The Computer Deconstruction Lab Presents Introduction to Vacuum Tubes (aka Valves)

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Background

- Former CDL Board Member
- Been building electronic projects since teenager
- Extra Class Ham- WA2SFF
- Designed and constructed many Tube Receivers and Transmitters
- Restored Vacuum Tube Radios
  - Swan six meter Transceiver
  - Multiple Drake Radios
  - Multiple Hallicrafters Radios
  - Philco Floor Model Radio

Important Safety Warning !!!!

- Vacuum Tubes get HOT!
- Vacuum Tubes use lethal voltages
- Make sure all test equipment is rated for the voltages
- Make sure all leads on test equipment are rated for the voltage
- Make sure all leads on test equipment are not frayed
- When working on LIVE vacuum tube equipment:
  - Put one hand in your pocket and only use the other hand
  - Use insulated tools

When working on OFF vacuum tube equipment

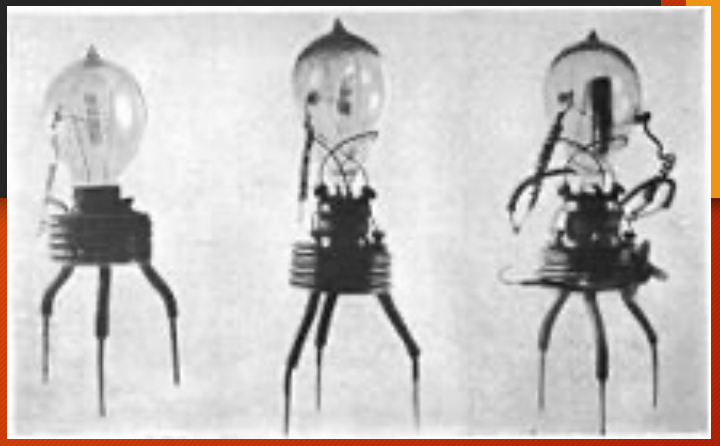
- Never assume that there are not lethal voltage in off equipment
- Discharge all high voltage capacitors by shorting them to ground
- Put one hand in your pocket and only use the other hand
- Use insulated tools

What Started it all?
The Light Bulb

- Filament installed inside bottle with no air (vacuum)
- When a filament in a light bulb is heated up,
  - light is emitted
  - electrons are released from the filament, called "Thermionic Emission"
- Discovered in 1873
- These electrons can be captured by added an additional element in the light bulb called an "Anode"
- This new device was called a diode

Diode

- Several scientists experimented with these diodes
- John Fleming applied the diode to radio signals thus improving the operation of a radio receiver
- A second use is to rectify Alternating Current (AC) to Direct Current (DC)
- The diode and all vacuum tubes have all air removed
- Some tubes have gases in them instead of air

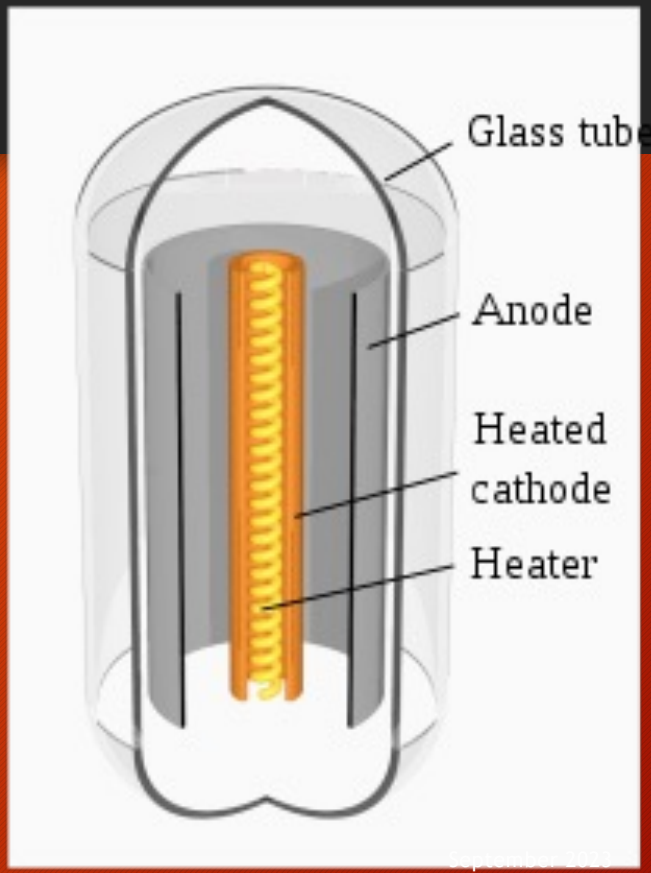


Early Diodes by Fleming

Modern Diode (6AL5)

Evolution in Design of Tubes

- First Improvement was adding material that emitted electrons better than the filament
- The electron emitter is called a cathode
- The cathode is heated up by the filament
- Later designs used elements in concentric circles, or other shapes like rectangles
- Some tubes have a chemical (called a getter) in them that absorbs gases to protect the vacuum

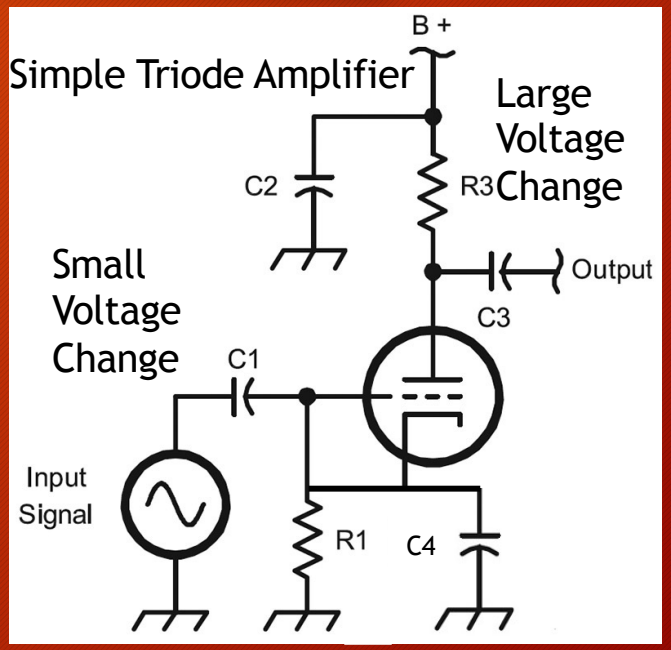


Also known as a plate

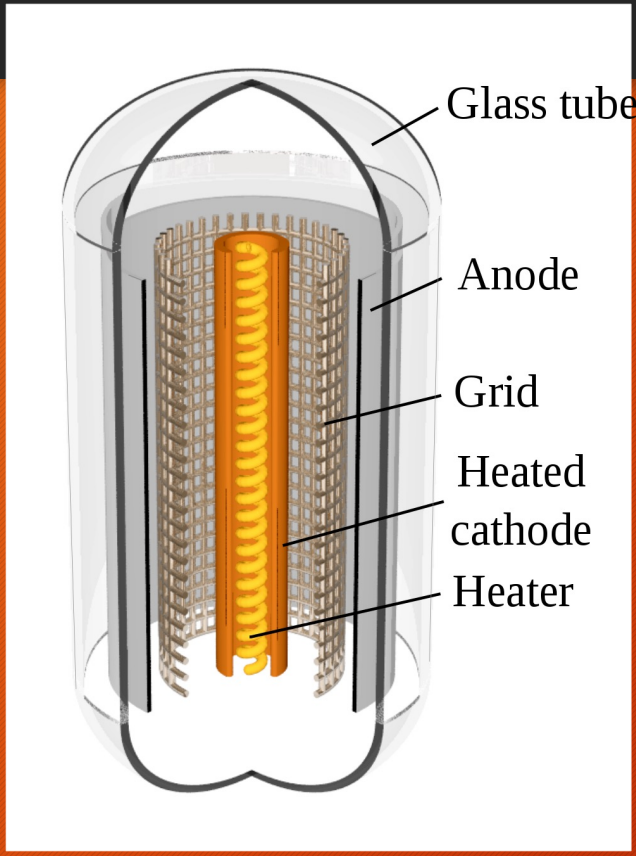
Also known as Filament

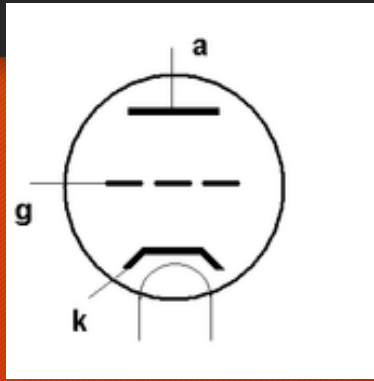
Triode

- Lee de Forest is credited with inventing the triode tube in 1907 while experimenting to improve his original (diode)
- When an open wire grid is placed between the filament/cathode and plate (anode), he discovered the ability of the resulting device to amplify signals.
- A negative voltage applied to the grid, referenced to the cathode, reduces the current reaching the plate.
- Varying the grid voltage varies the plate current and with an impedance in the plate circuit, it varies the voltage on the plate, thus amplifying the signal.



Triode





Schematic for Triode.
From top to bottom:
plate (anode),
control grid,
cathode,
heater (filament)

Evolution of Triode

- Triodes as they evolved over 40 years of tube manufacture, from the RE16 in 1918 to a 1960s era miniature tube
- Some examples are:
  - 6C4
  - 12AX7
  - 6J5
  - 6SN7
  - 6C5

Voltages needed for Triode

- Three voltages are needed to power a triode
  - A-battery: Filament Power
  - B-battery: Plate Power
  - C-battery: Grid Voltage
- Since the grid voltage is negative, no power is drawn from the C battery.
- Later electronic designs eliminated the C-battery
- Later battery powered radios only used A and B batteries.

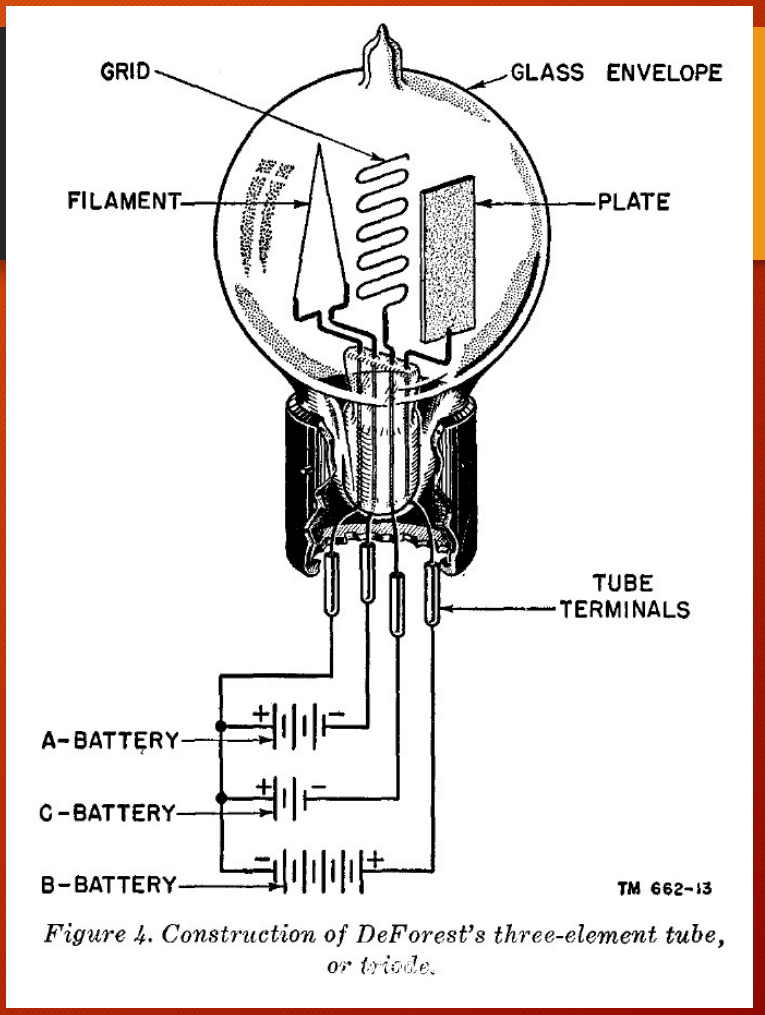
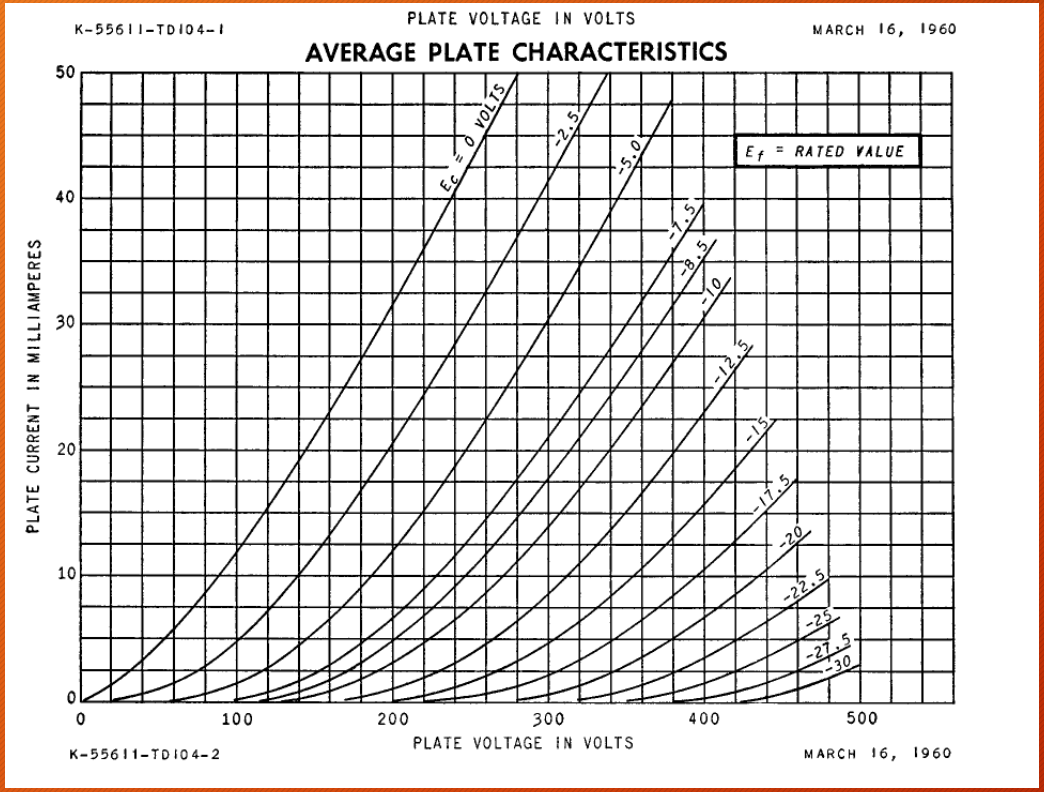


Figure 4. Construction of DeForest's three-element tube, or triode.

Tube Characteristic Graph



- A graph of: plate current vs. Plate Voltage for different grid voltages
- It is useful for design of amplifiers
- This for a 6C4 triode
- https://frank.pocnet.net/sheets/093/6/6C4.pdf

Problems with Triodes

- When two pieces of metal are placed near each other, even in a vacuum, they can pass information between them.
- This is called a capacitor
- A capacitor passes AC current and blocks DC current.
- The higher the frequency of the AC current, the better the capacitor passes the current.
- The elements in a tubes have capacitance though usually very small.
- As triodes were used at higher radio frequencies, the capacitance would feedback a signal from the plate to the grid and the circuit would begin to oscillate on some random frequency causing the amplifier to not work correctly

Neutralizing Triodes

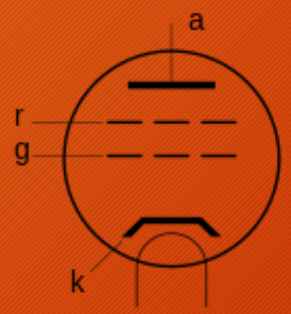
- To prevent the oscillation some of the output signal is feedback to the grid out of phase with the capacitance signal
- The feedback circuit is called a neutralizing circuit and the triode is said to be "neutralized"
  - Each tube and circuit, even of the same design, requires that the neutralizing circuit to be specially adjusted.
  - Replacing tubes or other circuit components required that the neutralizing circuit to be readjusted
  - Neutralizing Triodes circuits is a specialized skill and very tricky to perform
- For High Power Amplifiers, improperly adjusted neutralizing circuits can cause catastrophic failure of the tube.

Tetrode

- Walter H. Schottky invented the tetrode or *screen grid tube* in 1919, to fix the stability problems of the triode
- The screen grid uses a positive voltage less than the plate voltage
- The screen grid decouples the plate and the control grid, eliminating the need for neutralizing circuitry
- The useful region of operation of the screen grid tube as an amplifier was limited to plate voltages greater than the screen grid voltage
  - If the screen grid voltage is higher than the plate voltage, electrons migrate from the plate to the screen grid
  - Which causes the plate current to decrease with increasing plate voltages
  - See graph on next slide

Tetrode

- Tetrode Schematic symbol
- From top to bottom:
  - plate (anode),
  - screen grid,
  - control grid,
  - cathode,
  - heater (filament).



- In this region, the plate current decreases with increasing plate voltages
- The Tetrode can not be used as an amplifier in this region

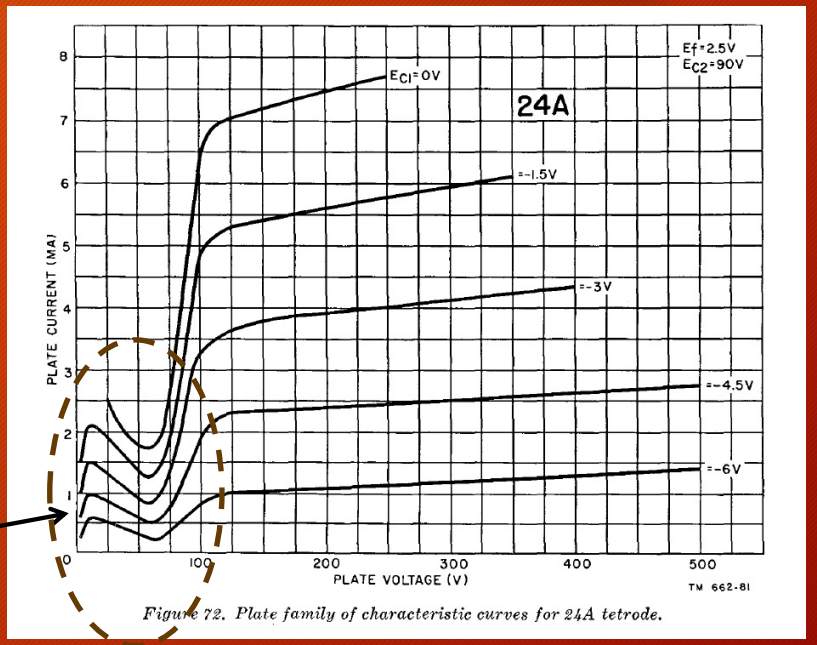
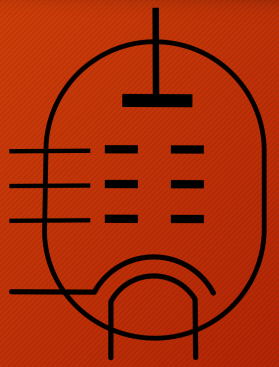


Figure 72. Plate family of characteristic curves for 24A tetrode.

Pentode

- Adding a third grid fixes the problem with the tetrode
- Bernard D. H. Tellegen invented the pentode in 1926.
- Pentodes became the major amplifier tube
- Pentodes are made in two classes:
  - Those with the suppressor grid wired internally to the cathode (e.g. EL84/6BQ5) and
  - Those with the suppressor grid wired to a separate pin for user access (e.g. 803, 837).

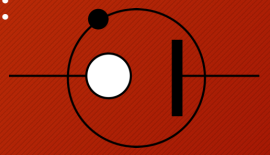


Electrodes, listed from top to bottom:
anode,
suppressor grid,
screen grid,
control grid,
cathode

Voltage Regulator (Not a Vacuum Tube)

- Some tube circuits need a constant controlled voltage to work correctly
- A voltage-regulator tube (VR tube) provides the controlled voltage
- VRs have two main differences from Vacuum Tubes:
  - Their glass envelopes are filled with a gas mixture,
  - They have a cold cathode; the cathode is not heated with a filament to emit electrons.
- Voltage Regular Tubes:
  - Rely on gas ionization
  - Require that the unregulated supply voltage must be 15-20% above the nominal output voltage to ensure that the discharge starts
  - Require that a minimum current flow through them and they get hot

Octal-based tubes, 5-40 mA current:



0A3 – 75 volts
0B3 – 90 volts
0C3 – 105 volts (best regulation of these four)
0D3 – 150 volts

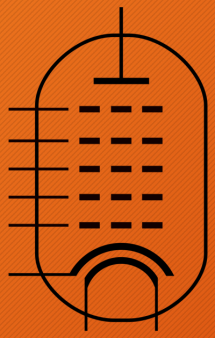
Miniature tubes, 5-30 mA current:

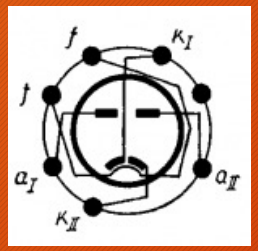
0A2 – 150 volts
0B2 – 108 volts (best regulation of these three)
0C2 – 72 volts

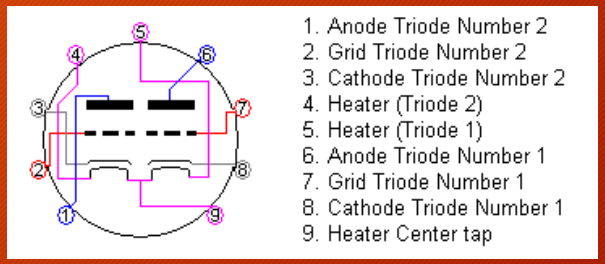
Multiple function tubes and Multi-section Tubes

- To make designs smaller and cheaper new tube types were developed:
- Multi function tubes
  - Pentagrid converter: A tube that performs the roles of oscillator and mixer in a receiver or transmitter has 5 grids
  - Some of the grids are used for the oscillator and others are used for the mixer
  - See slide on Radios
- Multi-section tubes
  - Multiple tubes can be put in the same envelope
  - Examples:
    - Dual triode
    - Triode and pentode
    - Triode and dual diode
    - Dual diode

Schematic of Some Tubes







Pentagrid Converter

Used in radio receivers

Examples:
6BE6, 12BE6

Dual diode

Used to detect AM radio signals

6AL5

Dual Triode

Used in audio Amplifiers

12AX7, 12AT7, 12AU7

Transmitting Tubes

- Some tubes are specially designed for High Power Transmitters
- Transmitting Tubes have there own numbering scheme
- Typically use Different tube bases than other tubes
- Are expensive
- Have limited life and are often replaced before they fail
- Some TV tubes are often used as medium power Transmitting Tubes
  - Have many limitations and
  - can fail catastrophically very easily

Types of Tubes

- Early: 4, 5, 6 pin
- 30s-50s: Octal
- Loctal
- 60s on:
  - Miniature 7 pin
  - Miniature 9 pin
- 70s: Nuvistor
- Compactron
- Other specialty

Labeling/Numbering of Tubes

- In the US, before standards, tube numbers were random
- The Radio Electronics Television Manufacturers' Association (RETMA) standardized must tubes in the US
  - Tubes numbers, comprise a number, followed by one or two letters, and a number
  - The first number is the (rounded) filament voltage
  - The letters designate a particular tube but say nothing about its structure; and
  - the final number is the total number of electrodes
- For example, the 12AX7 is a double triode
  - Two sets of three electrodes plus a 12.6 volt filament
  - The "AX" designates this tube's characteristics
  - Similar, but not identical, tubes are the 12AT7, 12AU7

Why so many tube types ?

- Diodes, Triodes, Tetrodes, Pentodes, Power Pentodes
- Different design needs:
  - audio amplifiers,
  - Radio Frequency Amplifiers,
  - Different gains or power output
  - Special low noise tubes
  - Support for car radios
  - Support for battery/portable radios
- Miniaturization
- Lower Cost
- Eliminate parts, for example Power Transformers

Where will you find tubes

- HiFi/Stereo Amplifiers
- AM radios
- FM radios and FM tuners
- TV sets of 40s, 50s, 60s

Some Example Circuits

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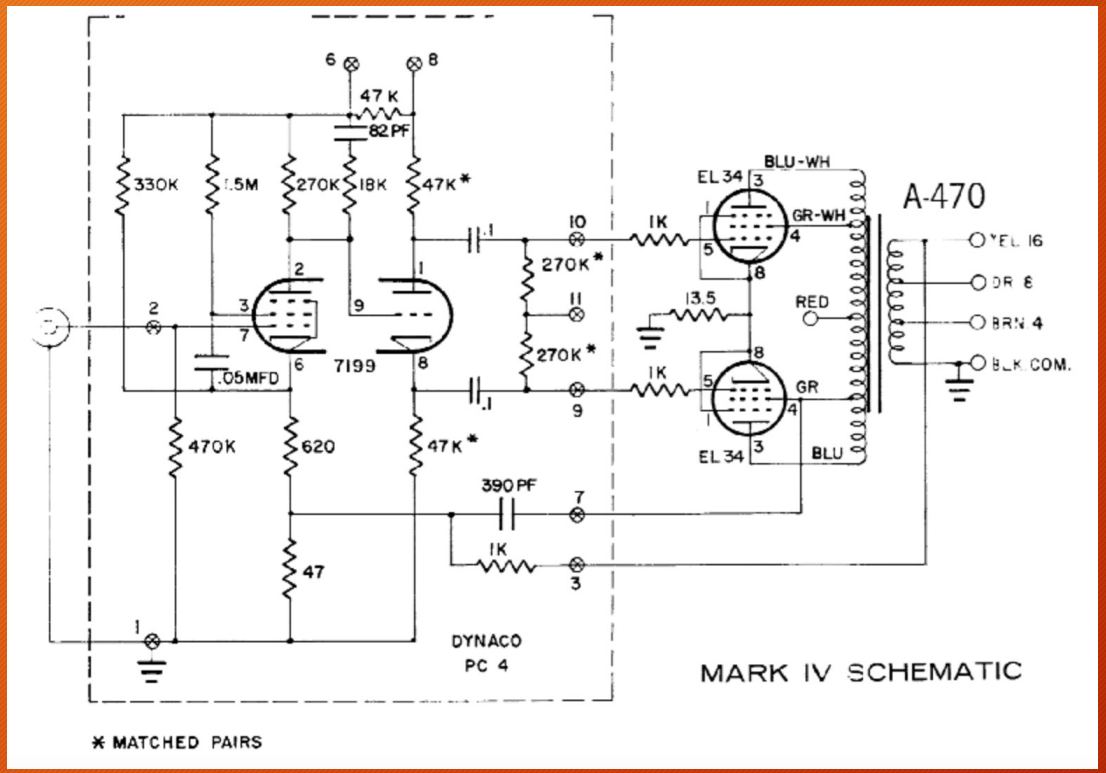
September 2023

Tube Amplifier

http://diyaudioprojects.com/Schematics/Dynaco-Dynakit-Mark-IV-Amplifier-Schematic.htm



- Design:
- Two identical amplifiers, one for each channel
- Pentode amplifier
- Triode amplifier
- Two Power Output Pentode Tubes in a format called Push-pull
- Transformer:
  - to convert high impedance needed for tubes (5000 ohms)
  - to lower impedance needed for speakers (8 ohms)

Common Hi-Fi Amplifier Tubes

Power Output

- 6V6
- 6L6
- KT-88
- KT-66
- EL-84 / 6BQ5
- 6146
- 807

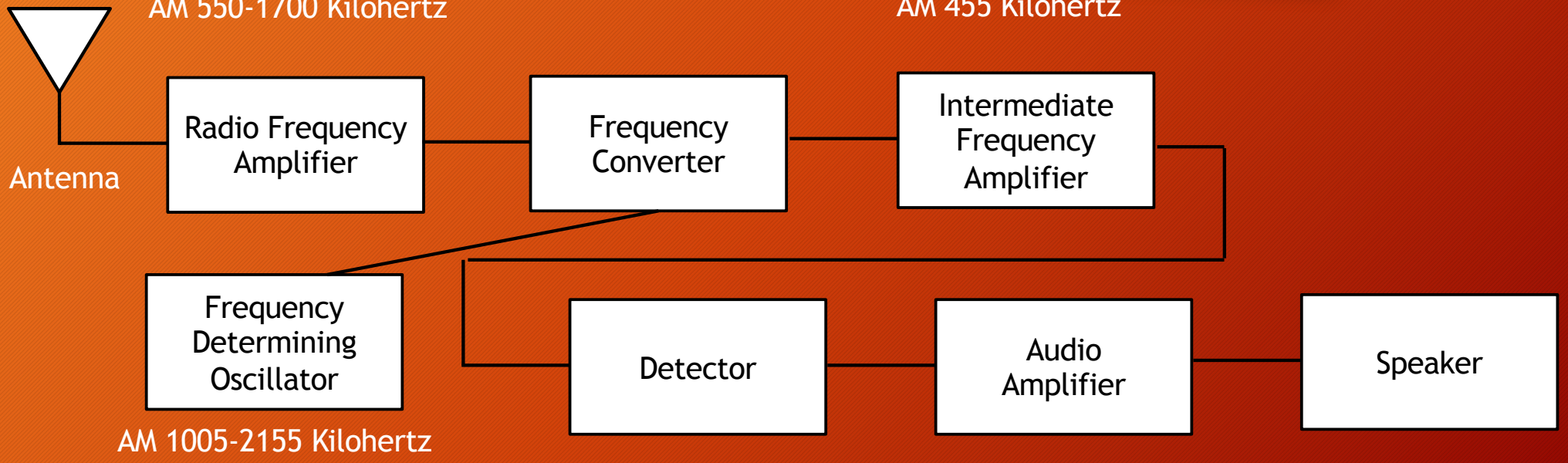
https://www.thetubestore.com/power-tubes

Amp and Pre-Amp

- 12AX7, 12AU7, 12AT7
- 6C4
- 6SN7
- 12AY7
- special low noise versions of above tubes

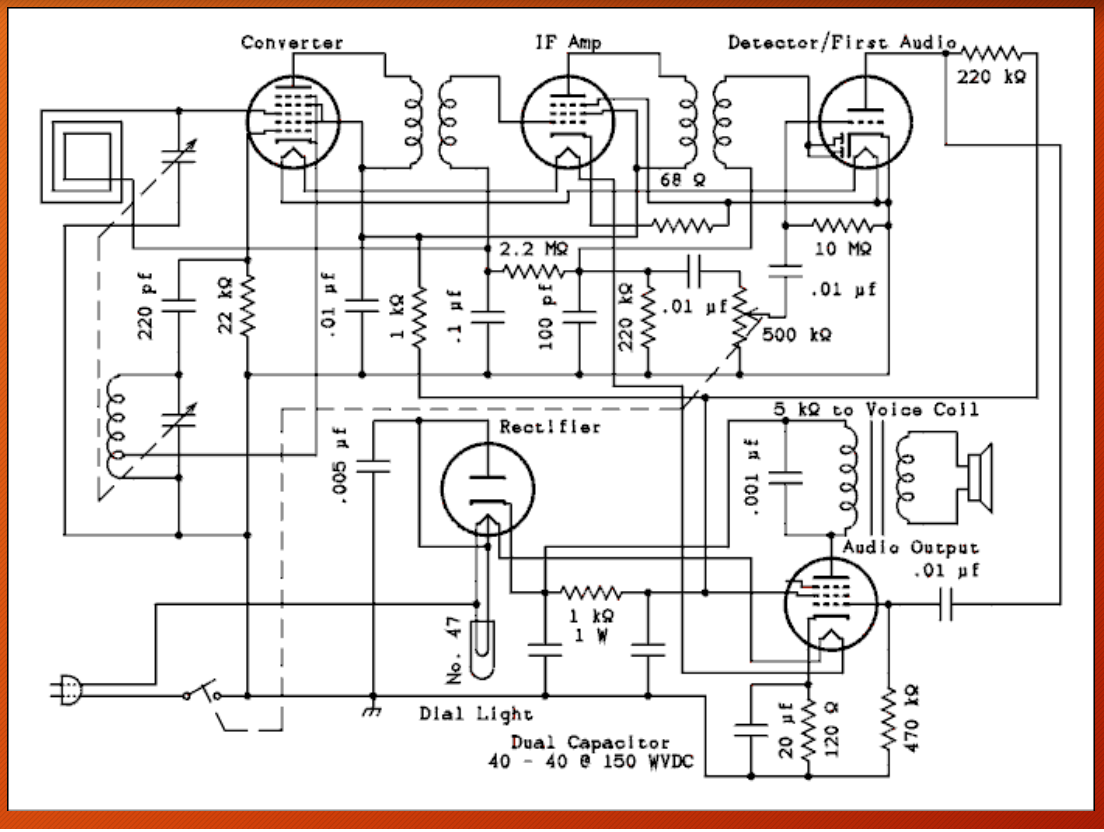
https://www.thetubestore.com/preamp-tubes

Traditional AM Radio Design 1918-2000s



AM Based on design by Edwin Armstrong U.S. patent 1,342,885 on 30 December 1918, which is issued on 8 June 1920

Example: 20s-60s Tube Radio "All American Five" Radio



Typical Tube line-up "All American Five" Radio

Tubes	Octal	Miniature	Battery
Converter:	12SA7	12BE6	1R4
IF amplifier:	12SK7	12BA6	1T4
Detector and first audio amplifier:	12SQ7	12AT6	1U4
Audio power output:	50L6	50C5	3S4 or 3V4
Rectifier:	35Z5	35Z4	batteries

Finally!!!

See Safety Warning on next slide

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Questions

References

- https://en.wikipedia.org/wiki/Vacuum_tube
- Manuals:
  - RCA Receiving Tubes Manuals (yearly issues)
  - RCA Transmitting Tubes Manuals (yearly issues)
  - Other brands of Tubes Manuals
  - http://www.bunkerofdoom.com/tube/man/
- For tube designs of transmitters and receivers
  - http://n4trb.com/AmateurRadio/GE_HamNews/ge_ham_news.htm
- For manuals on old tube equipment (mainly ham)
  - http://bama.edebris.com/manuals/
- For repair manuals: Sams Photofact, Rider Manuals (NJARC has many)
  - http://highgate.comm.sfu.ca/oldradio/