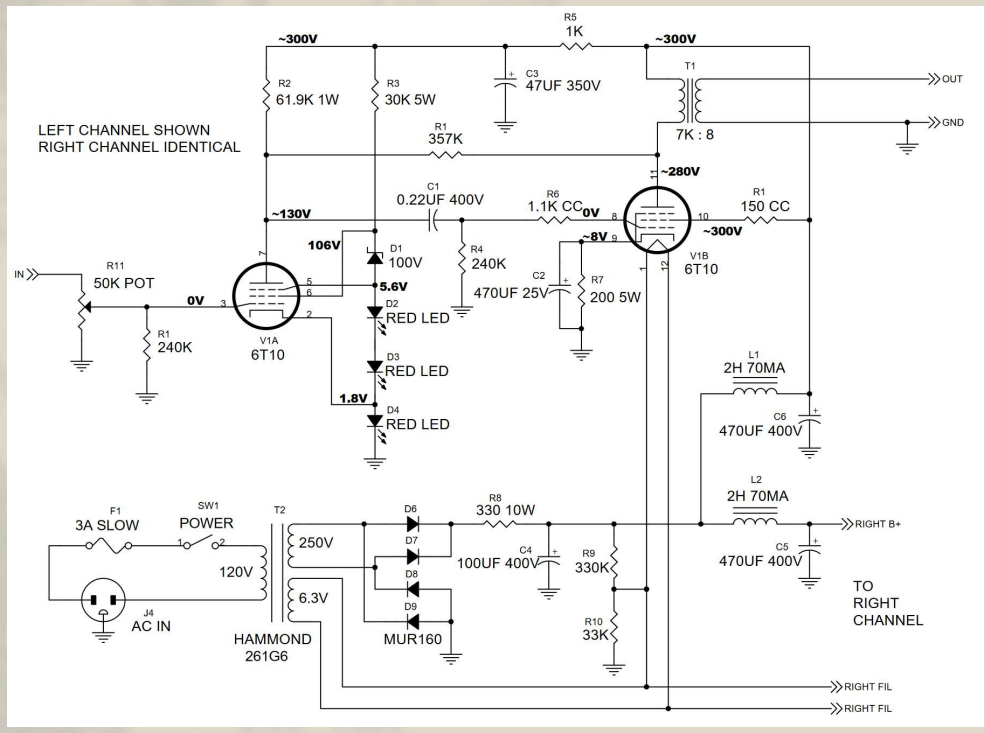






DCP plus audio output pentode

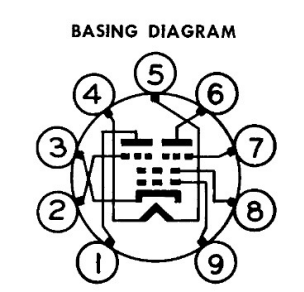
- DCPs were also made integrated with an audio output stage in a compactron envelope
  - They were designed to serve as a quadrature detector plus audio power amp in FM radios
  - These tubes can make nice single-tube audio amplifiers, using the DCP as a regular pentode
  - Types include 6AD10, 6AL11, 6BF11, and 6T10
  - I used the 6T10 in “the mighty midget” amp (audioXpress 5/2008) – the pentode is rated for 10 watts plate dissipation, and 4.2 watts out in single-ended A1 audio amplifier use
    - Note +5.6V on G3 of the DCP



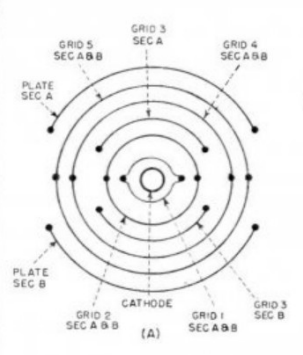
“Mighty midget” schematic

Twin DCP

- The twin DCP tube puts two DCPs together, sharing the cathode, G1, and G2, with separate G3 and plate
- These were used as color demodulators in TV
- Audio uses of these was proposed back in 2003
  - Morgan suggested that it might be a good CCS for a pair of cathode followers
  - Biasing up the G3s and connecting the plates together should make a good pentode
- Like a single DCP, biasing up G3 “squares up” the pentode curves
- Types include 6LE8, 6KF8/6BU8/6HS8, and 6GS8
  - Also twin DCP plus a triode: 6BA11 and a dual DCP: 6BV11



6LE8 pinout



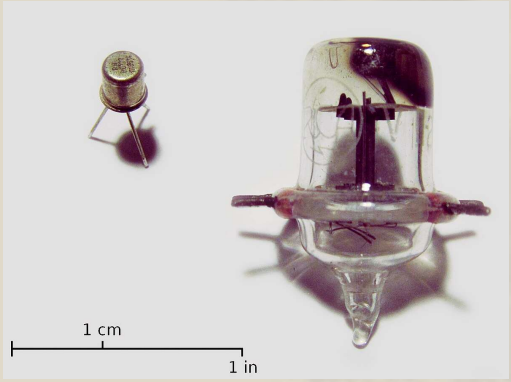
Twin DCP cross section

Acorn, disc seal, and planar triodes

High technology for the space age

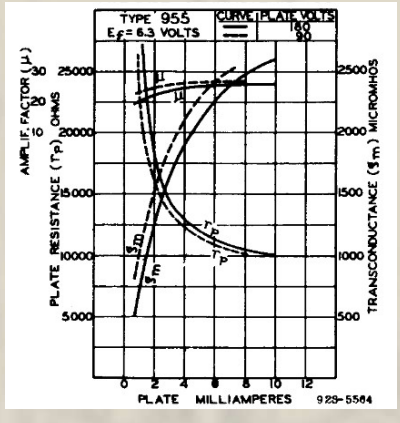
Acorn tubes

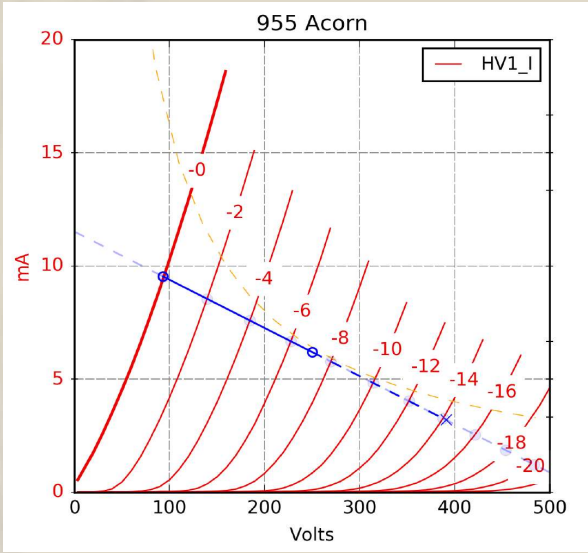
- Acorn tubes are small glass tubes with a conventional structure inside
- There are acorn triodes and pentodes – types 954 through 959 are acorns
- The 958 is a very linear DHT acorn
- They do take a strange socket – they are available, but cost more than some of the tubes



Acorn tube example: 955

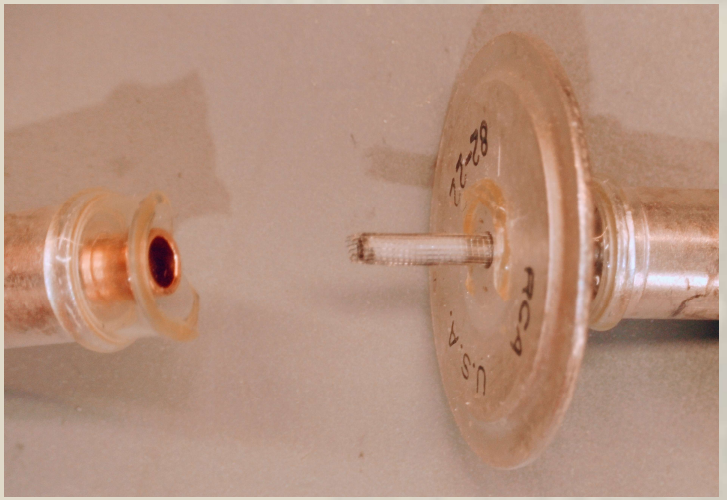
- The 955 is a common IDHT acorn tube that is actually quite good for audio
  - The gm is around 2.2mA/V and mu of 25, which is quite flat over current
  - 300V P-P out and a gain of 21 with a 47k load, at 250V 7mA
  - It's cheap, around €4.
  - This appears to be the same tube inside as the 9002 (in 7-pin-mini – it's also pretty cheap)
  - Thomas Mayer did a nice writeup on the 955
    - http://vinylsavor.blogspot.com/2020/06/tube-of-month-955.html

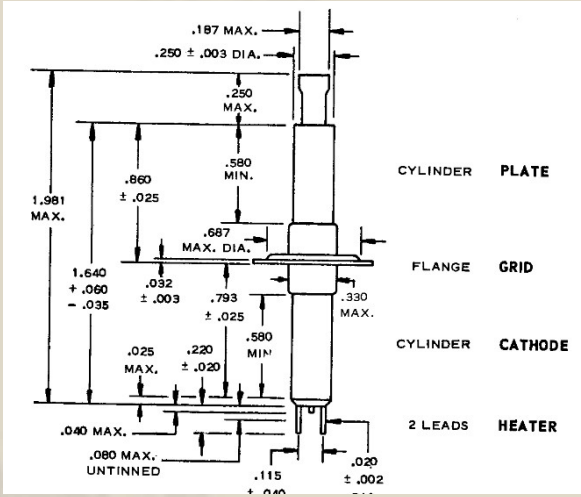




Pencil tubes

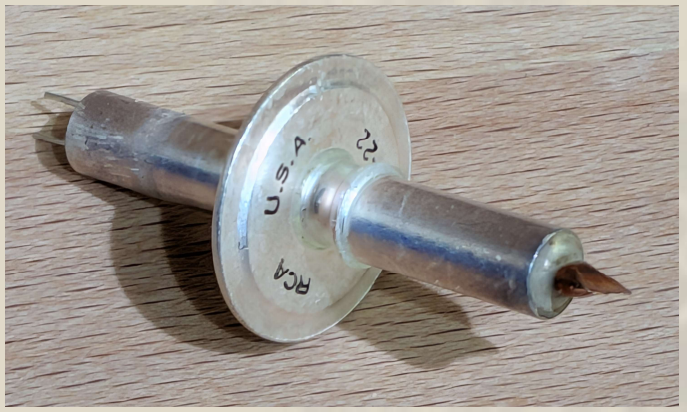
- A “disc seal” triode, the “pencil” tube is, well, shaped like a pencil. The filament comes out the two pins at the bottom, the plate is the cylinder at the top, and the grid (connected to the disc) is a screen between the cathode and plate.
- The 5876 is typical, with a gm of 6.5mA/V and a mu of 56
  - Also a class-C RF tube…

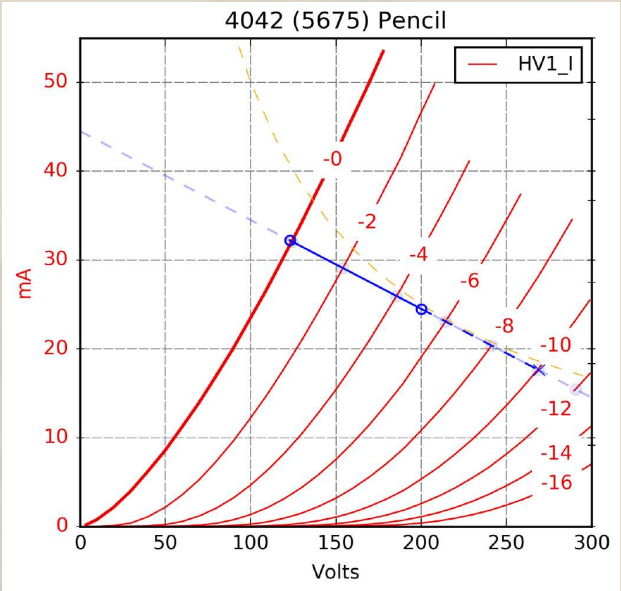




Pencil tube example: 4042

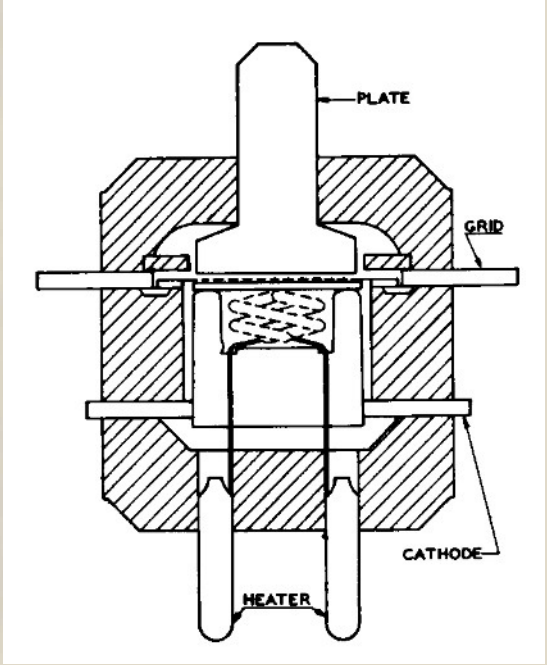
- The 4042 is a selected 5675 that was used in HP test equipment
  - It's a 5 watt medium mu triode – gm of 6.2 mA/V and mu of 20 (I measured 6.8 and 16)
  - With a 10k load, 200V Vp and -5V Vg, gain of 15 and max out of 150V P-P
  - These sell for between $5 and $20





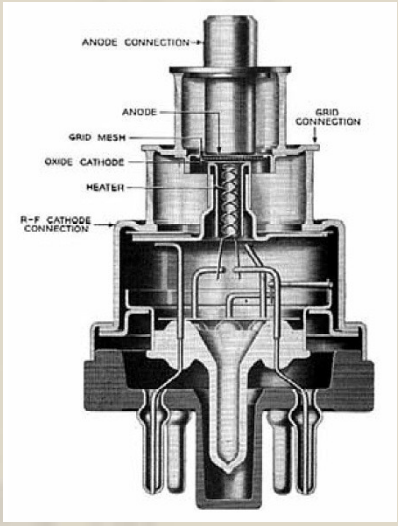
Planar triodes

- The quest for UHF and microwave radio led to some really odd triodes
- Many of these triodes have a planar structure, as opposed to the concentric structure that other tubes use
  - The grid structure is a flat array of tiny wires or a thin sheet of perforated metal
  - The plate is a flat plate
  - This construction allows very tight spacings and low parasitic inductances
- These tubes are not always inexpensive, but they are interesting nonetheless
  - Some have amazing characteristics



Lighthouse tubes

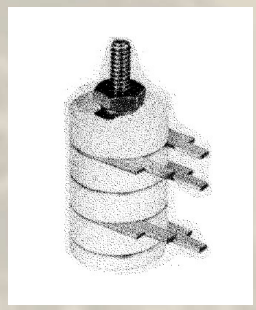
- The lighthouse tube is an early example of a planar triode
- The 100 watt 2C39 is quite common, with a gm of 24.8mA/V and mu of 95
- Other 2Cxx tubes are similar, with different gm and mu
- Since most were intended for class-C RF use, most of these are maybe not so useful for audio…



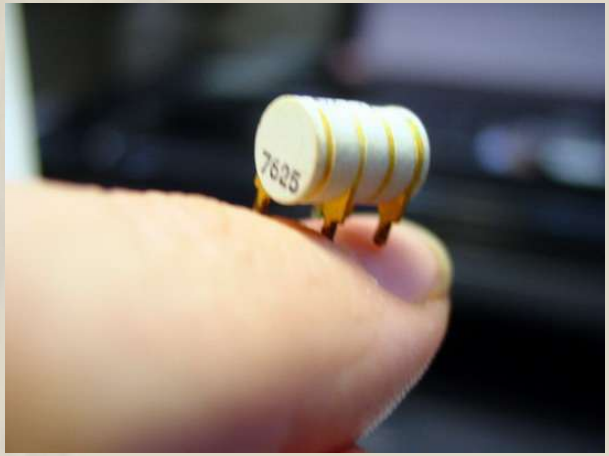
Metal / ceramic triodes

- Planar triodes can also be constructed using ceramic and metal
  - These are recent developments from the mid-late 1960s through the 1980s
- Some can be soldered directly into a PCB
  - Many are medium mu, high gm, and could be useful in audio
  - These include 7625, 7296, 7462, 7720,
  - 7296, 7588, 8081, 8082 and 8083 can be mounted on a heatsink
    - 7588 has a gm of 45 mA/V and a mu of 175!
- Some of these are expensive, some are not

8082 tube



Heatsink mounting



7625 tube

Really high performance…

- The 7768 metal/ceramic tube has a mu of 100 and a gm of 50mA/V!
- It is not cheap – around €100 – but compared to an EC8020 which is selling for €1,000 – €5000 each, not so bad
  - It should make a great phono stage

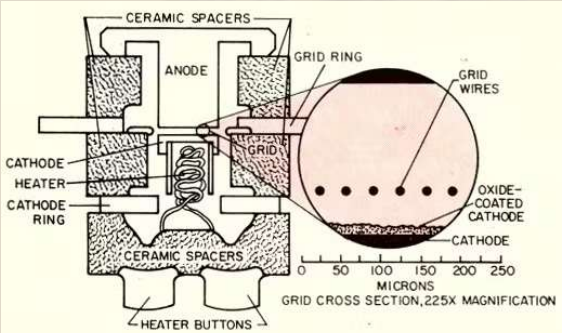


Fig. 1. Planar ceramic triode. This sectioned view is magnified eight times. Note the rugged construction which allows for close element spacing with reliability, essential for good microwave performance. The inset (magnified 225 times) shows the detail of the cathode-grid anode area.

Planar ceramic structure

7768 tube

Multi-element tubes

Tubes with 2, 3, or 4 tubes inside

Triode-diodes, triode-pentodes, etc.

- Not exactly odd, but there are many multi-element tubes out there that are neglected by audio designers
- In the later development of tubed televisions, many tubes were developed with more than one tube element inside one envelope to save money
  - Triodes and pentodes with diodes, and triode plus pentodes are very common
    - Triode/diode and triode/pentodes were used as an AM detector and audio amp
    - Triode / pentodes are a “sweet spot” because they fit in a 9-pin miniature envelope, so there are probably 100 types
  - Many of these re-used the guts of standard audio tubes
    - An example: 6AQ7 triode plus dual diodes has ½ of a 6SL7 inside. It costs €3 vs. €30
    - Another example: 6LY8 has ½ of a 12AX7 inside… and it sells for $3
- Some of these tubes have incredibly good specs
  - That 6LY8 also gets you a frame grid pentode with a gm of 20mA/V!
- There are HUNDREDS of useful tube types like this
- …and even more if you are willing to use odd heater voltages

6JT8 and 6LY8

- The 6LY8 is about $3.00. The very similar 6JT8 is $0.75.

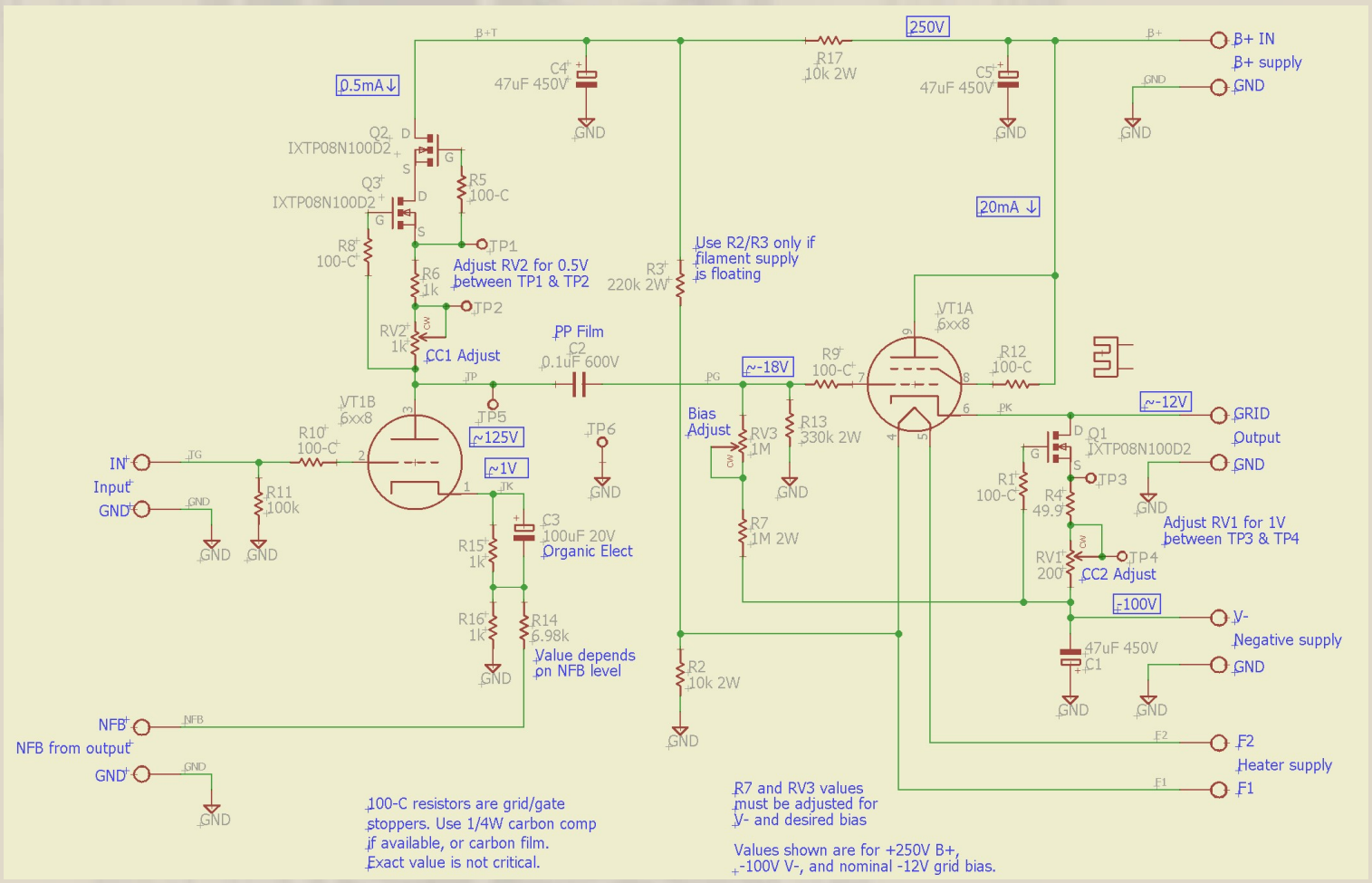
This is a 12AX7

Gm of 20mA/V!

AVERAGE CHARACTERISTICS		Pentode Section	Triode Section	
Plate Voltage	35	200	250	Volts
Screen Voltage	100	100	---	Volts
Grid-Number 1 Voltage	0	---	-2.0	Volts
Cathode-Bias Resistor	---	82	---	Ohms
Amplification Factor	---	---	100	
Plate Resistance, approximate	---	60000	59000	Ohms
Transconductance	---	20000	1700	Micromhos
Plate Current	54	19.5	1.0	Milliamperes
Screen Current	13.5	3.0	---	Milliamperes
Grid Voltage, approximate Ib = 10 Microamperes	---	---	-5	Volts
Grid-Number 1 Voltage, approximate Ib = 100 Microamperes	---	-6.3	---	Volts

6LY8 A2 driver

Tube	Pent Gm	Triode mu
6JT8	20k	100
6LY8	20k	100
6KV8	21k	70
6KR8	20k	46
6LQ8	21k	46
6LB8	20k	30
6HZ8	12.6k	70



That's it...

- Go find some odd tubes!

- Questions?
- Comments?