

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

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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

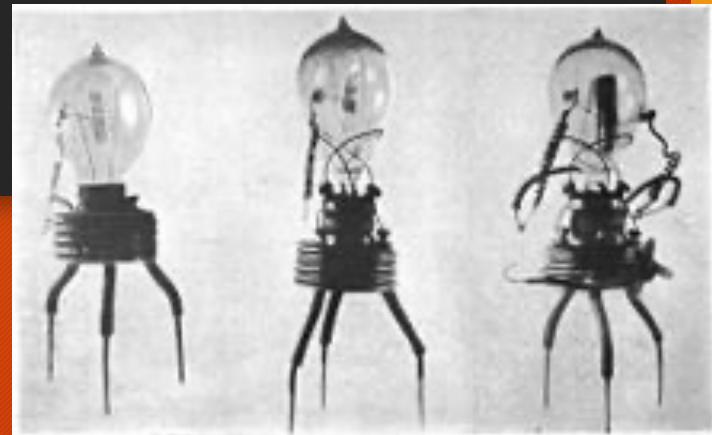
What Started it all? The Light Bulb

- 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



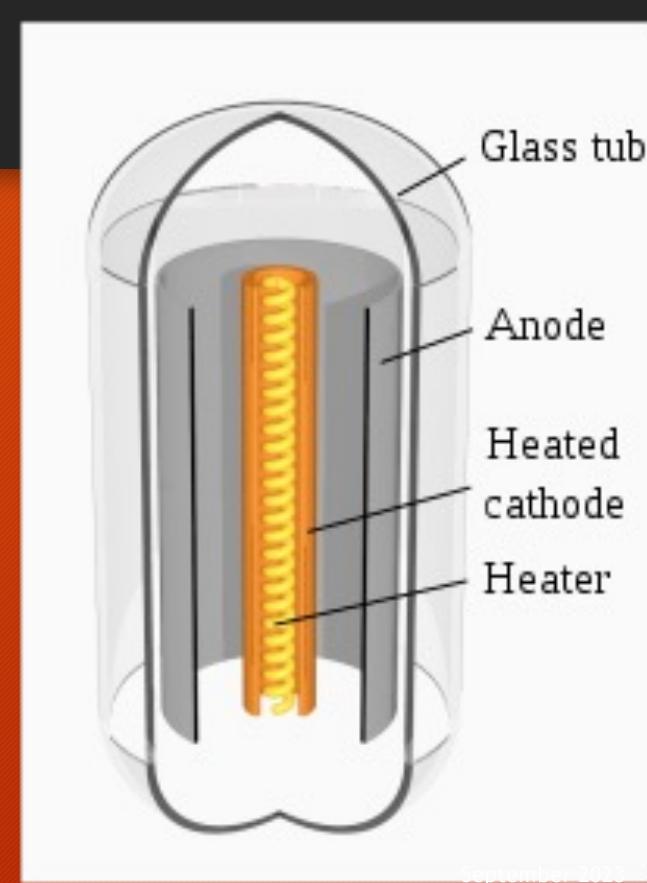
Early Diodes by Fleming



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

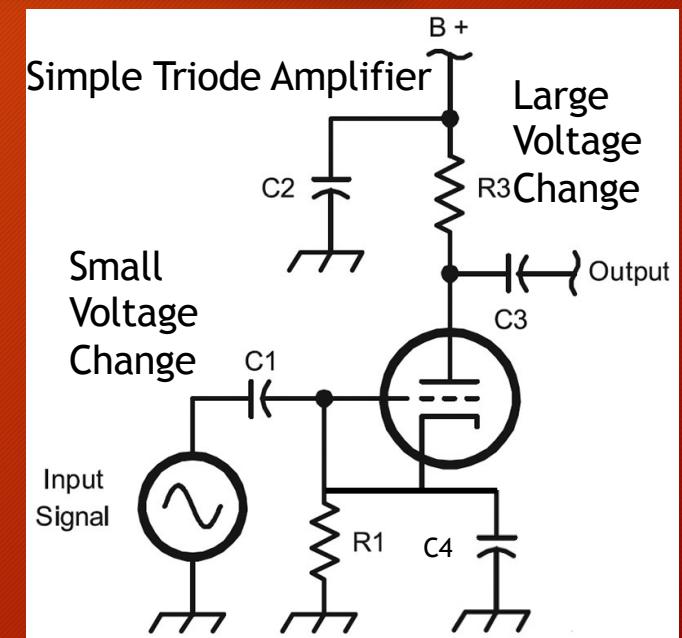


Also known
as a plate

Also known
as Filament

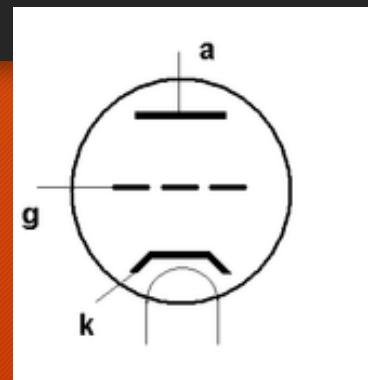
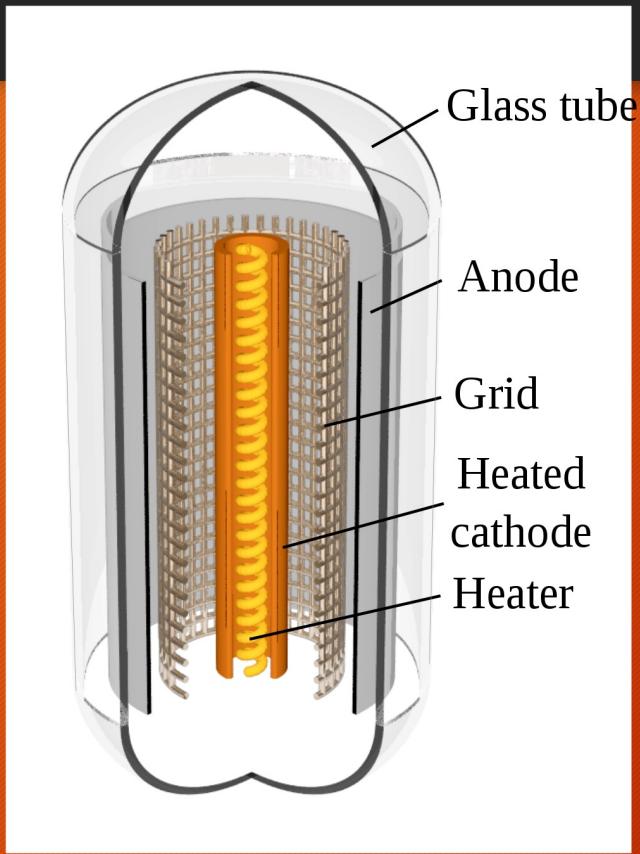
Triode

- 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.



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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



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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.

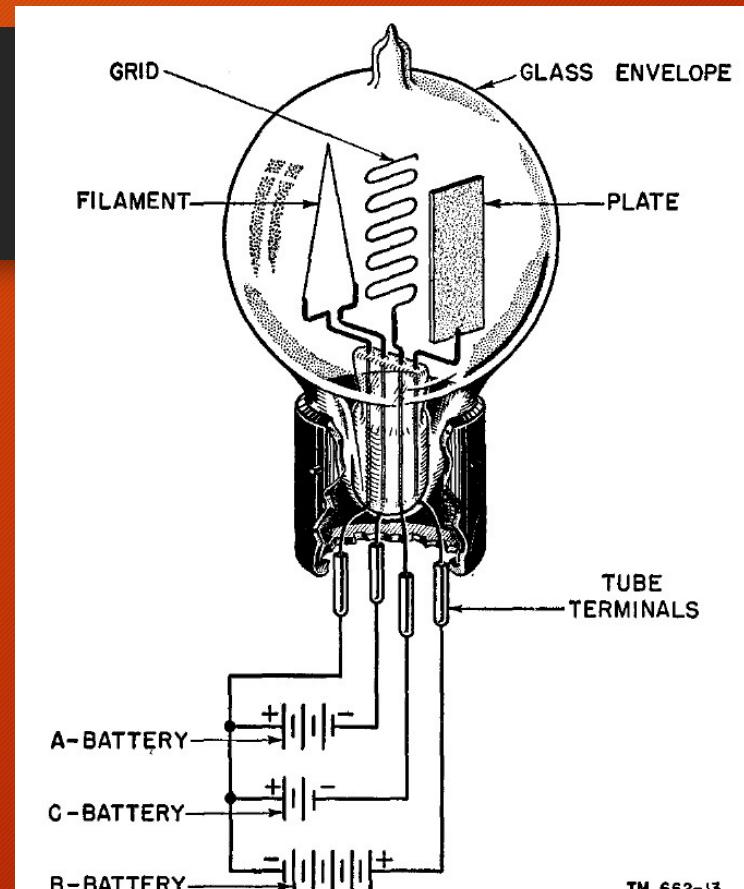
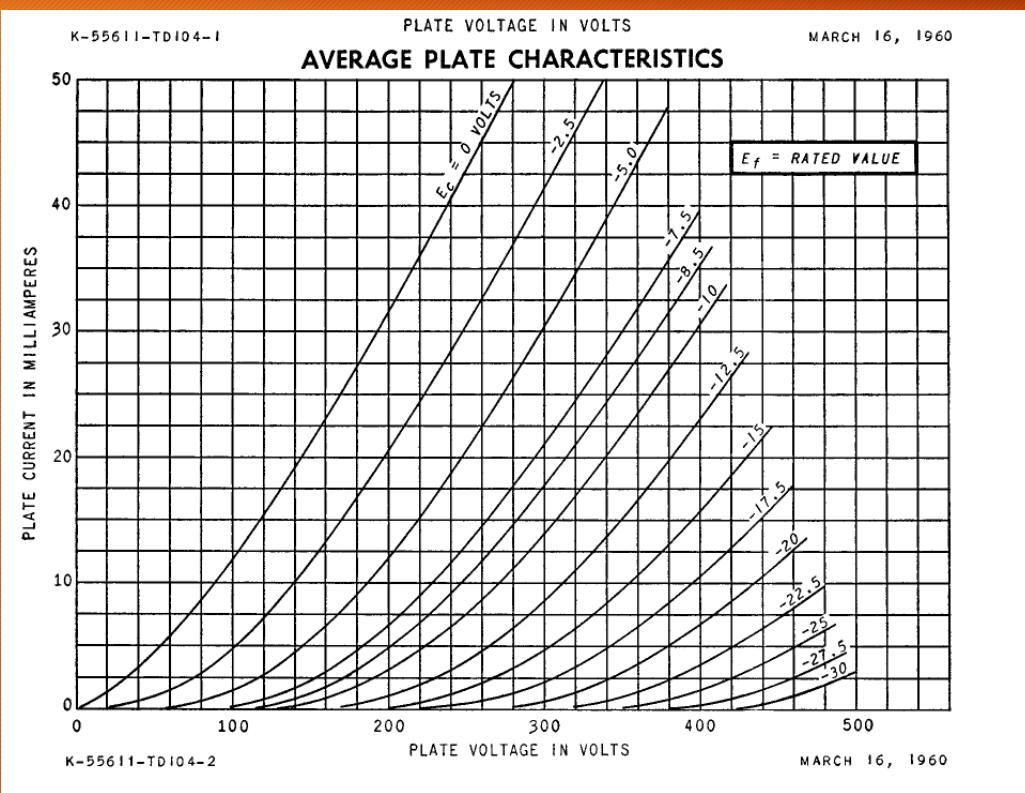


Figure 4. Construction of DeForest's three-element tube,
or triode.

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

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- 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

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Neutralizing Triodes

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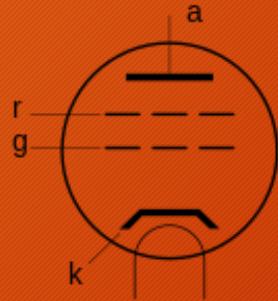
- To prevent the oscillation some of the output signal is feedback to the grid out of phase with the capacitance signal
- The feedback circuit is called a neutralizing circuit and the triode is said to be "neutralized"
 - Each tube and circuit, even of the same design, requires that the neutralizing 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.

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- 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

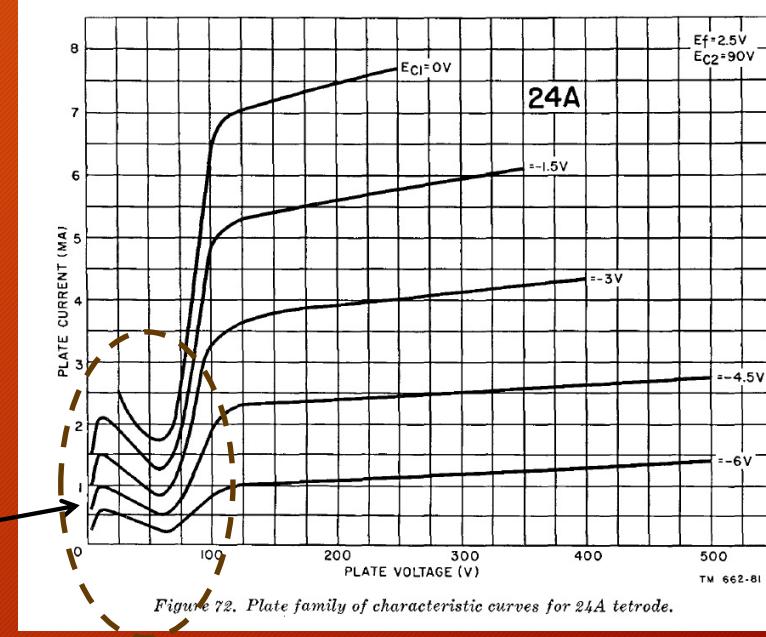


Figure 72. Plate family of characteristic curves for 24A tetrode.

Pentode

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- 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

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Voltage Regulator (Not a Vacuum Tube)

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- 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

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Multiple function tubes and Multi-section Tubes

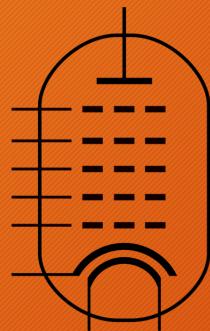
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- To make designs smaller and cheaper new tube types were developed:
- Multi function tubes
 - Pentagrid converter: A tube that performs the roles of oscillator and mixer in a receiver or transmitter has 5 grids
 - Some of the grids are used for the 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

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Schematic of Some Tubes

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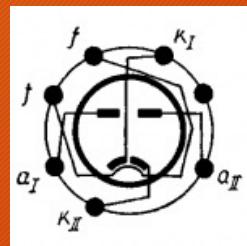


Pentagrid Converter

Used in radio receivers

Examples:

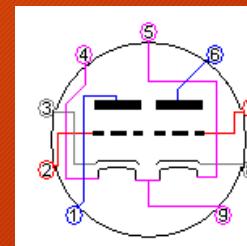
6BE6, 12BE6



Dual diode

Used to detect AM radio signals

6AL5



1. Anode Triode Number 2
2. Grid Triode Number 2
3. Cathode Triode Number 2
4. Heater (Triode 2)
5. Heater (Triode 1)
6. Anode Triode Number 1
7. Grid Triode Number 1
8. Cathode Triode Number 1
9. Heater Center tap

Dual Triode

Used in audio Amplifiers

12AX7, 12AT7, 12AU7

Transmitting Tubes

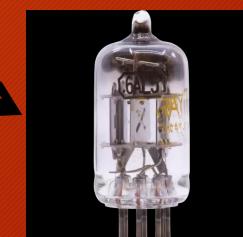
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- Some tubes are specially designed for High Power Transmitters
- Transmitting Tubes have their own numbering scheme
- Typically use Different tube bases than other tubes
- Are expensive
- Have limited life and are often replaced before they fail
-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

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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



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Labeling/Numbering of Tubes

- In the US, before standards, tube numbers were random
- The Radio Electronics Television Manufacturers' Association (RETMA) standardized most 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 ?

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- 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

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Where will you find tubes

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

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Some Example Circuits

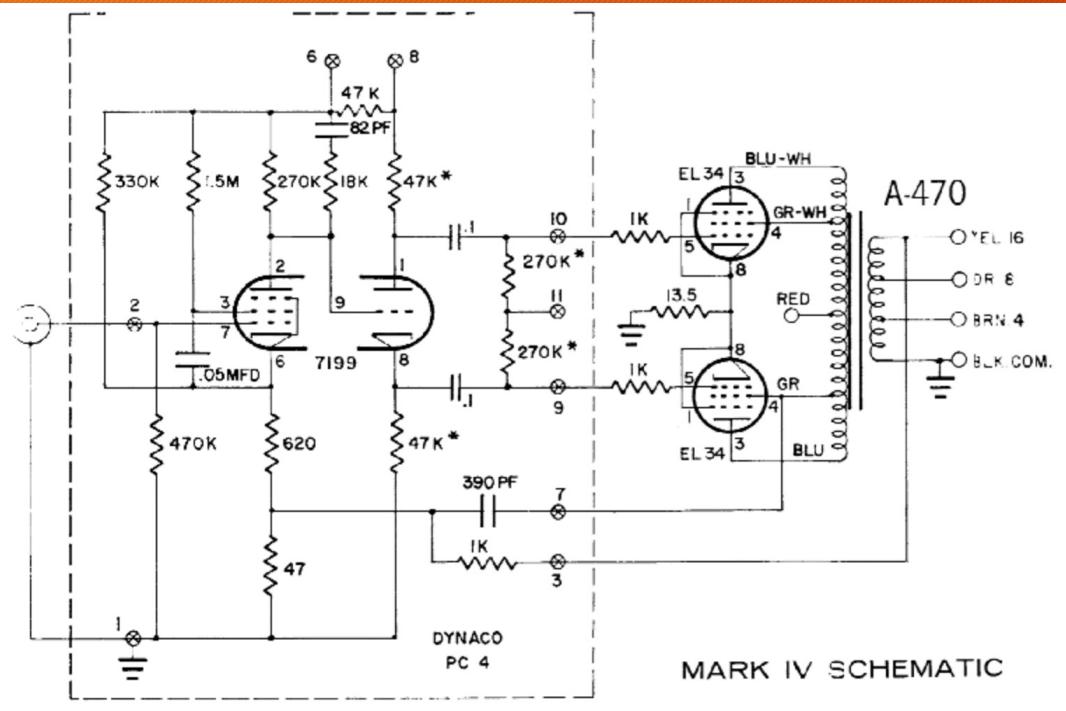
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Tube Amplifier

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

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- 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)

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Common Hi-Fi Amplifier Tubes

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Power Output

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

Amp and Pre-Amp

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

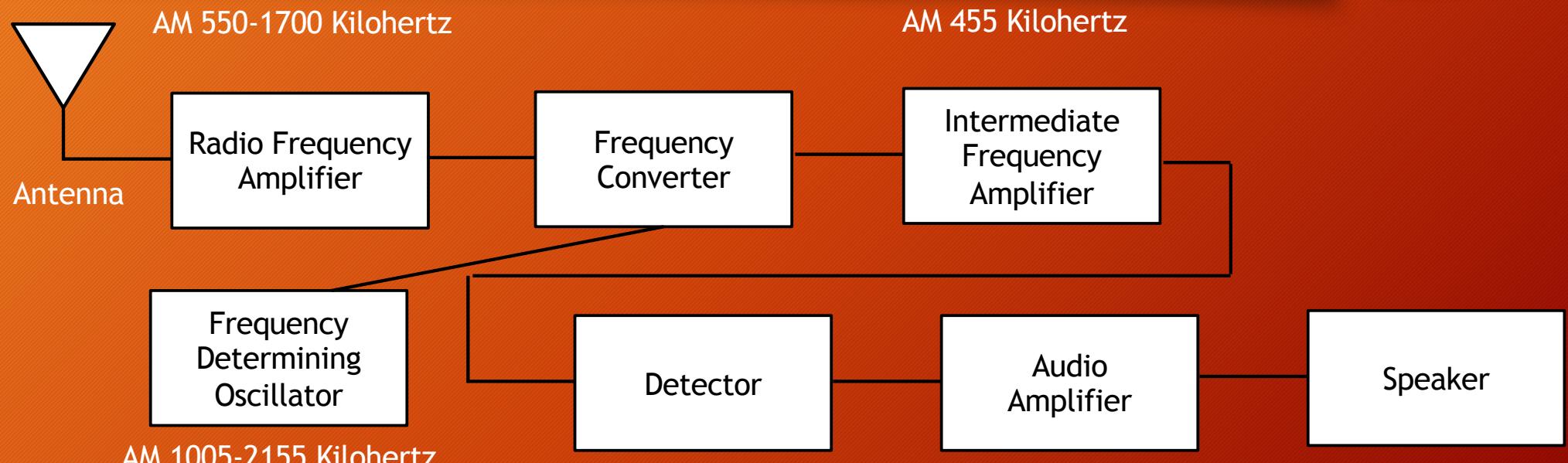
<https://www.thetubestore.com/power-tubes>

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

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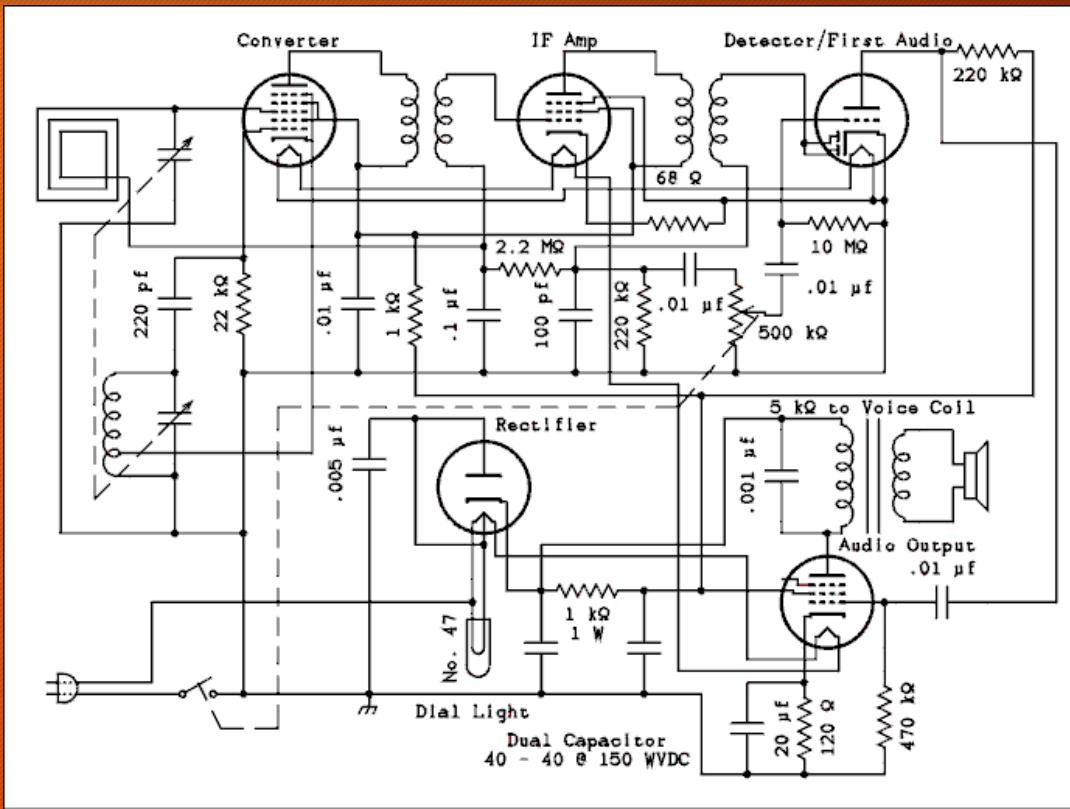
Traditional AM Radio Design 1918-2000s

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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



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Typical Tube line-up "All American Five" Radio

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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!!!

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See Safety Warning on next slide

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When working on OFF vacuum tube equipment

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Questions

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References

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- 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/>

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