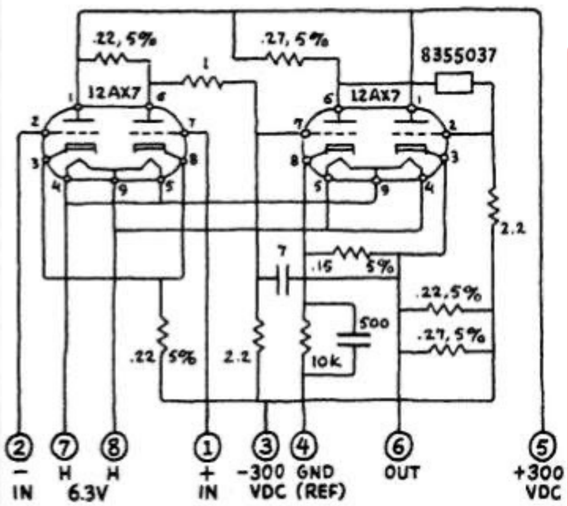
Lecture 6

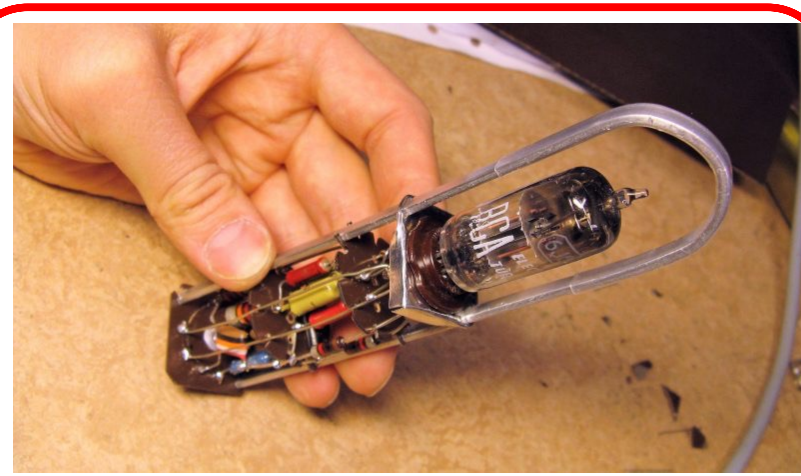
Tube and Early Transistor Electronics

We Did A Lot With Tubes

- Most modern designs started with tubes.



The first commercial Operational Amplifier



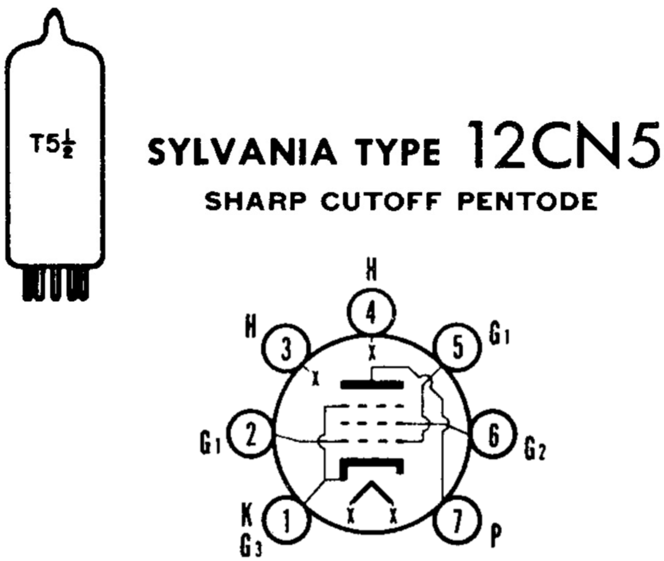
Triode-based Flip-Flop
From IBM 605

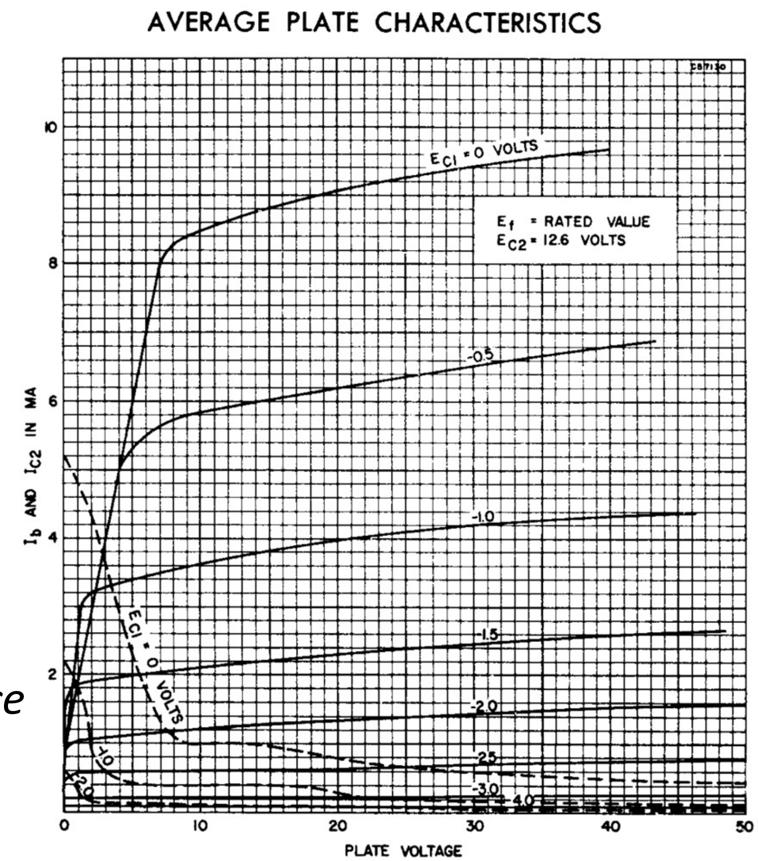
And many more…

https://www.talkbass.com/threads/tube-op-amps-experience-interests.1215611/

12CN5 12V Pentode Tube

- Use this in lab 05 and 06 to make an oscillator (Abraham Bloch circuit) and then an early op amp
- It acts *pentodic* at low voltages!





Convenient tube for us to use in class since it works at low voltages

The "soft-clipping"

- The fact that triodes **don't** transition very abruptly is one reason why people really assign "good" sound effects to triodes.

- They tend to not "clip" as hard because they very gradually turn on and off at the extremes of their operating range whereas pentodes (And later transistors) have very clearly defined ON/OFF regions

Conclusion

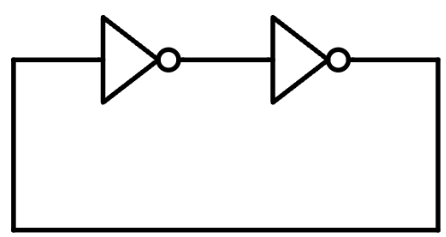
- Triodes Make Lousy Switches *especially when we are running them in low voltage starvation mode*
  - You can get that behavior out of them with the right conditions, but they are not very good “switching”-style amplifiers because of their I-V relationships

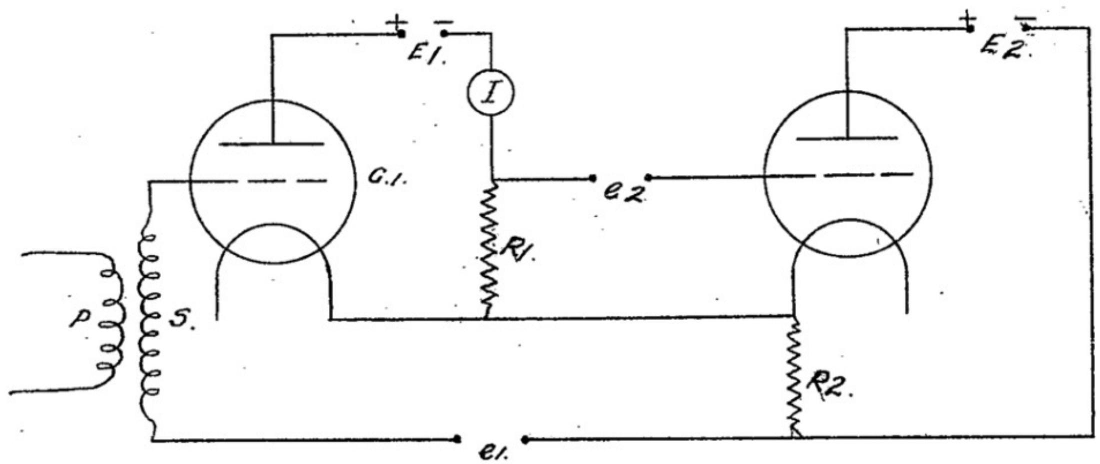
- Pentodes, on the other hand can be pretty good switches if you can position your bias point operation so that you’re jumping between the two regions of operation

The Bistable Multivibrator

- This was also discovered/developed right around 1919 by Eccles and Jordan
- Originally termed "trigger circuits" but they eventually became known as flipflops

Essentially just two NOT gates

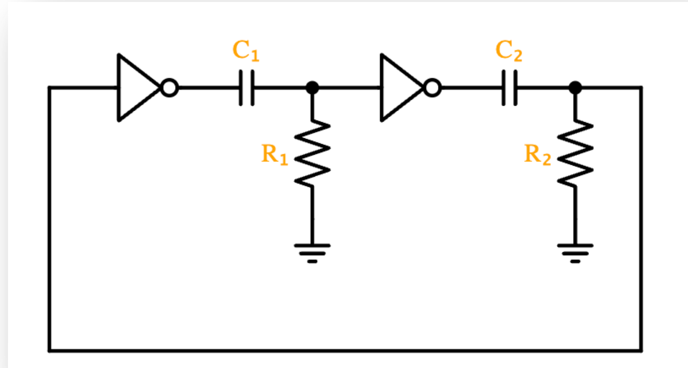


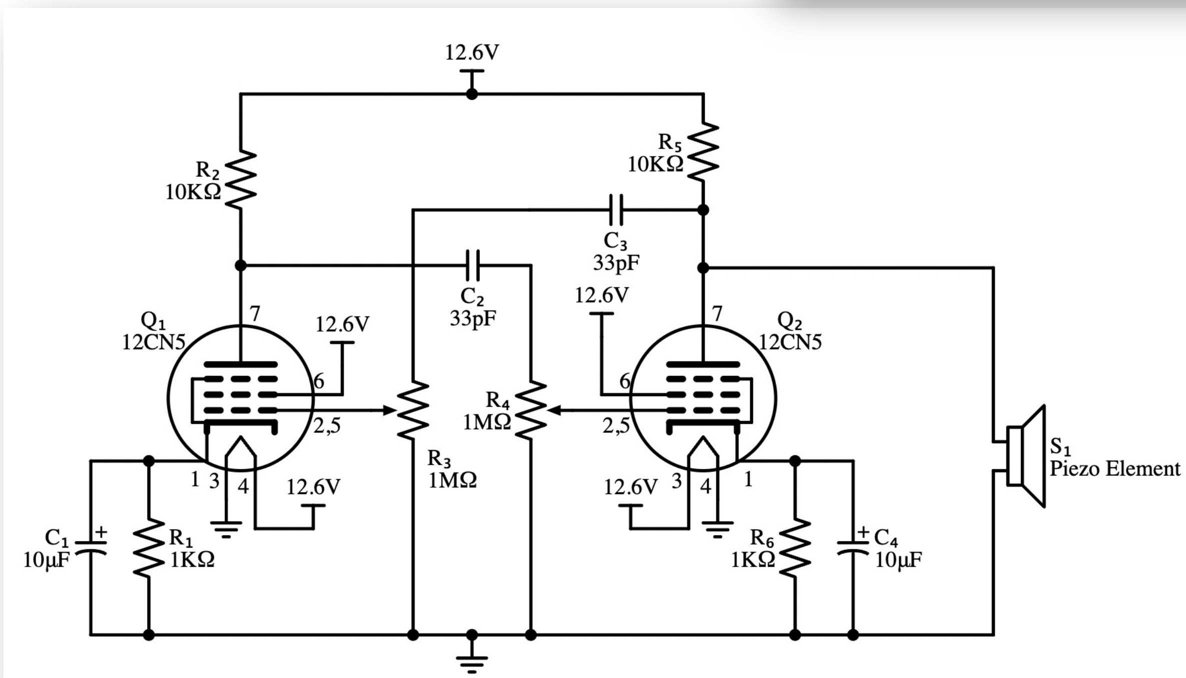


The original Eccles Jordan

Abraham Bloch Circuit (Lab 05)

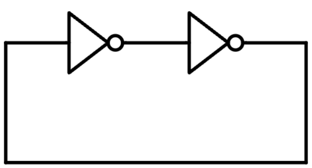
- Two inverters connected with high-pass filters...inherently unstable
- Will oscillate

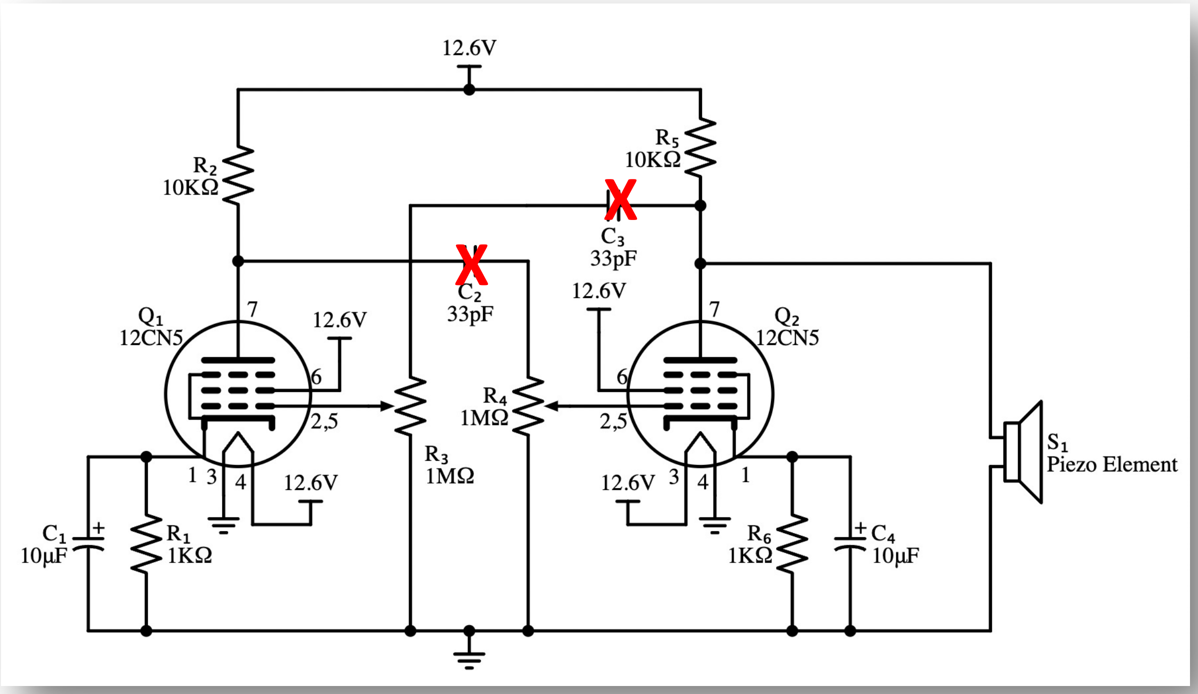




The Eccles Jordan Circuit

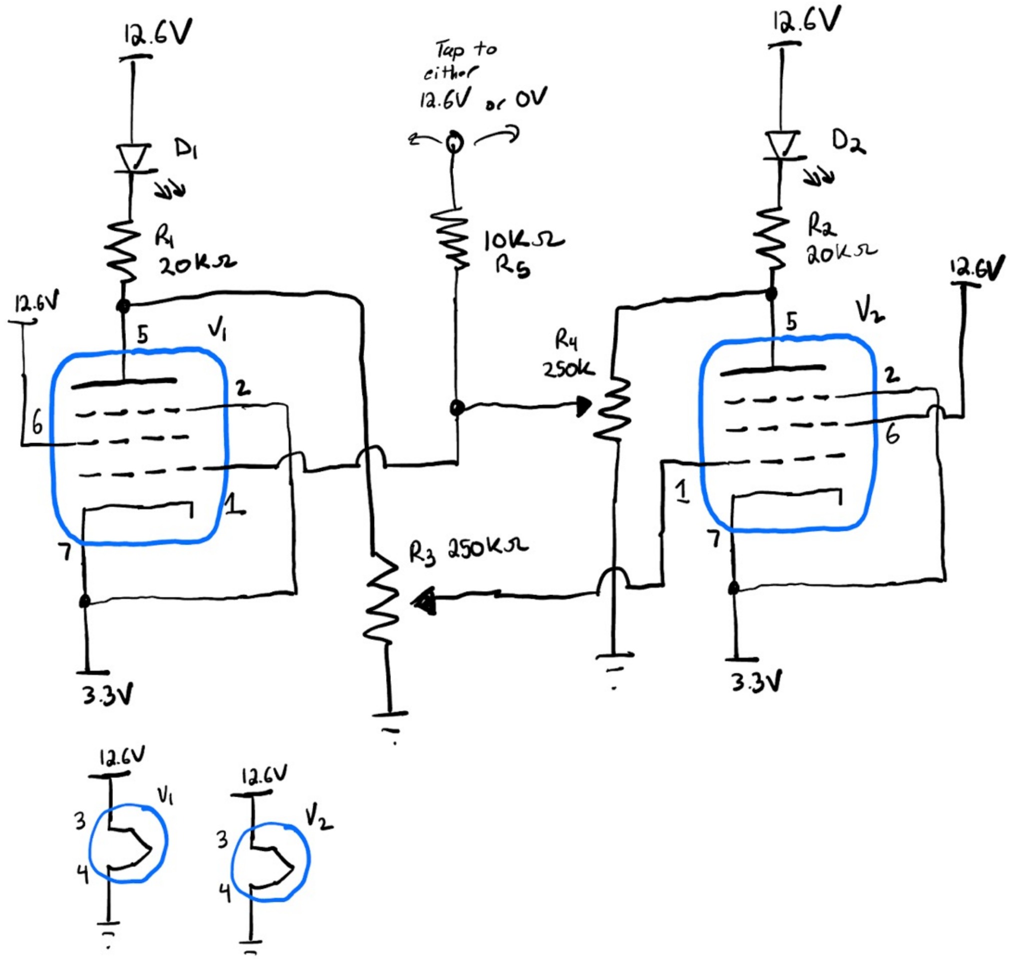
- Almost the same as the Abraham Bloch circuit just replace the capacitors with wires which introduce the high-pass–filter behavior...that allows the circuit to have two long-term stable positions instead of none (which causes the oscillation





Instead we'll Build the Flipflop with Pentodes

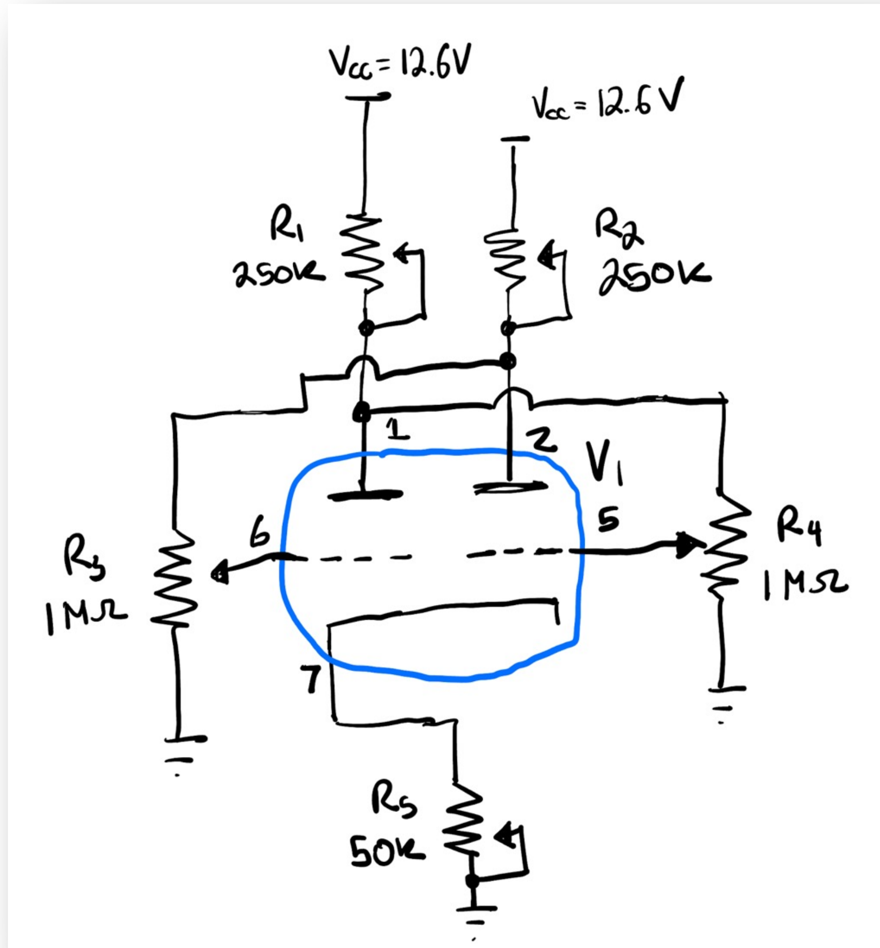
- Using the 12CN5 tubes you can in fact make a 12V stable flip flop



Sorry didn't lay this out in my pretty schematic drawing software

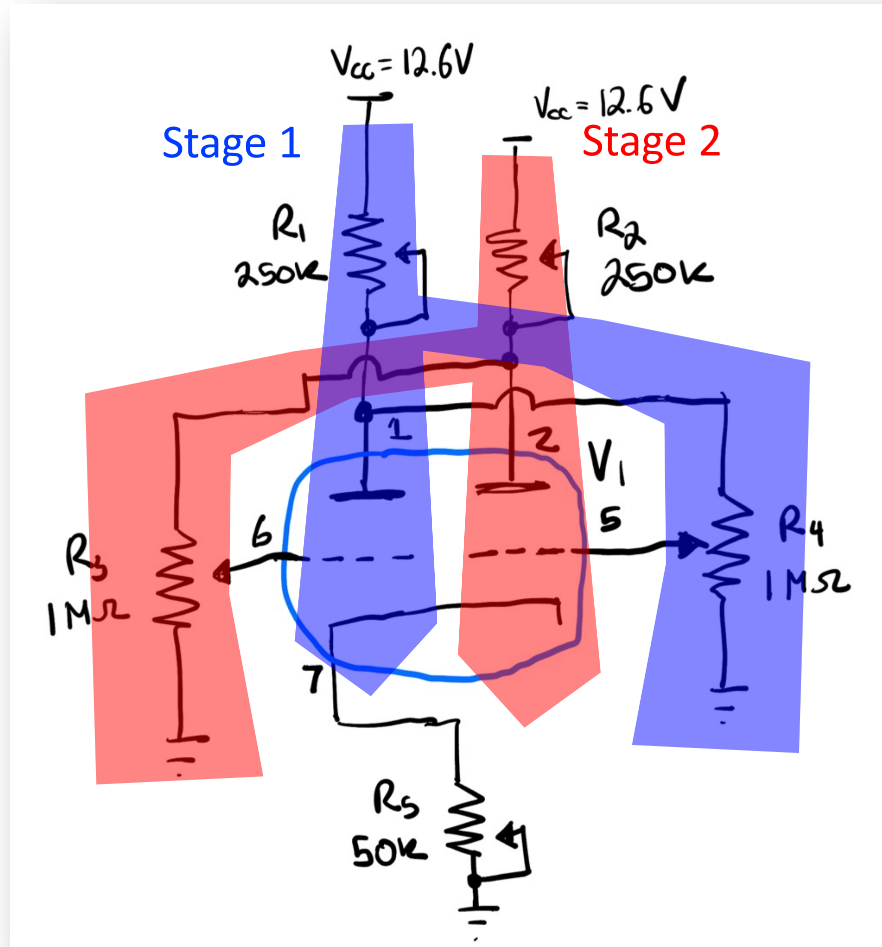
Can we do this with our Triodes?

- Could we make a bistable flip-flop circuit using just a triode?



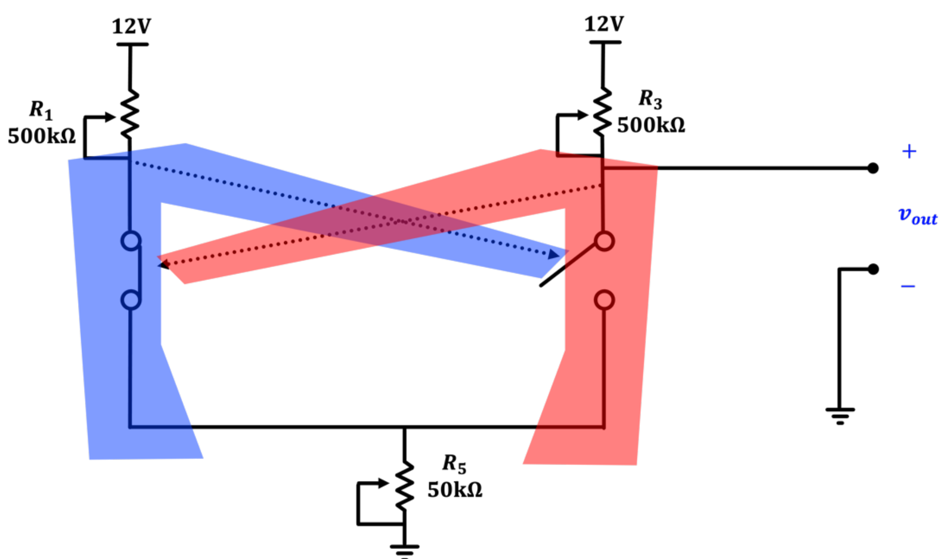
In theory should be relatively easy to implement something like this:

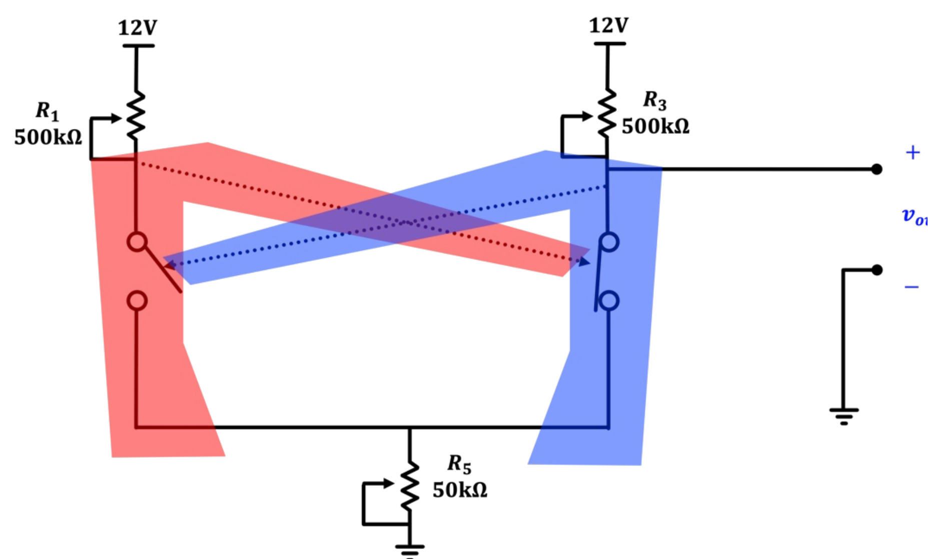
The "high" output of this stage 1 provides a "high" output to stage 2 which causes stage 2 to have a "low" output which is a "low" input to stage 1…which…



A Bistable Circuit

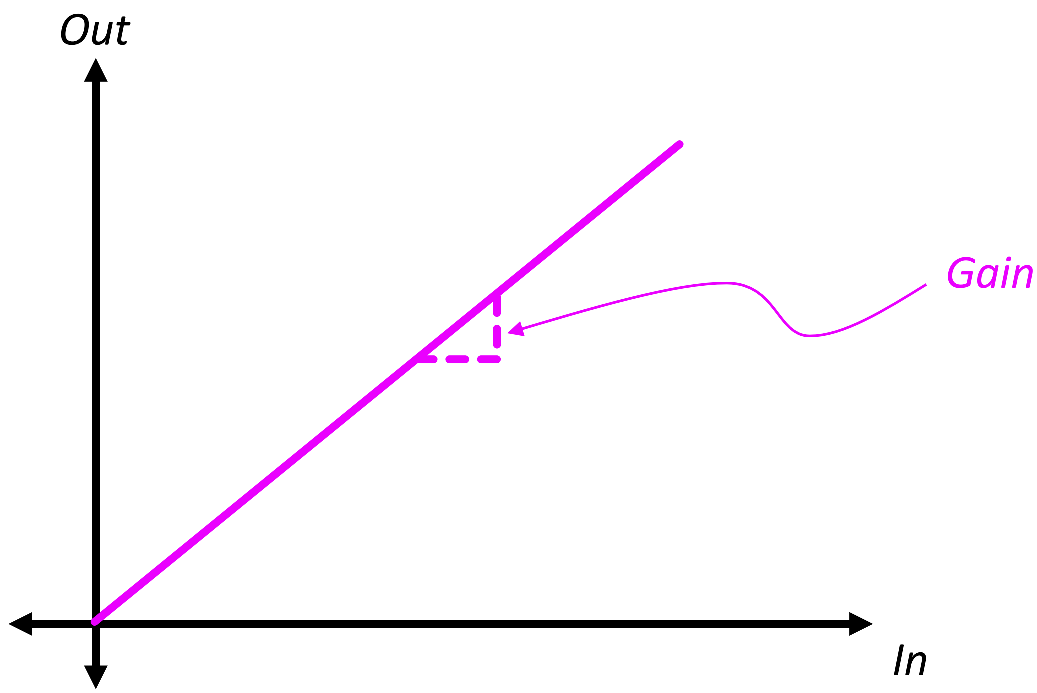
- In order for a Bistable circuit to work reliably the active devices need to act more “switch-like” than “amplifier-like”.
- Doing so will give a much cleaner behavior that’s also more digital:





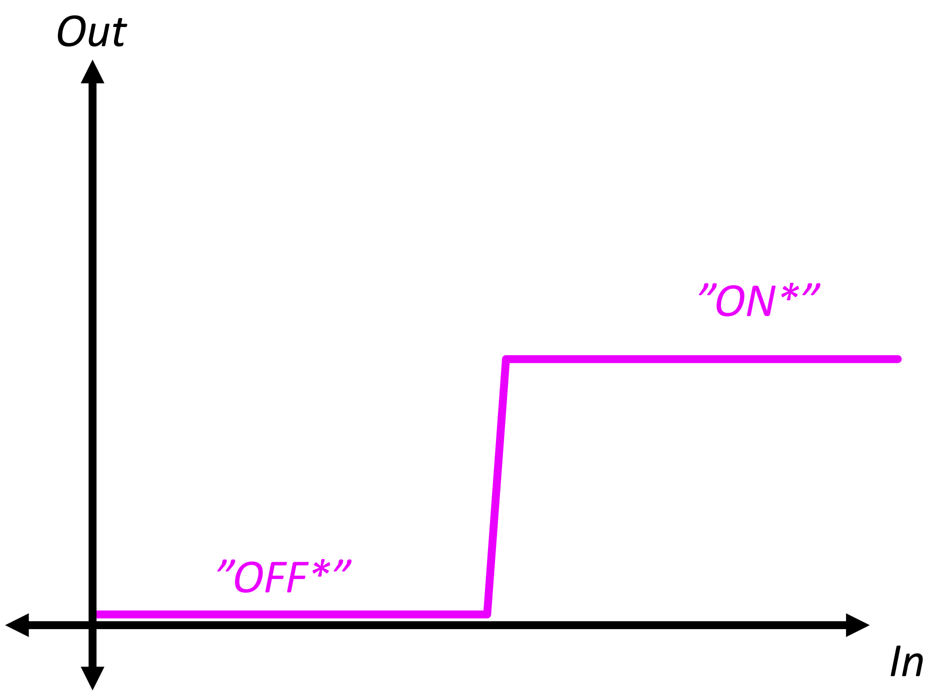
For a Analog Amplifier…

- We generally want a nice, linear in/out relationship
- Ideally the In/Out relationship is predominantly linear



For a Digital Amplifier…

- We want an amplifier that is over-driven and/or saturated
- Something that clips ideally at both ends of its extremes
- Something that is best described by an if/else or piecewise function

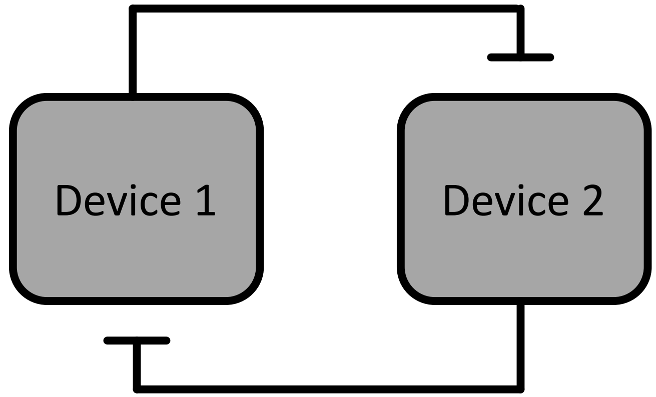


- In the case of a flip-flop we really want something to work that way
- The more non-linear, the better and more stable it will be

** Or some other descriptive name*

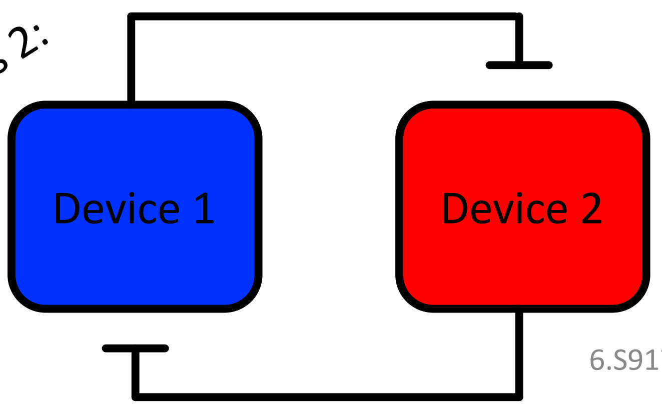
A Jordan-Eccles Circuit (Bistable Flip-flop)

- Built around the idea of two active (amplifying) devices mutually suppressing one another.

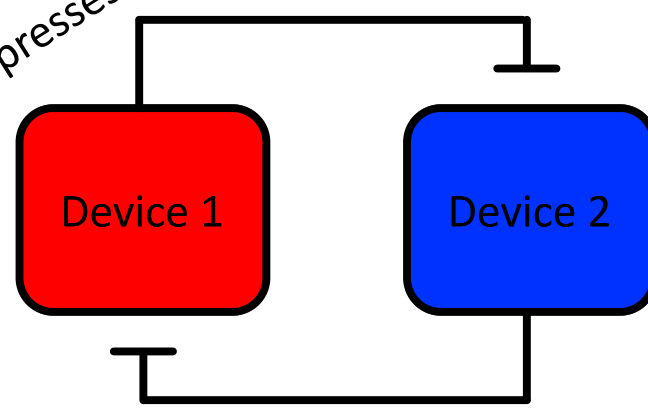


- When tuned, the circuit will stabilize to one of two operating points:

1 suppresses 2:

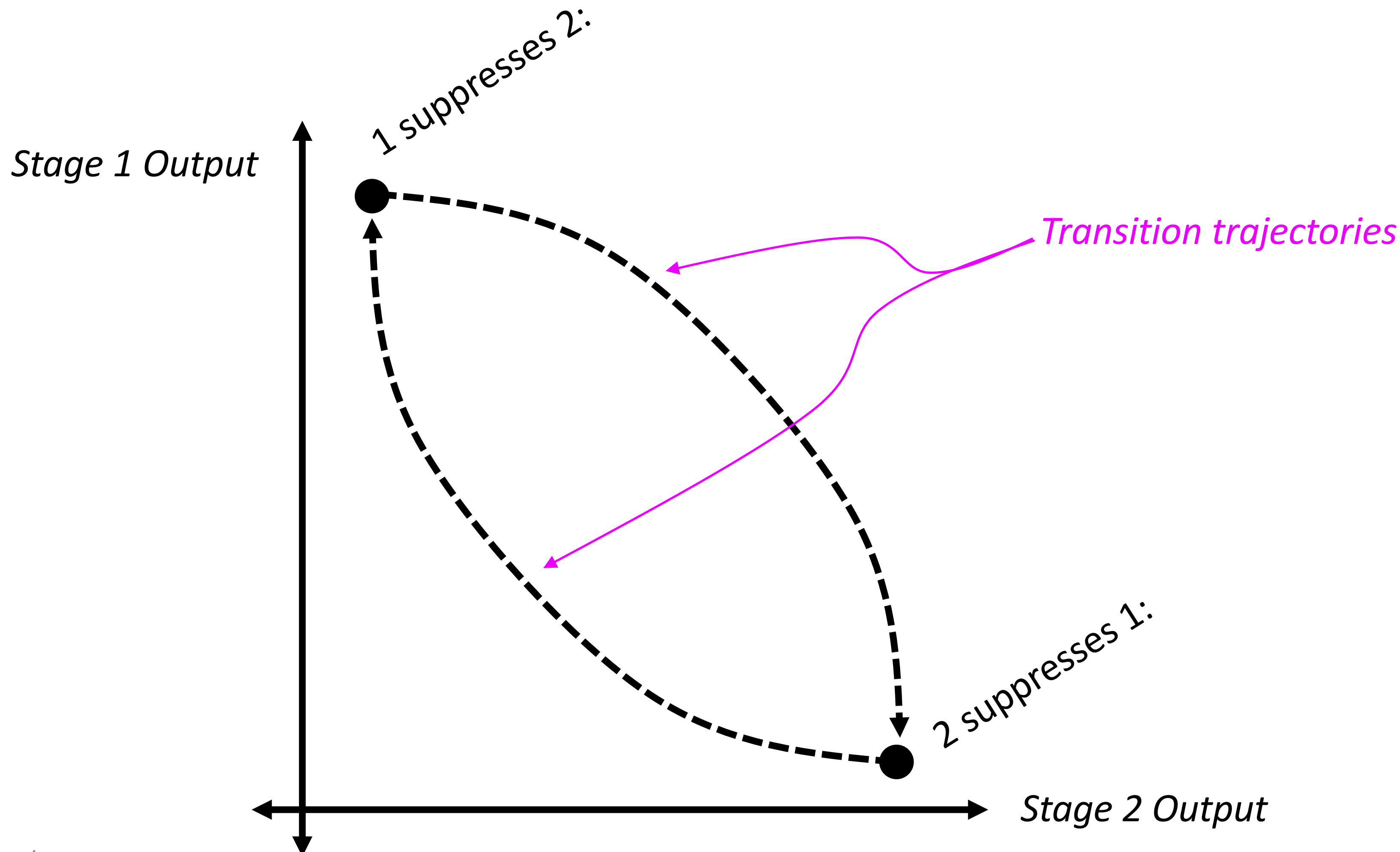


2 suppresses 1:

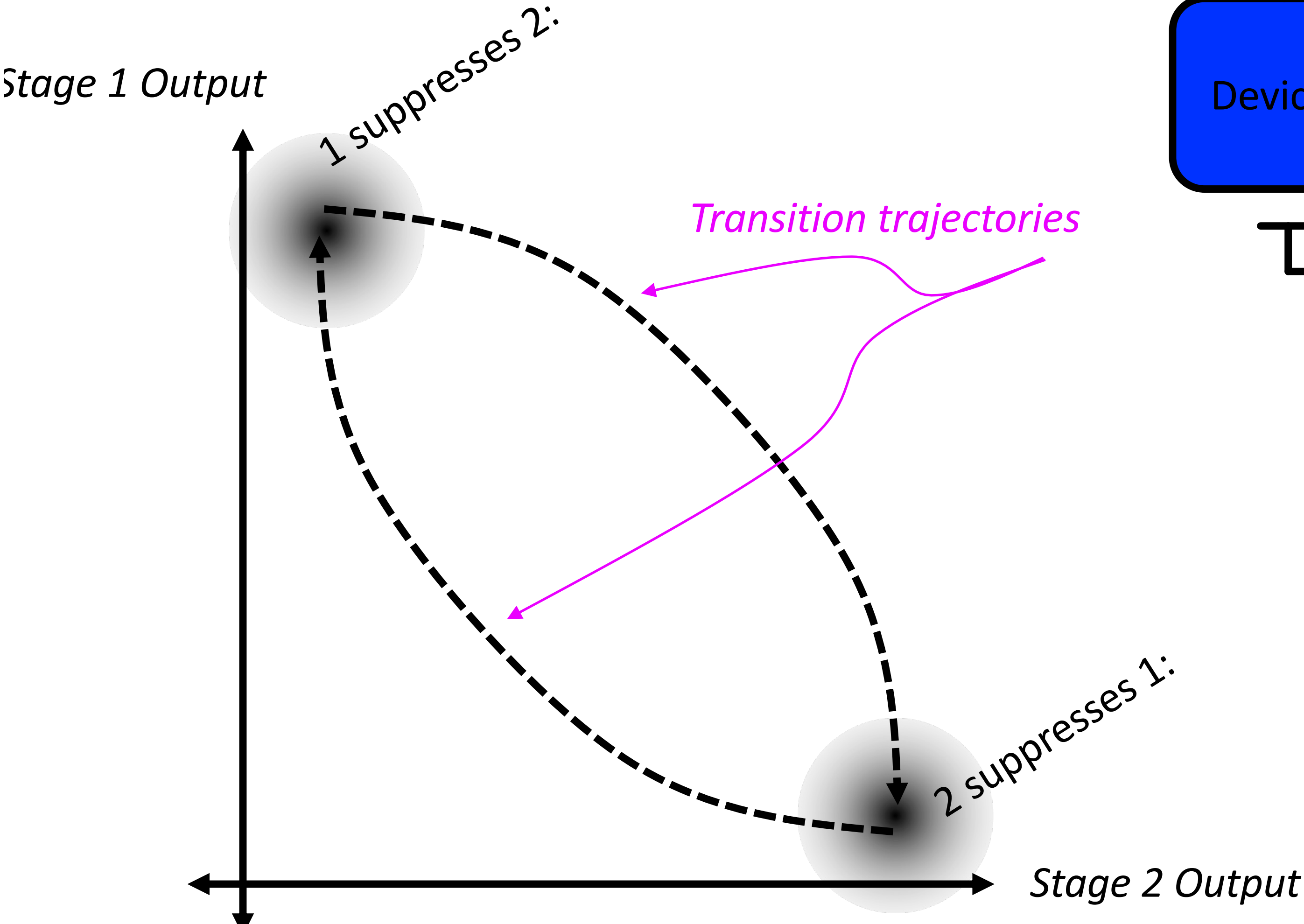


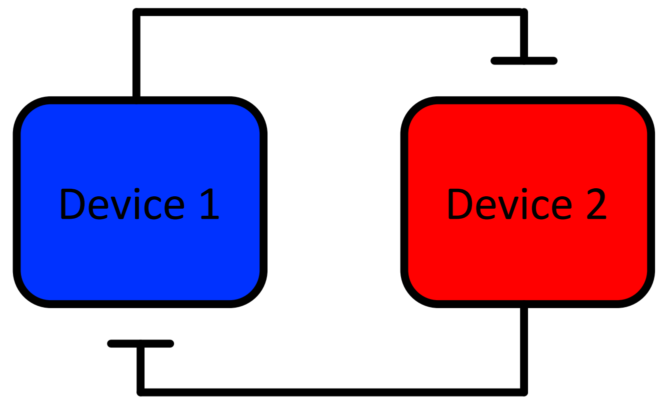
Map of Stability

- If the two sides can turn on/off very sharply, you can get a very clear map of two stable points

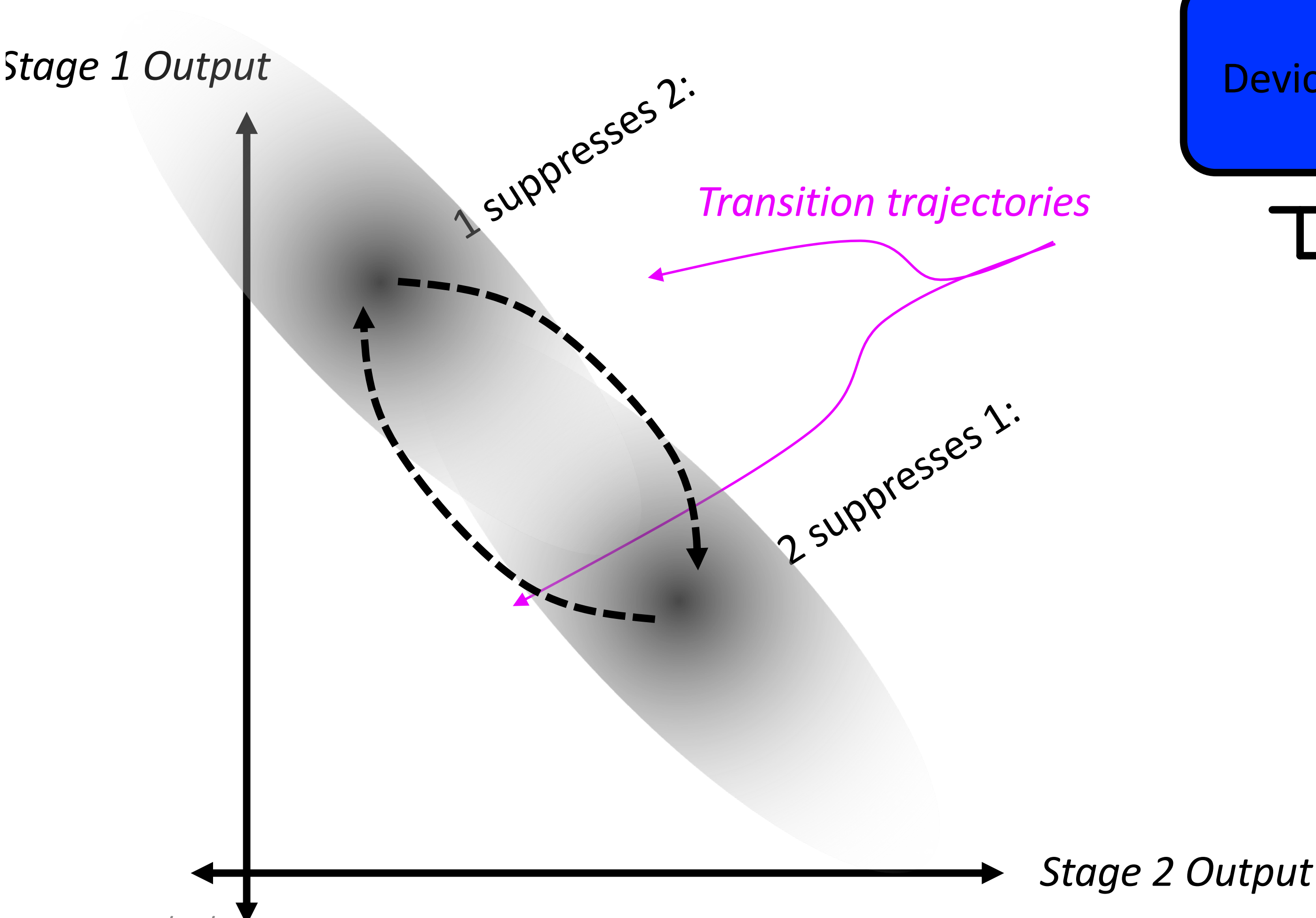


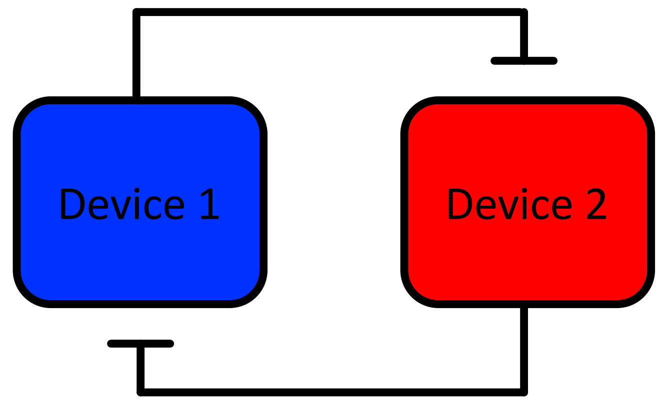
The Less Switch-Like Our Amplifiers Look, the Less Ideal Our Stability Map Will Become…



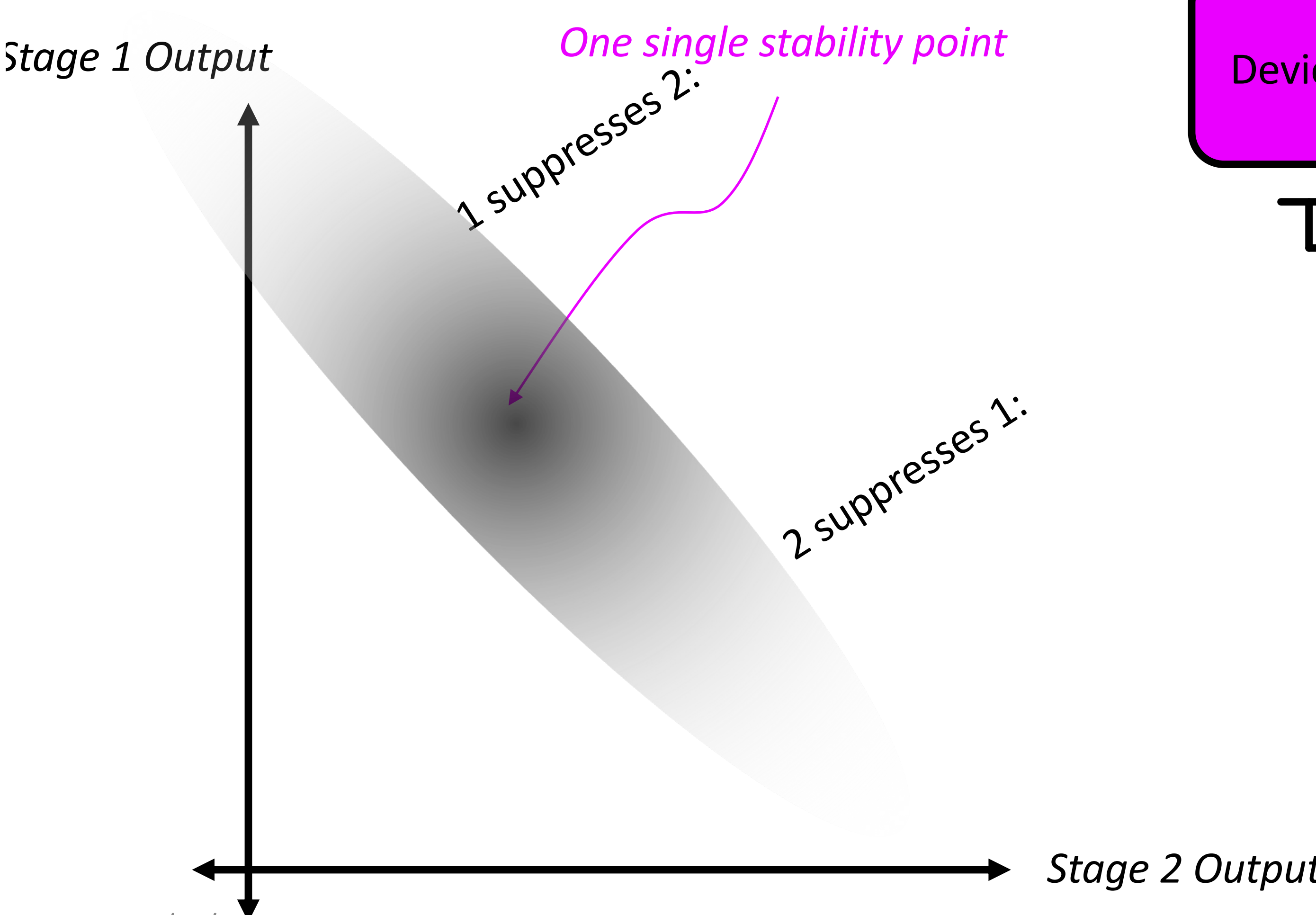


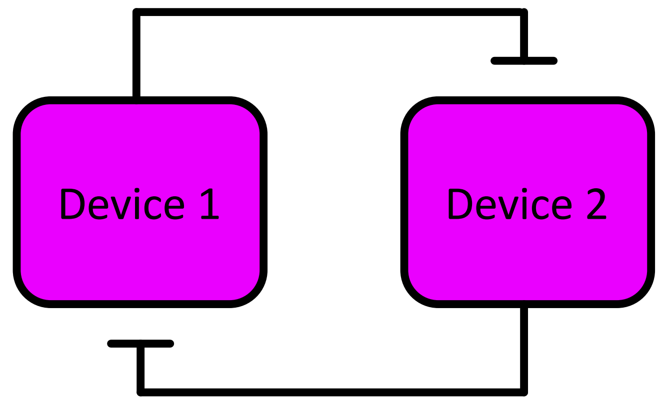
If Our amplifiers *really* can't act like switches, then…





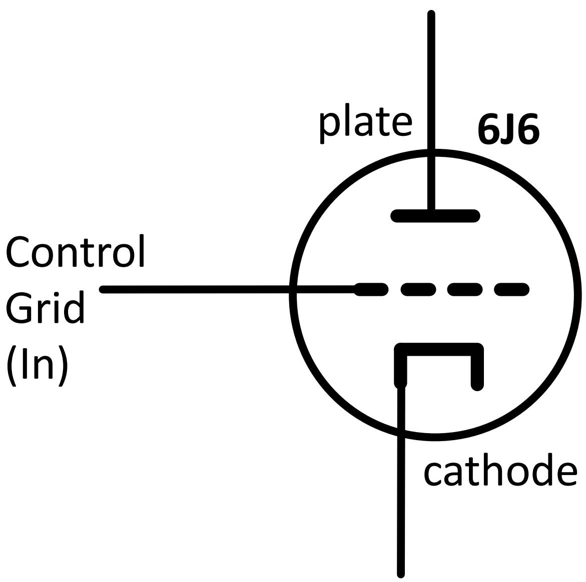
If Our amplifiers *really, really* can't act like switches, then…

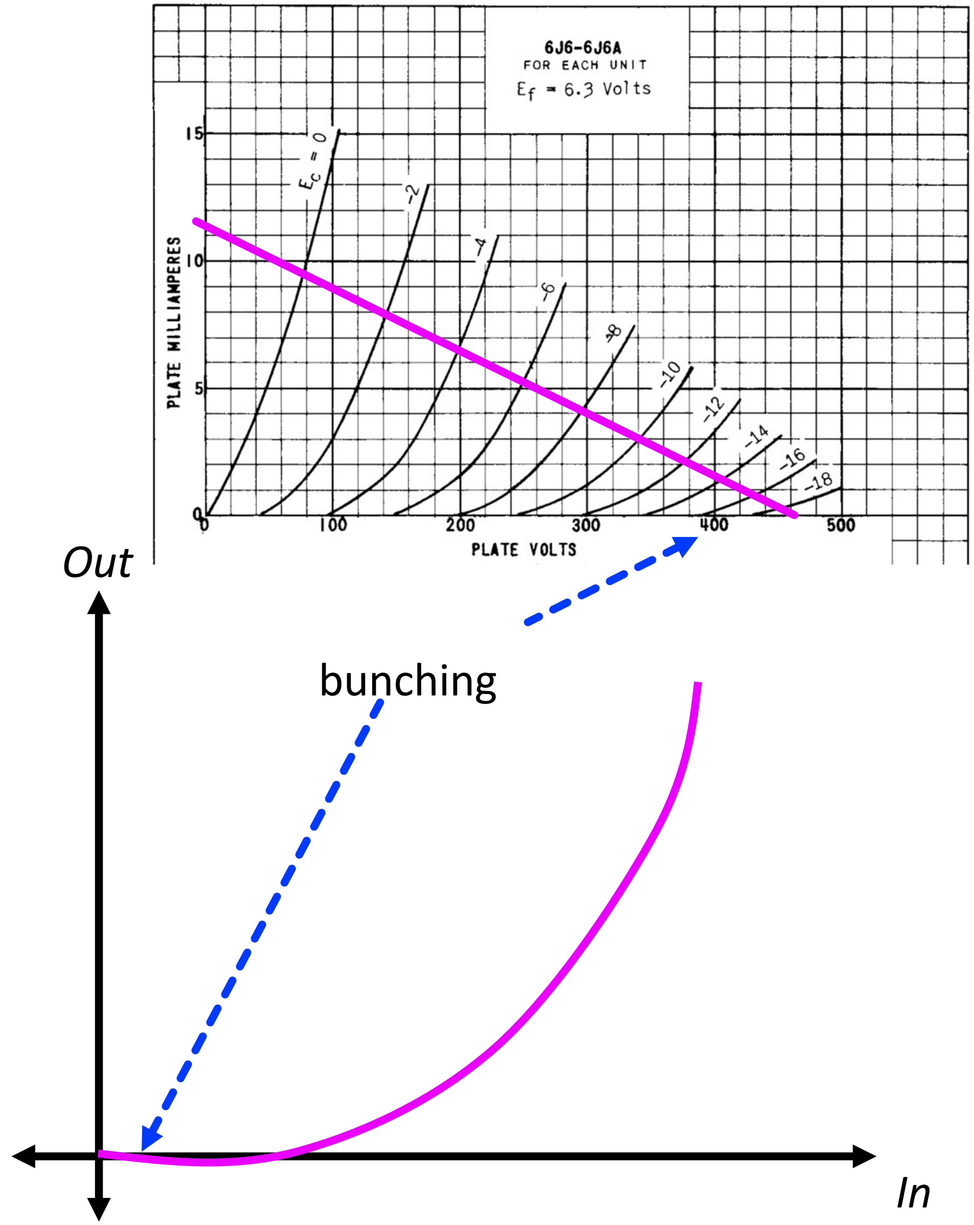




So...Can Our Amplifiers Act as Switches?

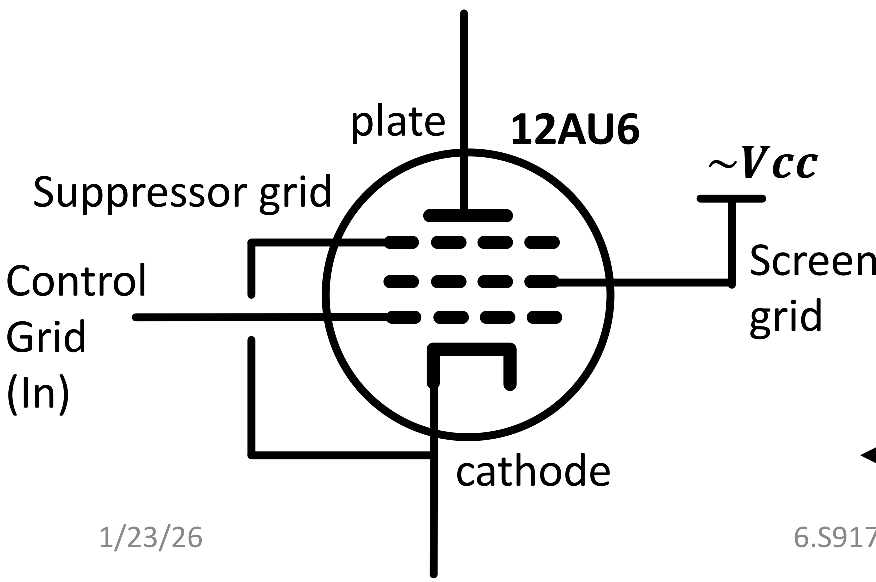
- Consider the ***Triode***:

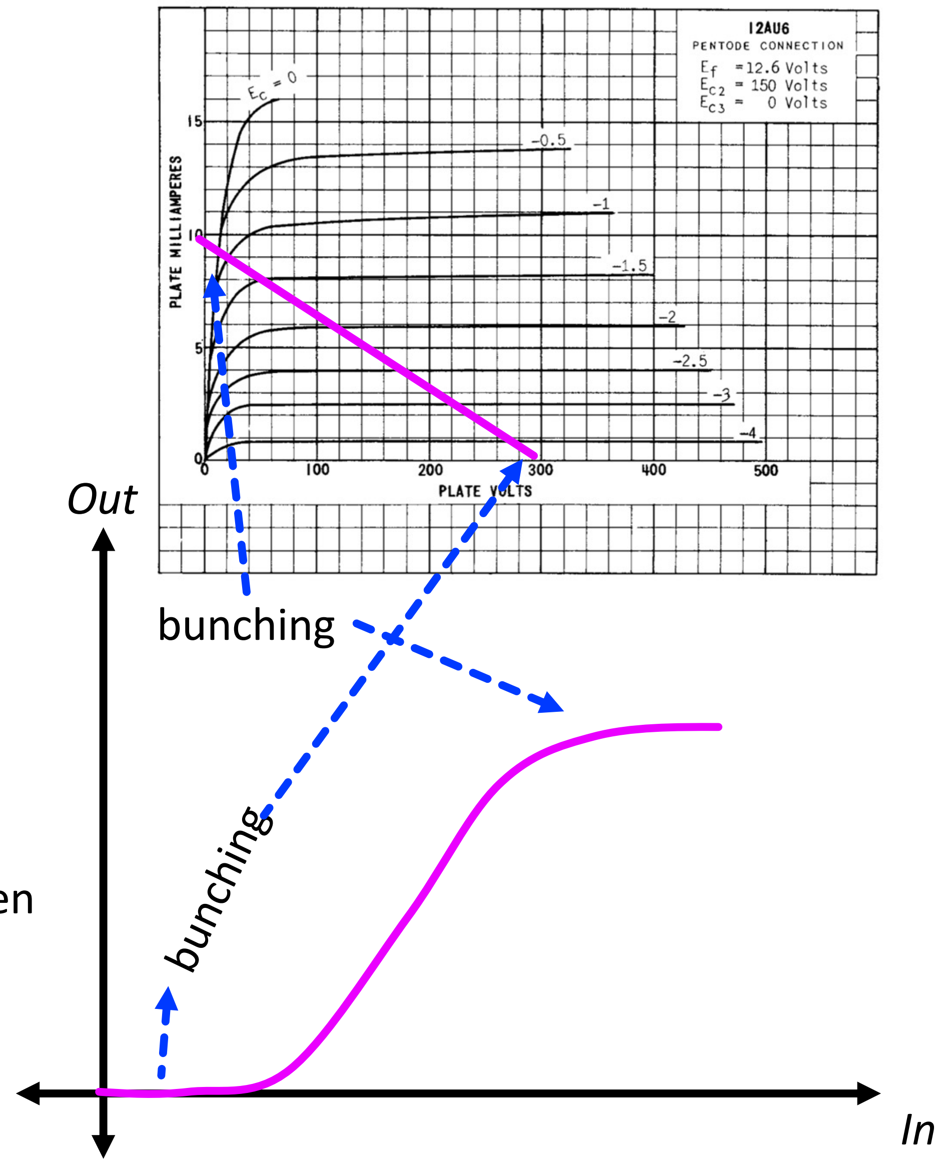




Can Our Amplifiers Act as Switches?

- Consider the Pentode
- Originally developed to fix Miller Capacitance.
- In the Process we got new I-V relationships for our output terminals

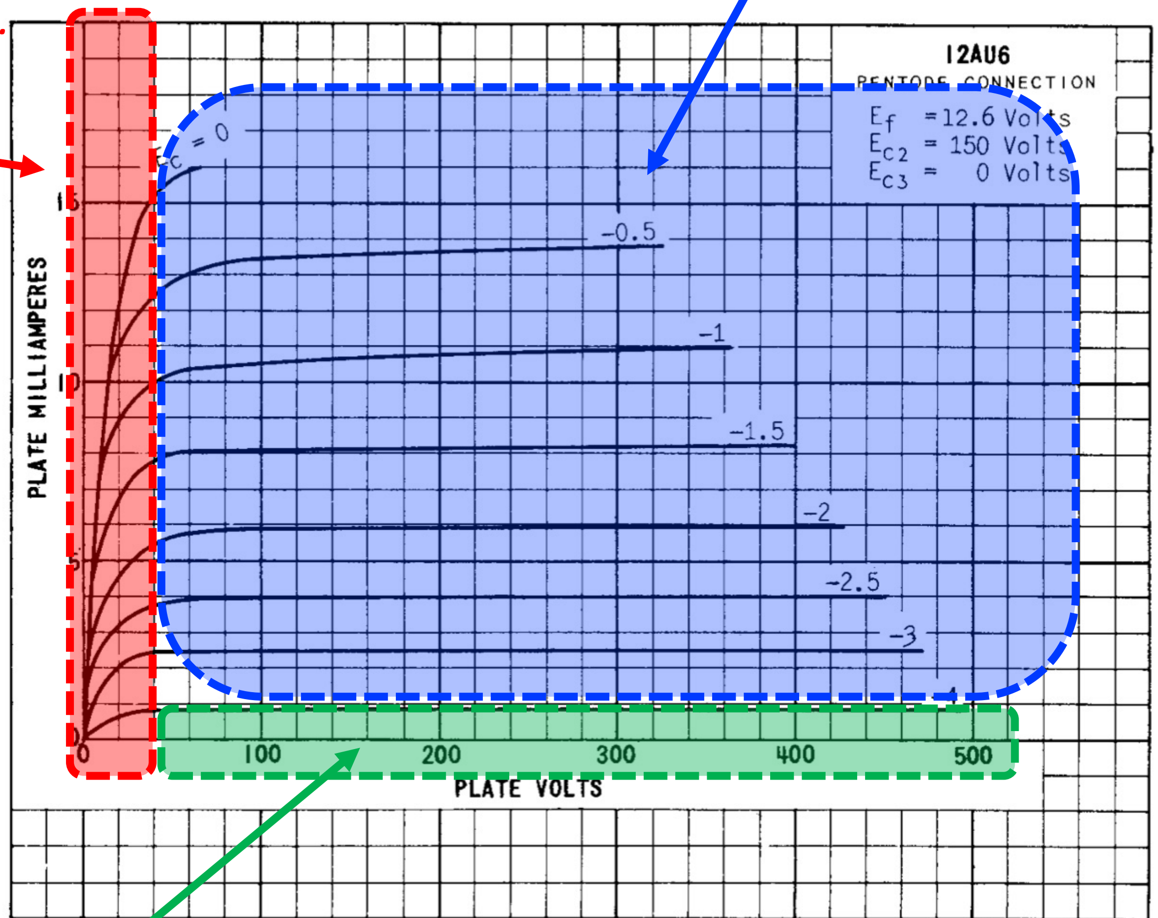




Pentode Curves

Current varies with voltage quite cleanly
Good for regular amplifiers

Very steep I/V relations…
like a low-Ohm resistor…
or a wire…
Or a closed Switch!



Almost no I for any V
like a high-Ohm resistor…
or an open…
Or a open Switch!

Triodes Don't Give Us Much in the Way of Abrupt Changes in their behavior

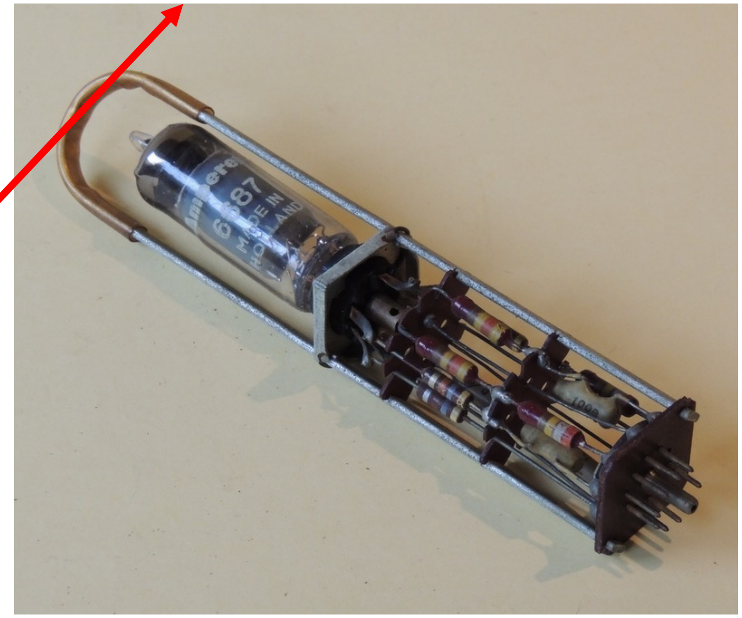
Beyond that we get these sort of diagonal lines which gradually evolve from infinite ohms to less and less ohms.
Fine for regular linear amplifiers maybe. Not really switch-like

*Triodes **do** have a cutoff range where if grid voltage below threshold, no current flows*

Almost no I for any V like a high-Ohm resistor… or an open… Or a open Switch!

IBM

- Early Flip-Flop circuit
- Notice the voltages (we don’t got those :/ so tube is working a lot less ideally)
- They used about 1500 of these modules for the FFs in an early IBM computer



1950s tube flip flop

http://www.calculatormuseum.nl/calculators/computers_IBM701.html

Interesting…

- The two-tube multivibrator can either:
  - oscillate for us (very nice)
  - Sit in one of two states for us (also very nice)
- Why is that second one very nice?

- Because it can remember!
- You pull one grid low and then remove it, the circuit sits in one position
- You pull the other grid low and then remove, the circuit sits at the other position
- We can use these positions to store 1 bit

Interesting…

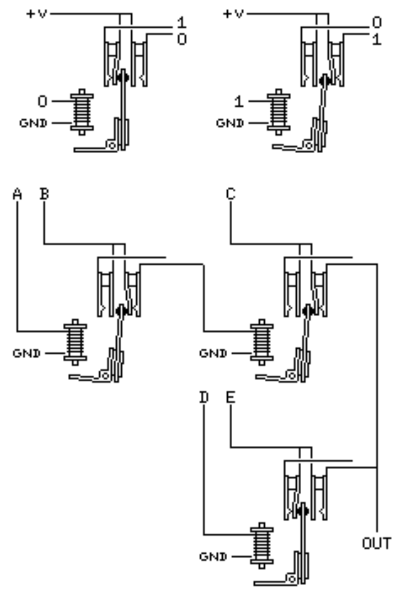
- The first computers weren't until the 1940s so we're jumping ahead a bit, but all throughout the 1920s and 1930s, tube circuits like this were used to gradually build up Computer Theory.
- A very insightful line in Claude Shannon's 1948 paper (where he introduces the "bit") finally links together formally memory and hardware (I feel shivers when I read this):

"A device with two stable positions, such as a relay or a ***flip-flop circuit****, can store one bit of information. N such devices can store N bits, since the total number of possible states is* 2^N *and* $\log_2 2^N = N$*."*

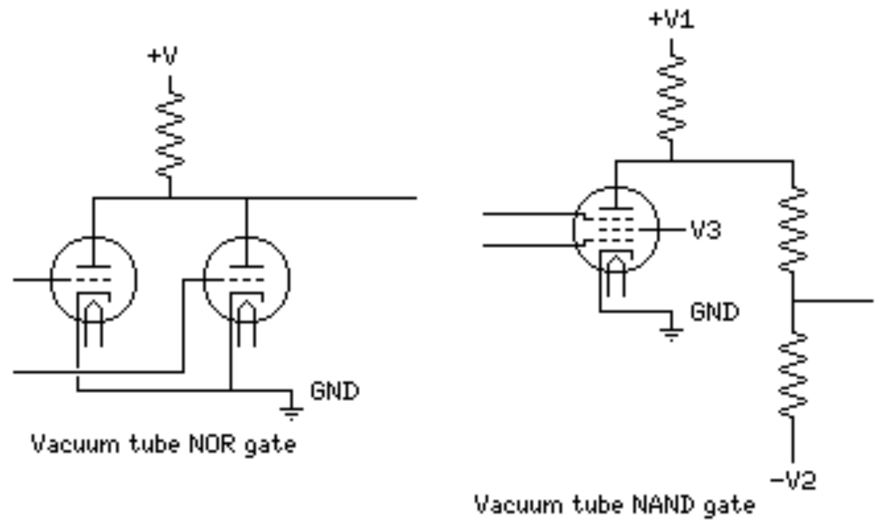
-Claude Shannon, 1948

Combine those FlipFlops with the ability perform Boolean logic operations

- Using either relays or vacuum tubes make some logic:



Relay Logic Gates like you built in Lab 01



Vacuum Tube Logic Gates
(Can be done with triodes at high voltage...or low voltage pentodes if their ”shoulder” is low enough)

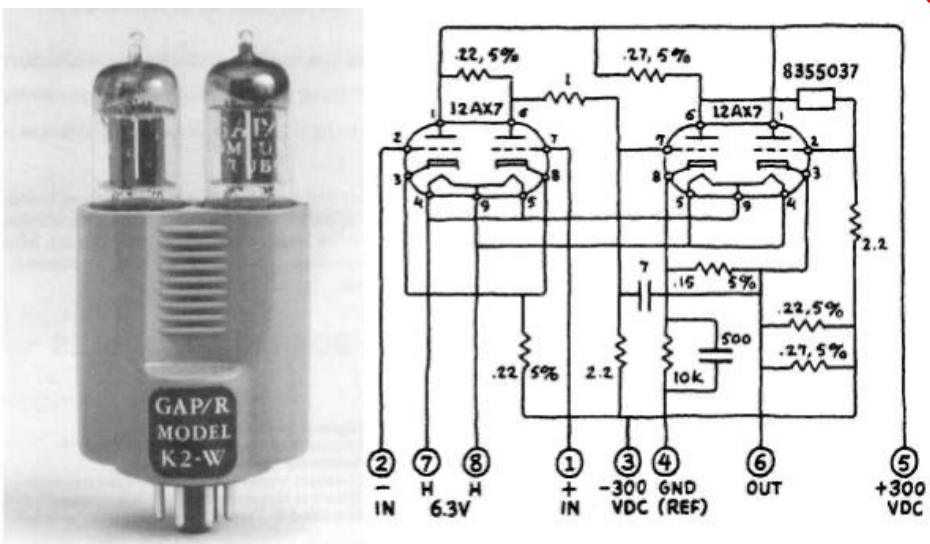
http://www.quadibloc.com/comp/cp01.htm

If you can make NAND (or NOR)

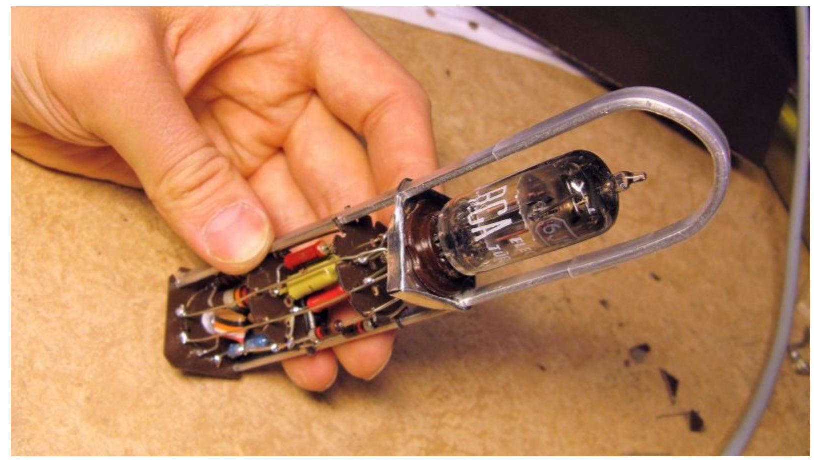
- **Any** Boolean logic expression can be reduced to either the following shape:
  - $Y = \overline{A|B|C| \ldots}$ *(which is a NOR)*
  - *OR*
  - $Y = \overline{A\&B\&C\& \ldots}$ *(which is a NAND)*
- With the ability to remember bits and the ability to perform logic operations of any type you can now start building **finite state machines**.
- With access to sufficient memory/instructions, this is easily expanded to full-fledged computers!!!!

We Did A Lot With Tubes

- Most modern designs started with tubes.



The first commercial
Operational Amplifier



Triode-based Flip-Flop
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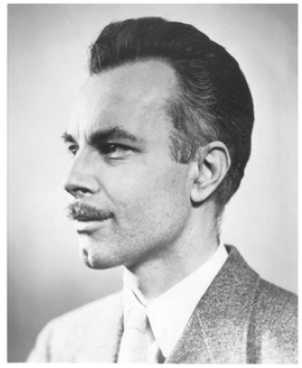
Op Amps

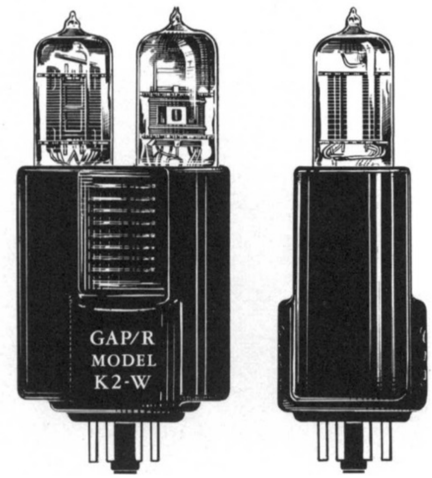


ELECTRONIC ANALOG COMPUTING INSTRUMENTS

Model K2-W Operational Amplifier

GAP/R MODEL K2-W

- The idea of op amps was formalized right towards end of WW2 (1945-1950)
- George Philbrick developed op amps and sold tube-based ones right out of Cambridge/Boston in mid 1950s
- Building block of much modern analog circuitry

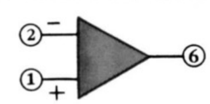


Model K2-W is the same operational amplifier, engineered and designed into this compact form, that has proved so successful in the Philbrick Analog Components. Using these plug-in units as basic subassemblies, feedback computing devices of all speeds may be assembled with only the simplest of wiring. The versatile K2-W is already serving in widespread applications. It features balanced differential inputs for minimum drift and maximum utility, and embodies both high performance and economy of operation in one unit.

This type of high gain amplifier, with appropriate feedback connections, maintains the two inputs at a nearly equal potential. Such properties give rise to a large number of operational applications.

Among the many feedback operations which the K2-W will readily perform are: addition, subtraction, integration, differentiation, multiplication, division, inversion, impedance-conversion, and the injection of current.

OPERATIONAL SYMBOL



BASE PIN CONNECTIONS

1: Pos. Input
2: Neg. Input
3: Minus 300VDC
4: Ground
5: Plus 300VDC
6: Output
7 & 8: Heaters, 6.3V AC or DC

GENERAL SPECIFICATIONS

GAIN:
15,000 DC, open-loop
POWER REQUIREMENTS:
4.5 Milliamps. at +300 VDC
4.5 Milliamps. at −300 VDC
0.6 Amperes at 6.3V
TUBE COMPLEMENT:
2 12AX7
BASING: Octal plug
CASE: Black plastic, molded

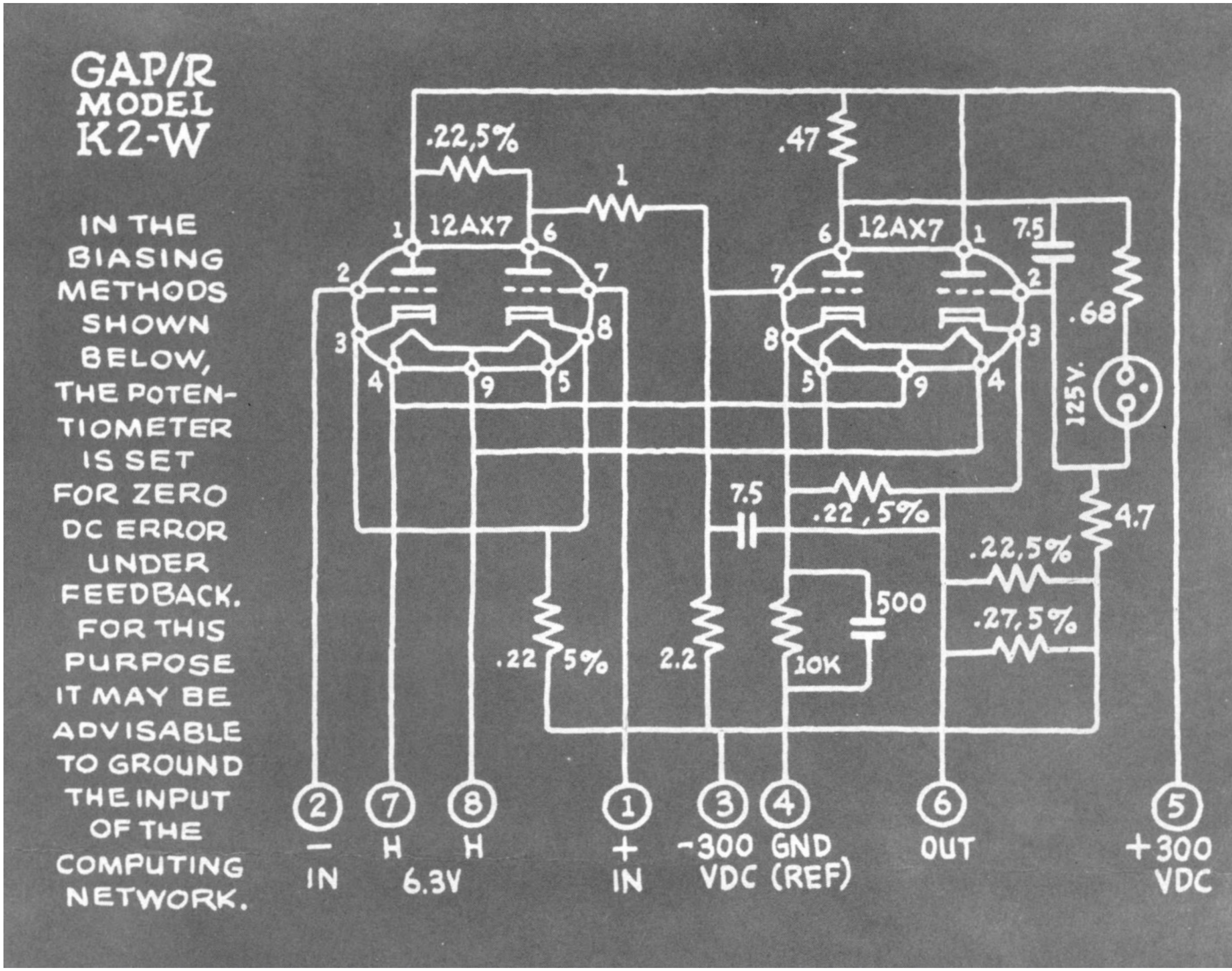
INPUT IMPEDANCE:
Above 100 Megohms
OUTPUT IMPEDANCE:
Less than 1 K open-loop; below 1 ohm fully fed back
DRIFT RATE:
5 Millivolts per day, referred to the input
HEIGHT: 4½ Inches overall
WEIGHT: 2.8 ounces

VOLTAGE RANGE:
−50 VDC to +50 VDC, at output and both inputs
INPUT CURRENT:
Less than 0.1 Microamp., for either input
OUTPUT CURRENT:
−1 Milliamp. to +1 Milliamp., driving 50 K load over full voltage range

INPUT BIAS:
Positive input should be made to operate about 1.5 V *high* at balance, normally requiring adjustable external bias
RESPONSE:
2-Microsecond rise time, with band width over 100 KC when used as inverter

http://www.philbrickarchive.org/k2-w_refurbished.pdf

The first Commercially Available Op Amp



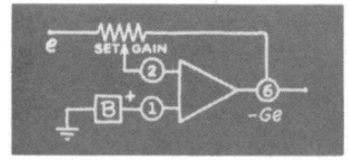
Example Applications

- Literature use to sell the op amps showed all the useful circuits you could do with them.

APPLICATIONS

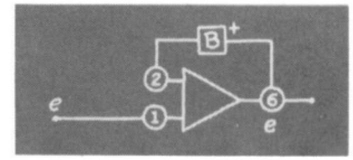
In general terms, the field of application of the K2-W Amplifier is in measurements and active transformations, in the range from DC to above 100 KC. It is primarily intended for feedback operations, where fidelity is made to depend almost entirely on the external circuit arrangements employed.

There are already more such applications than may readily be presented, and new computing connections are being conjured up every day. The following group of applications is merely typical. The circuits shown have been selected since they are fundamental as well as useful; they should suggest a variety of other forms.



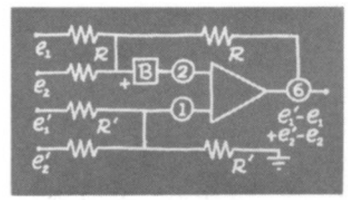
WIDE-RANGE AMPLIFIER

The usual feedback and feed-forward resistors are here embodied in a single potentiometer. A voltage gain of minus one is given by the central setting.



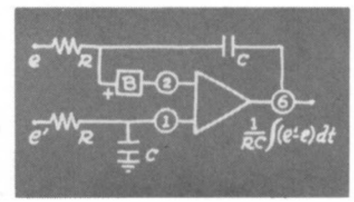
VOLTAGE REPRODUCER

This exceedingly simple arrangement supplies the need for a "follower" without attenuation or distortion, and with an output impedance well below one ohm.



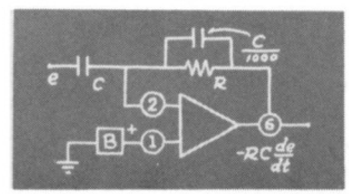
ADDER-SUBTRACTOR

A number of simpler and possibly more familiar circuits are special cases of this one. By using unequal resistors, a more general form of linear combination is made possible.



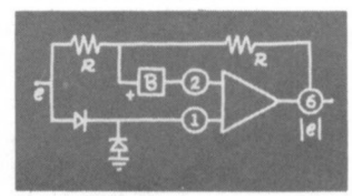
SUBTRACTING INTEGRATOR

A positive or negative integral may be obtained by grounding one input. Unless an integrator is in a stable loop it must be subjected to some sort of "clamping" process.



STABLE DIFFERENTIATOR

The smaller shunt capacitor will prevent ringing or singing, and introduces very little error. In certain difficult cases one might also add a small resistor in series with the input capacitor.



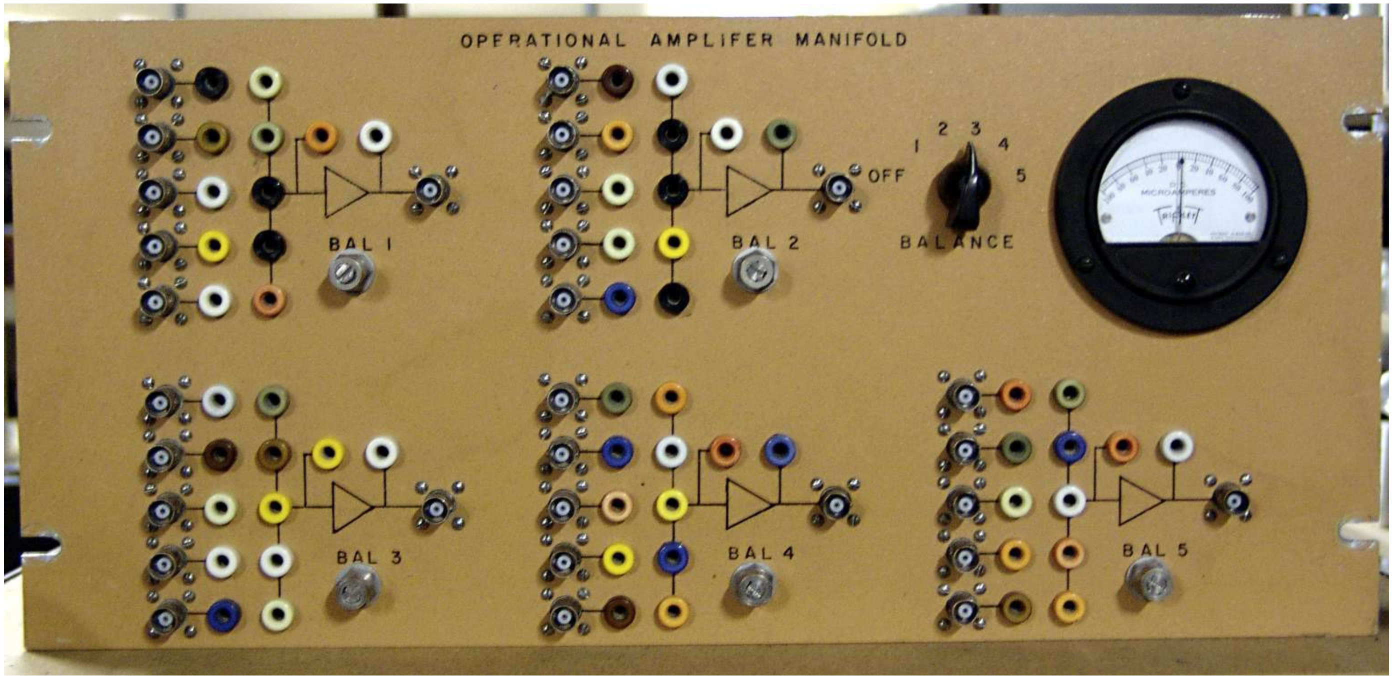
ABSOLUTE-VALUE CIRCUIT

Reversing both diodes will reverse the sign of the output. To the AC Power engineer this is simply a "full wave rectifier", but as a computing device it is useful in a much wider sense.

Early Analog Computer

- In competition with early digital computers were analog computers.
- The idea with these was you'd use operational amplifiers as programmable math blocks to solve differential equations/perform simulations
- The voltage and current levels would "model" the phenomena of interest and you'd measure the output
- In conjunction with L's and C's and diodes, Op amps can do integration, differentiation, exponentiation, logarithms.

http://www.dvq.com/oldcomp/analog/philbrick.htm



- Use jumpers, R’s, C’s, L’s in between to perform differential equation calculations and other things

http://www.dvq.com/oldcomp/analog/philbrick.htm

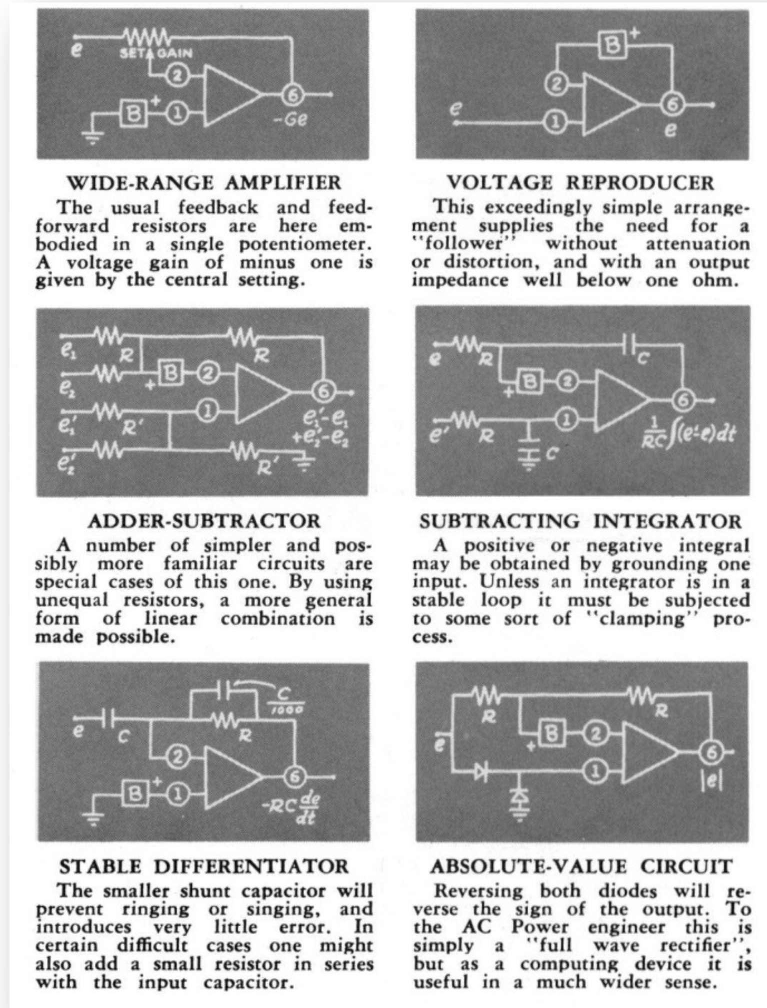
Why Analog vs. Digital?

- Digital computers start with an inherently less-dense usage of electricity to represent information (represent one-of-two) whereas analog could represent 1000's or more.
- Digital computers essentially rely on speed to overcome this initial down-side and early digital computers were not that fast.
- So analog computers were valuable up until the early 1960s in certain numerical simulation situations....

Op Amp Usage

- When we use op amps we do something weird... we...

- Connect the output back to the input...but do so in a destructive way!



WIDE-RANGE AMPLIFIER

The usual feedback and feed-forward resistors are here embodied in a single potentiometer. A voltage gain of minus one is given by the central setting.

VOLTAGE REPRODUCER

This exceedingly simple arrangement supplies the need for a "follower" without attenuation or distortion, and with an output impedance well below one ohm.

ADDER-SUBTRACTOR

A number of simpler and possibly more familiar circuits are special cases of this one. By using unequal resistors, a more general form of linear combination is made possible.

SUBTRACTING INTEGRATOR

A positive or negative integral may be obtained by grounding one input. Unless an integrator is in a stable loop it must be subjected to some sort of "clamping" process.

STABLE DIFFERENTIATOR

The smaller shunt capacitor will prevent ringing or singing, and introduces very little error. In certain difficult cases one might also add a small resistor in series with the input capacitor.

ABSOLUTE-VALUE CIRCUIT

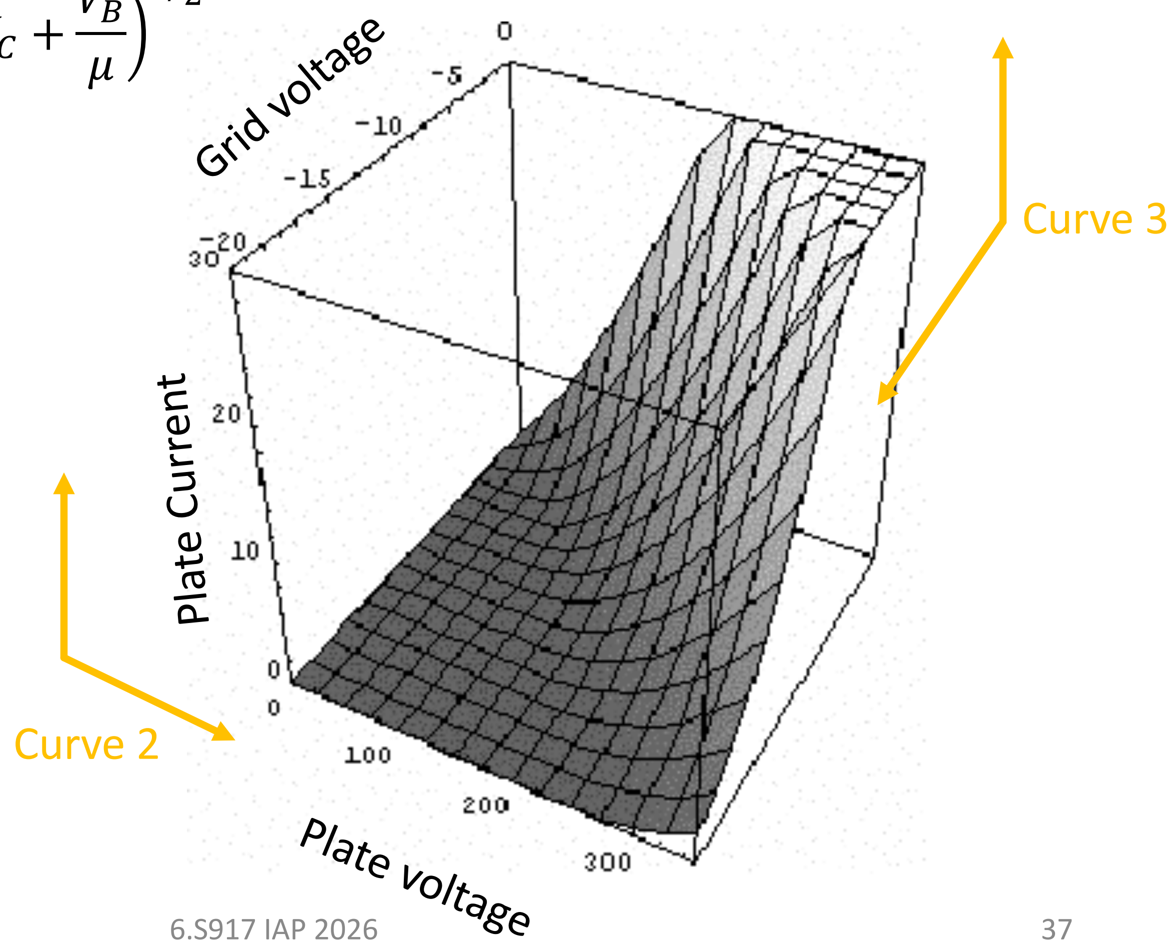
Reversing both diodes will reverse the sign of the output. To the AC Power engineer this is simply a "full wave rectifier", but as a computing device it is useful in a much wider sense.

Not Exactly Linear

- You may have noticed, that our triode is not exactly a linear amplifier

$$I_B = P\left(V_C + \frac{V_B}{\mu}\right)^{3/2}$$

- Being linear is desired for amplification
- How did they make good amplifiers?



https://www.john-a-harper.com/tubes201/

Still…

- Even early in the triode's life in the 1910's people wanted a more linear amplifier capability since *any* non-linearity was always going to be causing all those weird extra frequency components that could get annoying/impossible to filter
- So people set out searching how to linearize an amplifier!
- There were lots of problems…in particular as you made triodes with larger gains and when tetrodes and pentodes came in, they seemed to become *less and less linear**
- So the field kinda got jammed between the "more-gain" and "more-linearity" directions with no single fix.

*lots of non-idealities started to come into play

The Solution

- Harold Black approached the problem
- During a ferry ride into work in 1927 he came up with the idea of negative feedback
- It turned out that you could trade gain for linearity and other nice features
- The problem was that at first it was just a few years too early for it to be useful.

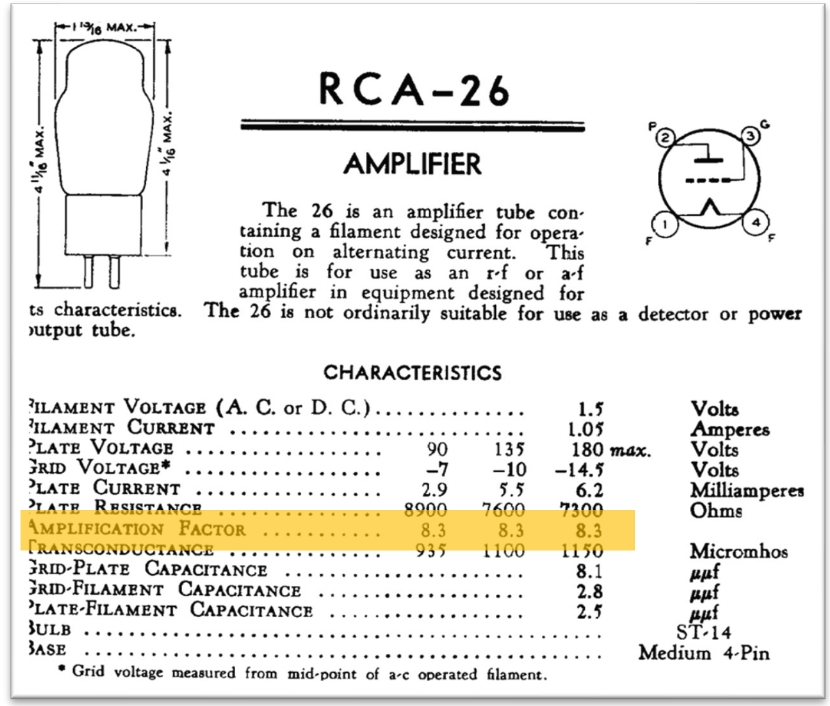
https://en.wikipedia.org/wiki/Harold_Stephen_Black

Feedback

Originally

- Early Triodes didn't have much gain so the value proposition of throwing away gain to achieve linearity wasn't exactly a good one…

In 1927:



RCA-26

AMPLIFIER

The 26 is an amplifier tube containing a filament designed for operation on alternating current. This tube is for use as an r-f or a-f amplifier in equipment designed for ts characteristics. The 26 is not ordinarily suitable for use as a detector or power output tube.

CHARACTERISTICS

Filament Voltage (A. C. or D. C.)			1.5	Volts
Filament Current			1.05	Amperes
Plate Voltage	90	135	180 max.	Volts
Grid Voltage*	−7	−10	−14.5	Volts
Plate Current	2.9	5.5	6.2	Milliamperes
Plate Resistance	8900	7600	7300	Ohms
Amplification Factor	8.3	8.3	8.3	
Transconductance	935	1100	1150	Micromhos
Grid-Plate Capacitance			8.1	μμf
Grid-Filament Capacitance			2.8	μμf
Plate-Filament Capacitance			2.5	μμf
Bulb				ST-14
Base				Medium 4-Pin

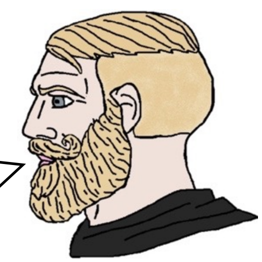
* Grid voltage measured from mid-point of a-c operated filament.

"Currently I have a voltage amplifier with a gain of 2.3 that is slightly non-linear and awful levels of input and output impedance "

Some loser engineer

"No. Are you crazy? Get away from me with your theories"

"Yes but imagine if you could make a voltage amplifier with a gain of 1.2 and potentially worse in/out impedances that is linear! Doesn't that sound enticing????"



Harold Stephen Black

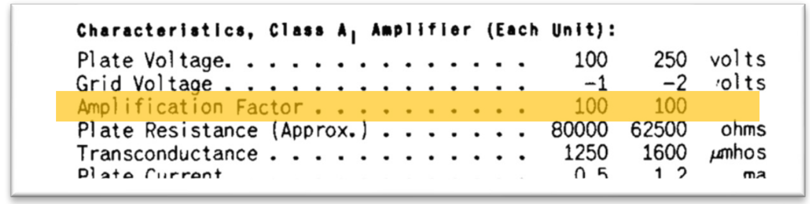
Feedback

A few years later…

High-Mu Twin Triode

9-PIN MINIATURE TYPE

For High-Fidelity Audio-Amplifier Appli-



Characteristics, Class A_1 Amplifier (Each Unit):

Plate Voltage	100	250	volts
Grid Voltage	−1	−2	volts
Amplification Factor	100	100	
Plate Resistance (Approx.)	80000	62500	ohms
Transconductance	1250	1600	µmhos
Plate Current	0.5	1.2	ma

- Tubes got better…better gain, cheaper, better I/O char

Some loser engineer

"Currently have voltage amp with gain of 270 that's non linear ☹"

In 1930s:

"Yes but imagine if you could make a voltage amplifier with a gain of 90 with negligibly worse in/out impedance that is linear! Doesn't that sound enticing????"

Harold Stephen Black

Transforms into

Now an enlightened engineer

"Your ideas intrigue me, and I would like to subscribe to your newsletter."

Harold Stephen Black

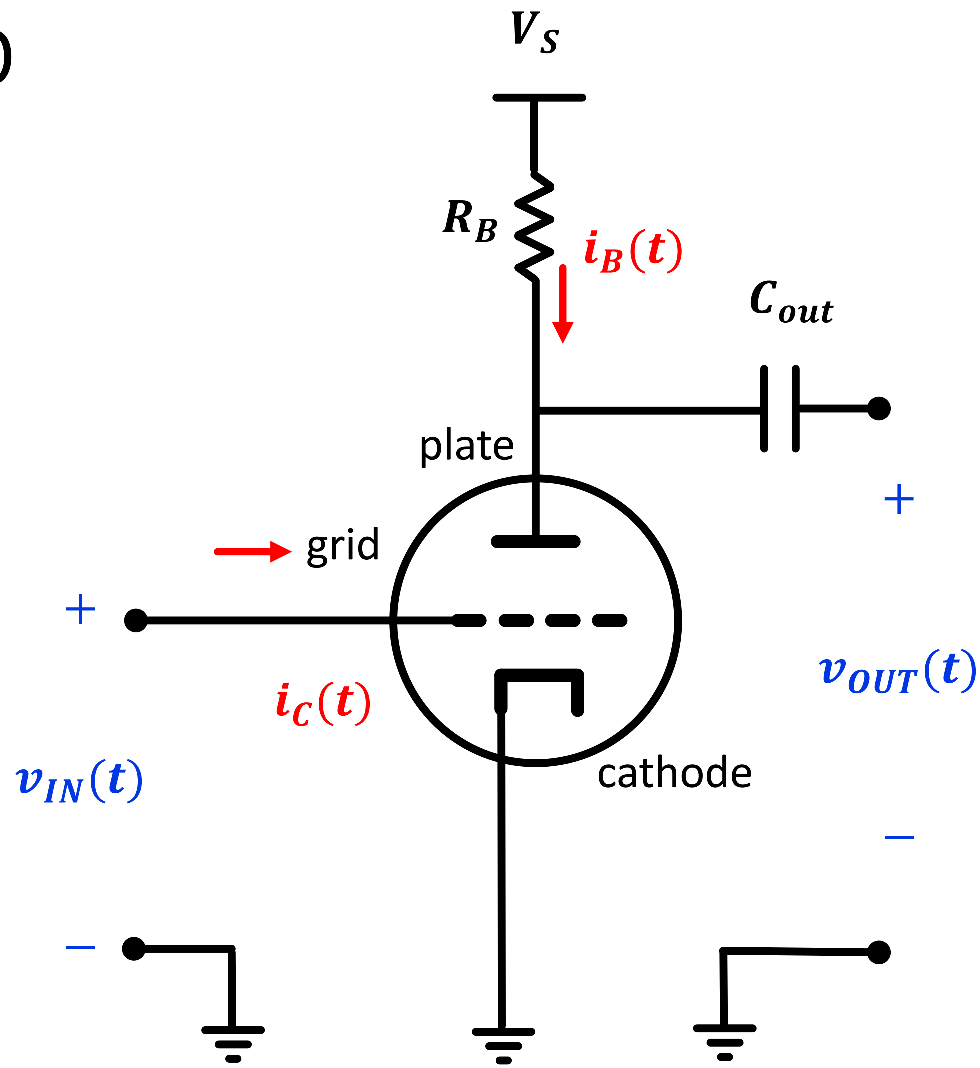
Basic Triode Setup

- Our Basic Triode setup in open loop:

$$v_{OUT} = A_o \cdot v_{IN}$$

What is A_o ? It was the value we eyeballed from looking at our load-line plots last week. It will be non-linear and will also be affected by source and load impedances.

Nominally: $A_o = -\frac{R_B \cdot \mu}{R_B + R_p}$



**ignore grid bias and things for these examples to keep things simple!*

Critical Coefficients

- Three important values characterize a Triode and are related by this equation:

$$R_p = \frac{\mu}{G_m}$$

Voltage amplification factor: The factor by which the grid voltage changes the voltage at the plate. (unitless)

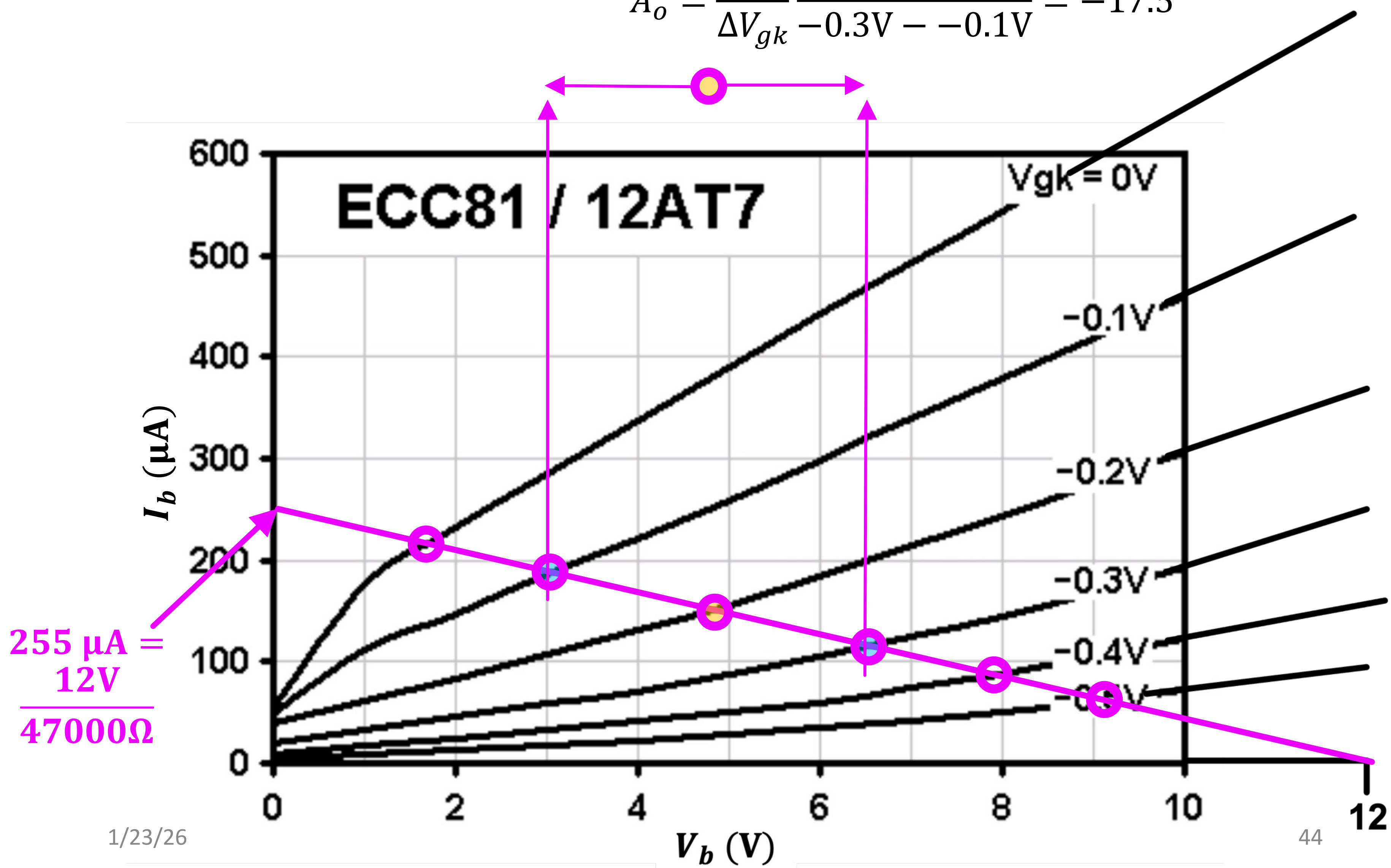
Plate Resistance: The output resistance of the tube at the plate (in Ohms)

Mutual Conductance (Transconductance): The factor by which a change in grid voltage causes a change in plate current (units of conductance…so Mhos or Siemens)

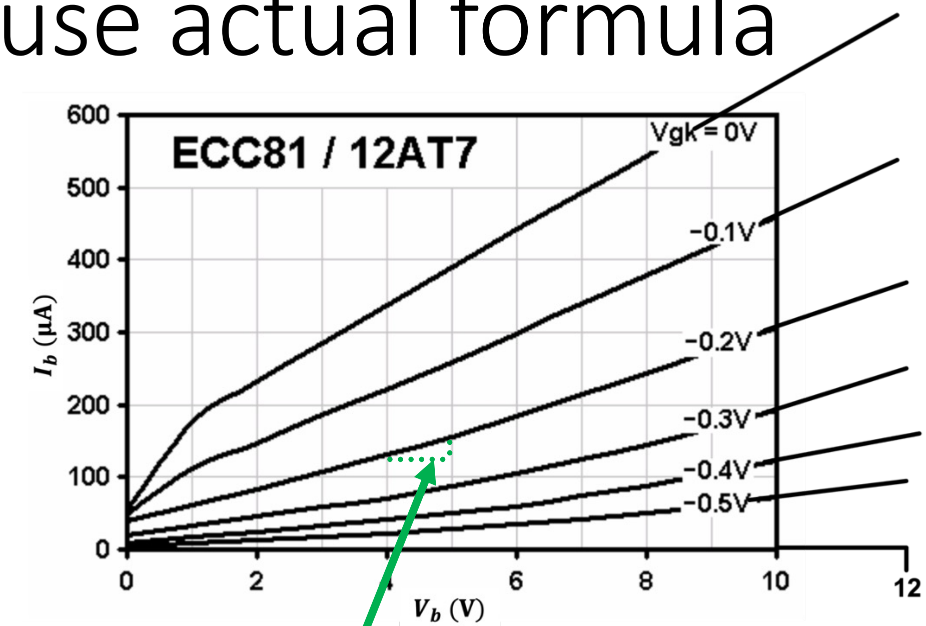
- These numbers are extracted from the values and slopes of the transfer function plots
- They are NOT Constants!

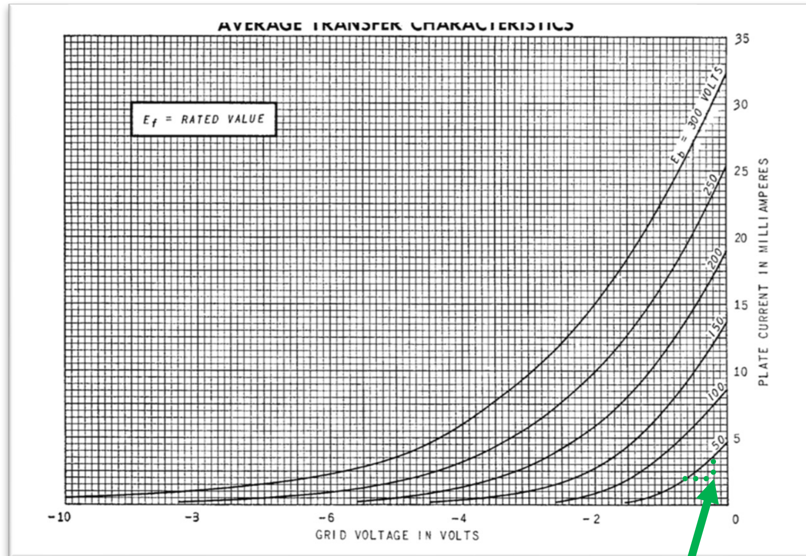
Graphically Extract Estimate/Average from Load Line

$$A_o = \frac{\Delta V_b}{\Delta V_{gk}} \frac{6.5\text{V} - 3\text{V}}{-0.3\text{V} - -0.1\text{V}} = -17.5$$



Extract parameters from Plots and then use actual formula





$$\frac{\Delta I_b}{\Delta V_b} = \frac{1}{R_P}$$

$$\frac{\Delta I_b}{\Delta V_c} = G_m$$

$$\mu = R_p G_m$$

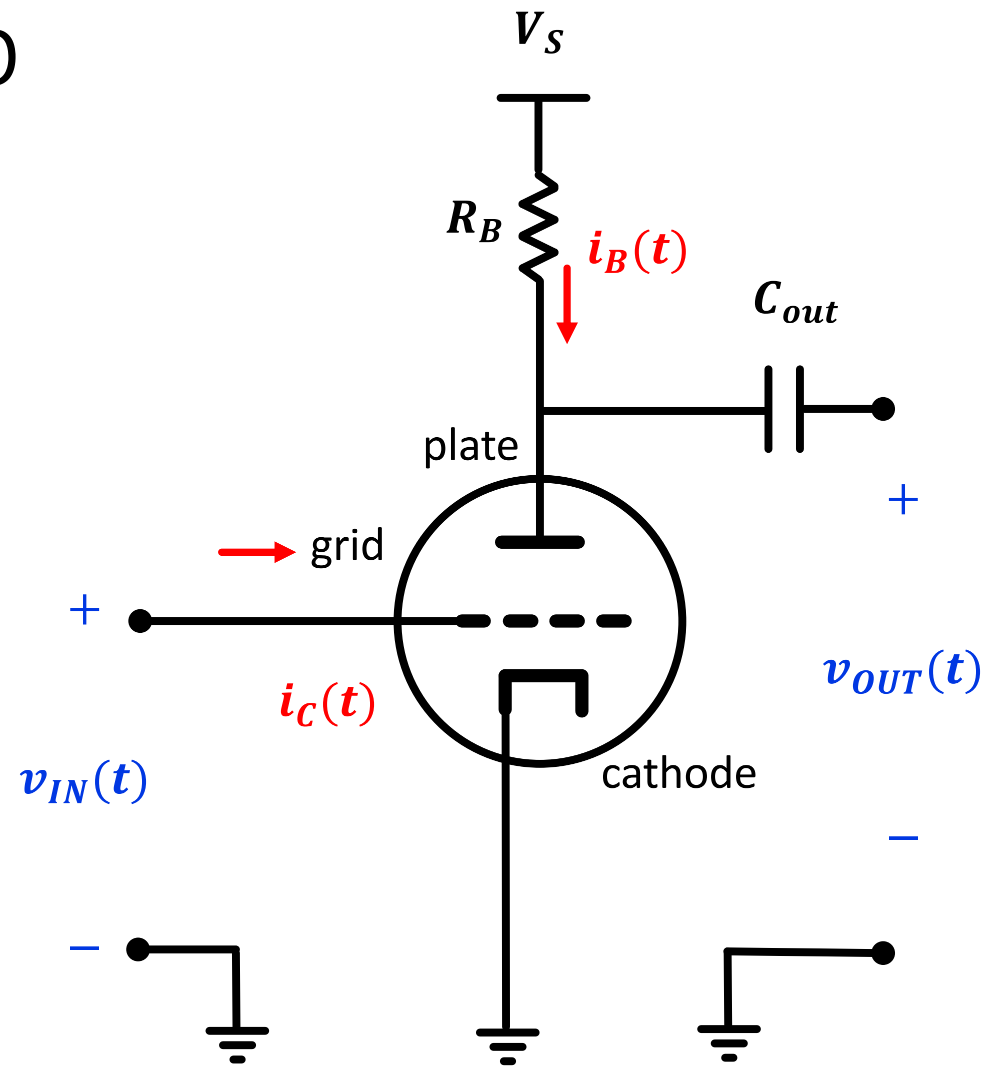
$$\boldsymbol{A_o = -\frac{R_B \cdot \mu}{R_B + R_p}}$$

Basic Triode Setup

- Regardless of how we get the open loop gain, the important thing is that it is a *varying, non-linear quantity!*

$$v_{OUT} = A_o(*) \cdot v_{IN}$$

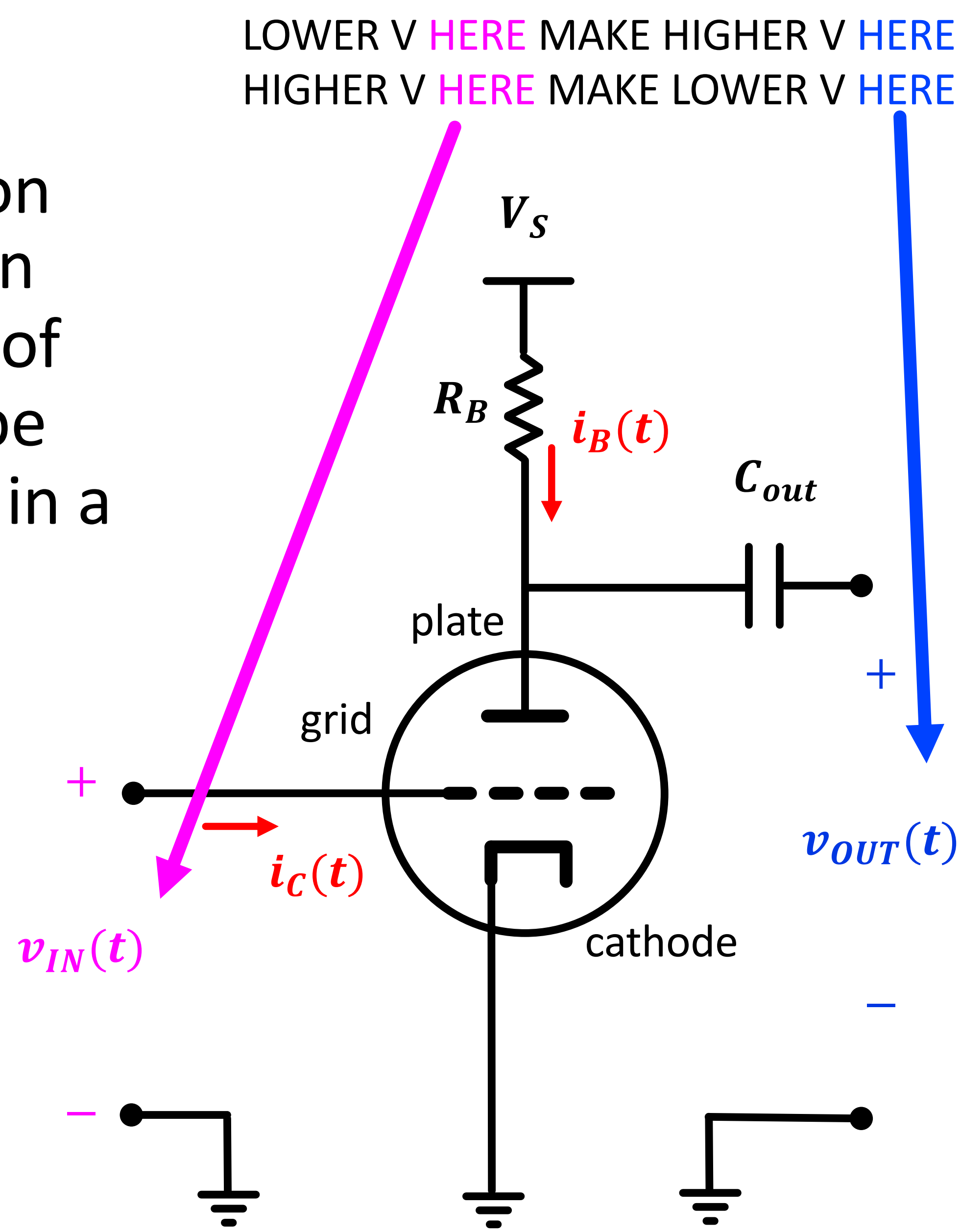
So let's just say that A_o is a function of everything (is wildcard) to indicate it is a nonlinear thing…and as a result, the entire equation is going to be nonlinear! Our job isn't to know exactly the nonlinearity, just recognize the shape*



**ignore grid bias and things for these examples to keep things simple!*

Sign of Gain

- Regardless of how non linear or not our open loop gain is, the sign of our gain will always be **negative** since we're in a inverting amplifier topology!



Add a Feedback Path

- Take some of our output…and using a voltage divider, feed it back to the input…
- Assuming $\boldsymbol{i_c}$ is ~0:

The voltage at the grid is:

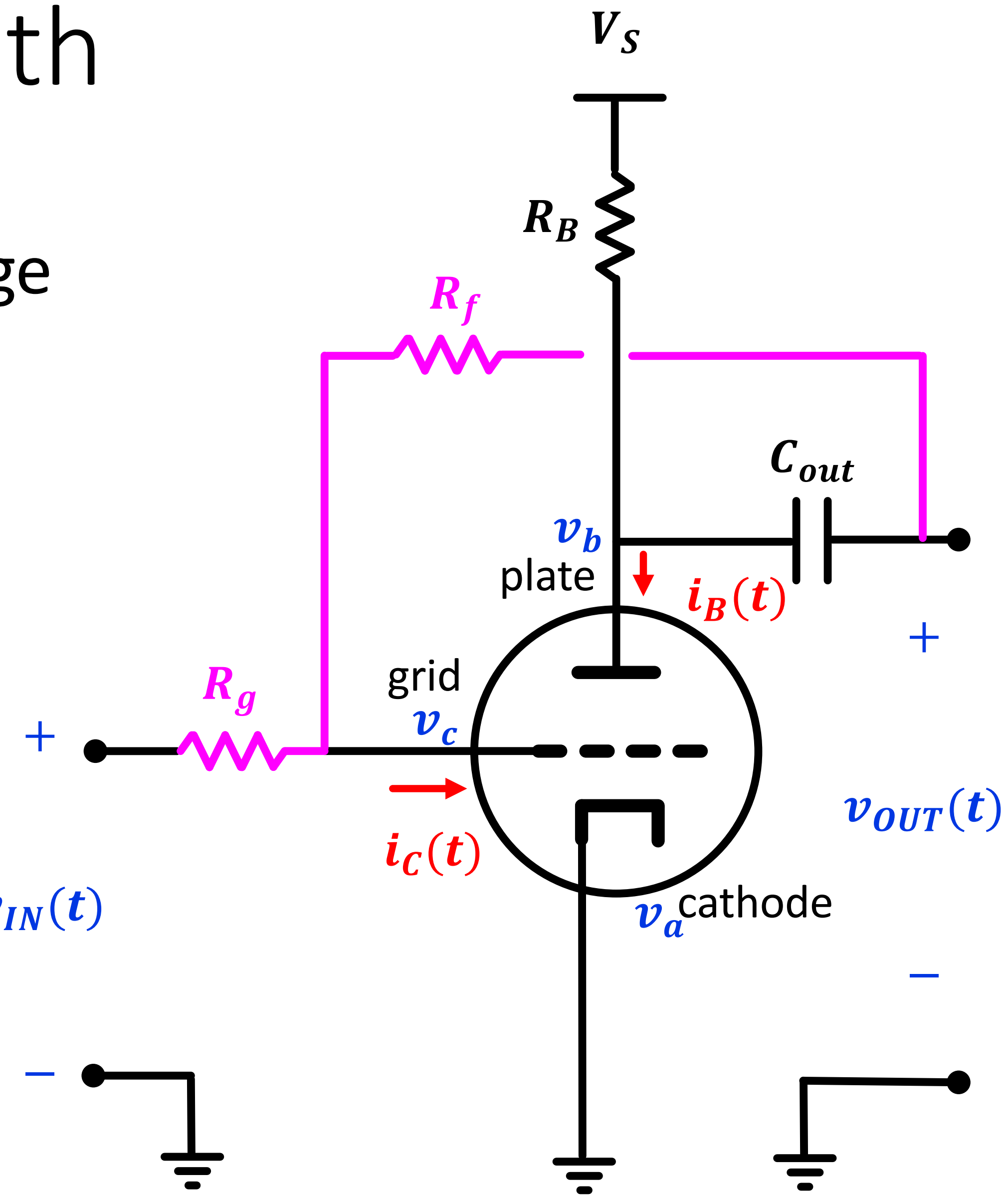
$$v_c = v_{in} + (v_{out} - v_{in})\frac{R_g}{R_g + R_f}$$

Like before the output is a function of voltage at input (grid):

$$v_{out} = A_o(*) \cdot v_c$$

Or put another way:

$$v_c = \frac{v_{out}}{A_o(*)}$$



So Putting This Together:

$$v_c = v_{in} + (v_{out} - v_{in})\frac{R_g}{R_g + R_f}$$

$$v_c = \frac{v_{out}}{A_o(*)}$$

Therefore:

$$\frac{v_{out}}{A_o(*)} = v_{in} + (v_{out} - v_{in})\frac{R_g}{R_g + R_f}$$

Therefore:

$$v_{out}\left(\frac{1}{A_o(*)} - \frac{R_g}{R_g + R_f}\right) = v_{in}\left(1 - \frac{R_g}{R_g + R_f}\right)$$

Therefore:

$$\frac{v_{out}}{v_{in}} = \frac{\left(1 - \frac{R_g}{R_g + R_f}\right)}{\left(\frac{1}{A_o(*)} - \frac{R_g}{R_g + R_f}\right)}$$

Therefore:

$$\frac{v_{out}}{v_{in}} = \frac{A_o(*)R_f}{(R_g + R_f - A_o(*)R_g)}$$

Therefore:

$$v_{out} = \frac{A_o(*)R_f}{(R_g + R_f - A_o(*)R_g)}v_{in}$$

Conclusions I

- The result of this feedback had some interesting properties…
- Let's say we had a <u>non-linear amp</u> system where the *gain was a function* of $\boldsymbol{v_{in}}$ such that: $\boldsymbol{A_o(*) = -10v_{in}}$
- If we just applied this to our known I/O equation:
  - $\boldsymbol{v_{out} = (-10 \cdot v_{in}) \cdot v_{in} = -10 \cdot v_{in}^2}$…in other words, $\boldsymbol{v_{out}}$ is ***highly non-linear*** with $\boldsymbol{v_{in}}$

$$\boldsymbol{v_{out} = -10 \cdot v_{in}^2}$$

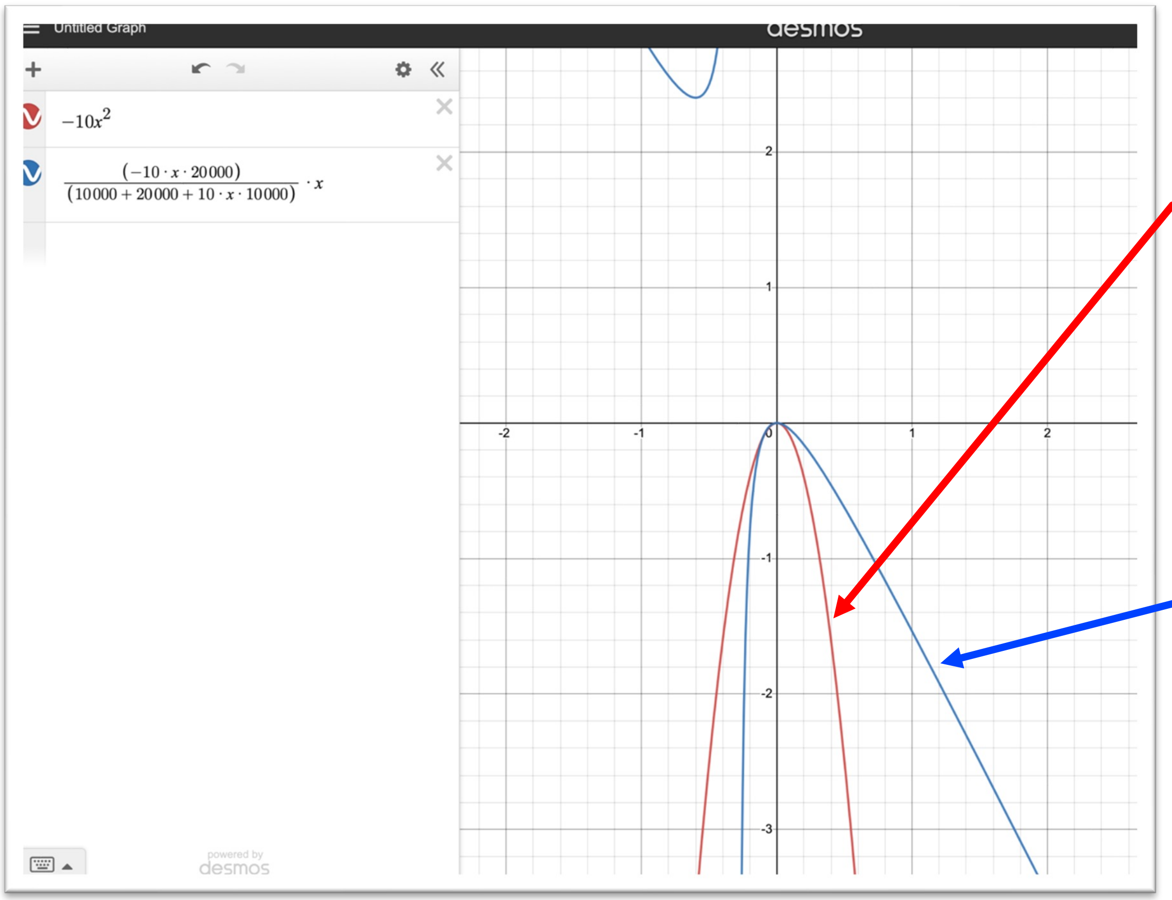
- In the context of feedback therefore:
  - $\boldsymbol{v_{out} = \frac{-10v_{in}R_f}{(R_g+R_f--10v_{in}R_g)} v_{in}}$

- For reasonable values for those resistors, this equation is actually more "linear" than the original

Conclusions I

$$v_{out} = -10 \cdot v_{in}^2 \qquad \text{vs.} \qquad v_{out} = \frac{-10 v_{in} R_f}{(R_g + R_f - -10 v_{in} R_g)} v_{in}$$

$$R_f = 20\text{k}\Omega \; R_g = 10\text{k}\Omega$$



The original open loop exhibits highly non-linear relation of input to output

The system with closed loop negative feedback exhibits a shape that looks more linear-ish, albeit at a lower gain aka shallower slope!

Conclusions II

- Further investigation reveals another interesting pattern. And this one is ***critical***:

- For the equation $\boldsymbol{v_{out}} = \frac{\boldsymbol{A_o}(*)\boldsymbol{R_f}}{(\boldsymbol{R_g}+\boldsymbol{R_f}-\boldsymbol{A_o}(*)\boldsymbol{R_g})}\boldsymbol{v_{in}}$ as the overall magnitude of $\boldsymbol{A_o}(*)$ gets larger and larger, ($\boldsymbol{A_o}(*) \rightarrow \infty$) both top and bottom of the fraction become dominated by it and the overall equation will simplify to the following:

- $\boldsymbol{v_{out}} \approx -\frac{\boldsymbol{R_f}}{\boldsymbol{R_g}}\boldsymbol{v_{in}}$

Conclusions I

- The result of this feedback had some interesting properties…
- Let's say we had a non-linear amp system where the gain was a simple function of $\boldsymbol{v_{in}}$ such that: $\boldsymbol{A_o(*) = -1000v_{in}}$
- If we just applied this to our known I/O equation:
  - $\boldsymbol{v_{out} = -1000 \cdot v_{in} \cdot v_{in} = -1000 \cdot v_{in}^2}$…in other words, $\boldsymbol{v_{out}}$ is highly non-linear with $\boldsymbol{v_{in}}$

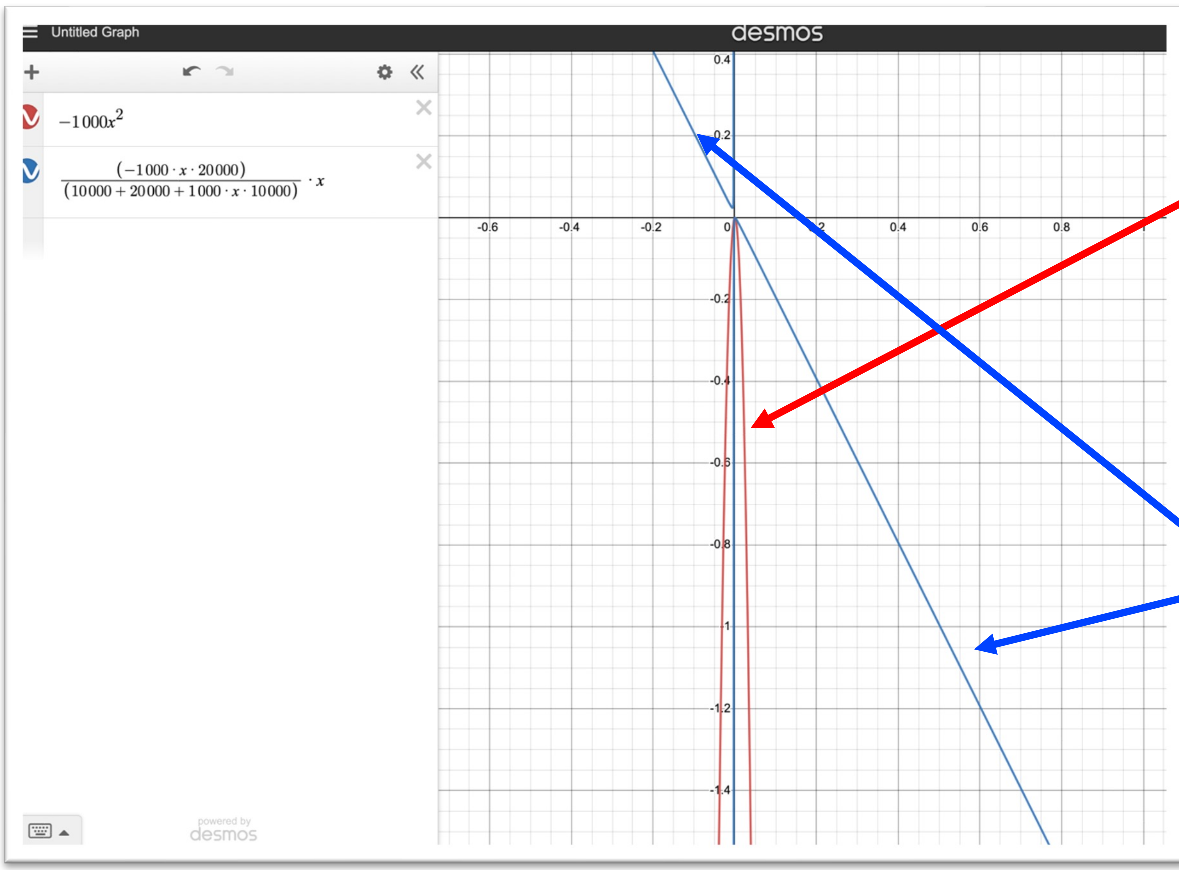
$$\boldsymbol{v_{out} = -1000 \cdot v_{in}^2}$$

- In the context of feedback therefore:
  - $\boldsymbol{v_{out} = \frac{-1000v_{in}R_f}{(R_g+R_f--1000v_{in}R_g)}v_{in}}$
- For reasonable values for those resistors, this equation is <u>far, far more "linear" than the original</u>

Conclusions II

$$v_{out} = -1000 \cdot v_{in}^2 \quad \text{vs.} \quad v_{out} = \frac{-1000 v_{in} R_f}{(R_g + R_f - -1000 v_{in} R_g)} v_{in}$$

$$R_f = 20\text{k}\Omega \; R_g = 10\text{k}\Omega$$



The original open loop exhibits highly non-linear relation of input to output

The system with closed loop negative feedback exhibits a shape that is essentially linear!

Conclusions IIb

- Because of the invention and perfection of negative feedback the exact “shape” of a tube’s gain curves became less important
- What became important was that you have *a lot of gain*. If you can have a lot of gain, even if non-linear, you can trade it off for a more linear behavior of gain at a more moderate overall magnitude of gain ***using negative feedback***
- This freed up engineers to push forward with making higher gain tubes and not obsess so much with the linearity of the tube itself! The circuit it lives in can fix that problem.

Results are Shockingly Good

- The original Harold Black paper from 1934, arguably one of the greatest EECS papers of all time imo, is built around the study of this circuit:
- A multi-stage tube amplifier with the output negatively fed back to the input:

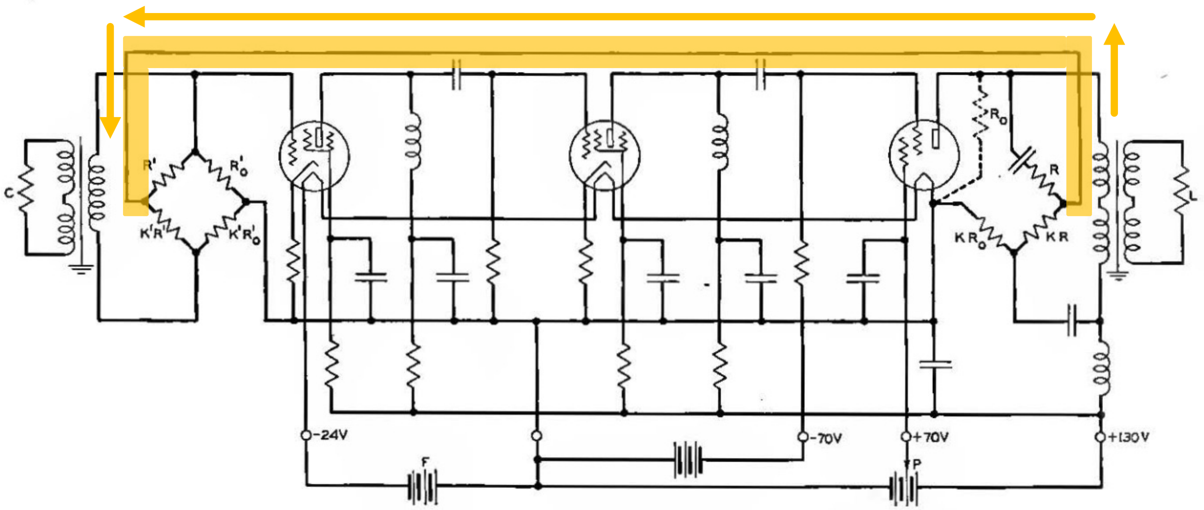


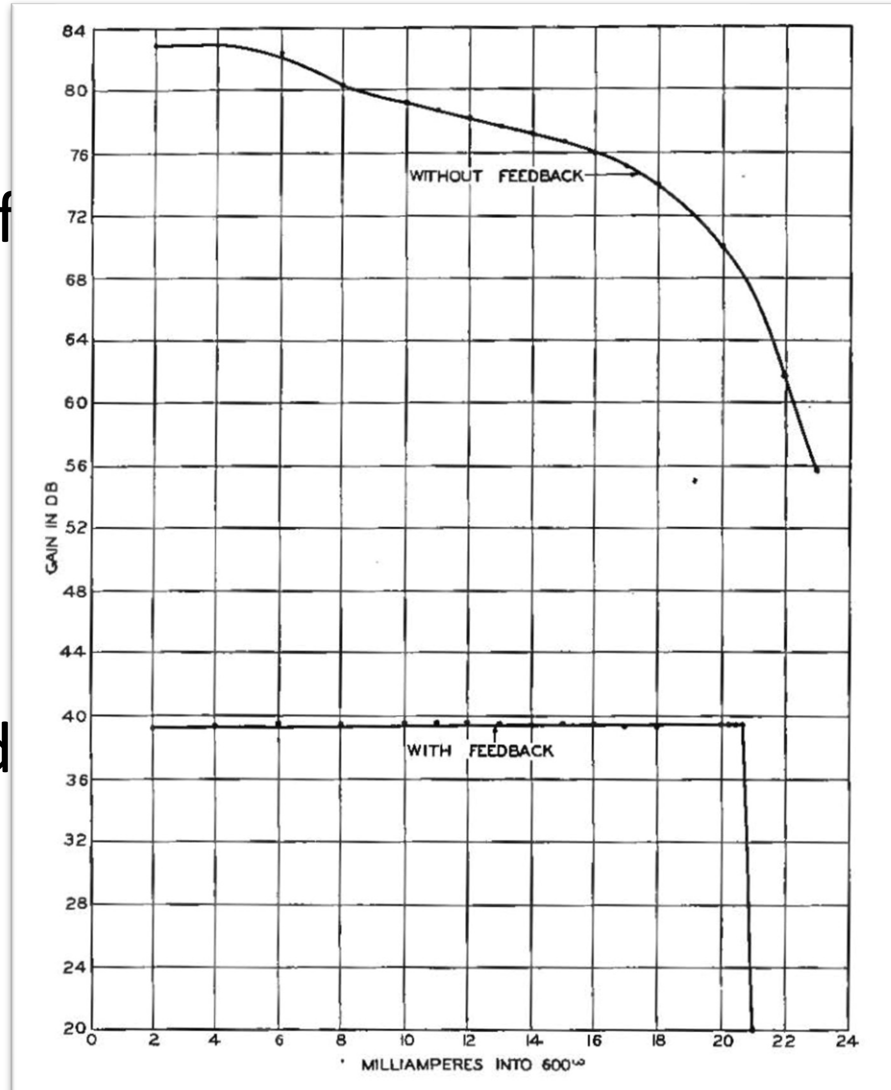
Fig. 2—Circuit of a negative feedback amplifier.

H.S. Black, "Stabilized feed-back amplifiers", *Electrical Engineering*, vol. 53, pp. 114-120, Jan. 1934.

Compare that circuit with/without feedback

- Gain now stays flat for a variety of output loads! (showing how as value of resulting output signal goes up/down, it stays proportional with input signal)

- Non-linearity suppressed at the expense of lower overall gain



H.S. Black, "Stabilized feed-back amplifiers", *Electrical Engineering*, vol. 53, pp. 114-120, Jan. 1934.

Works in Frequency Space Too!

- Gain stays constant for a variety of frequencies!
- Yes it is lower overall in magnitude but it is consistent!

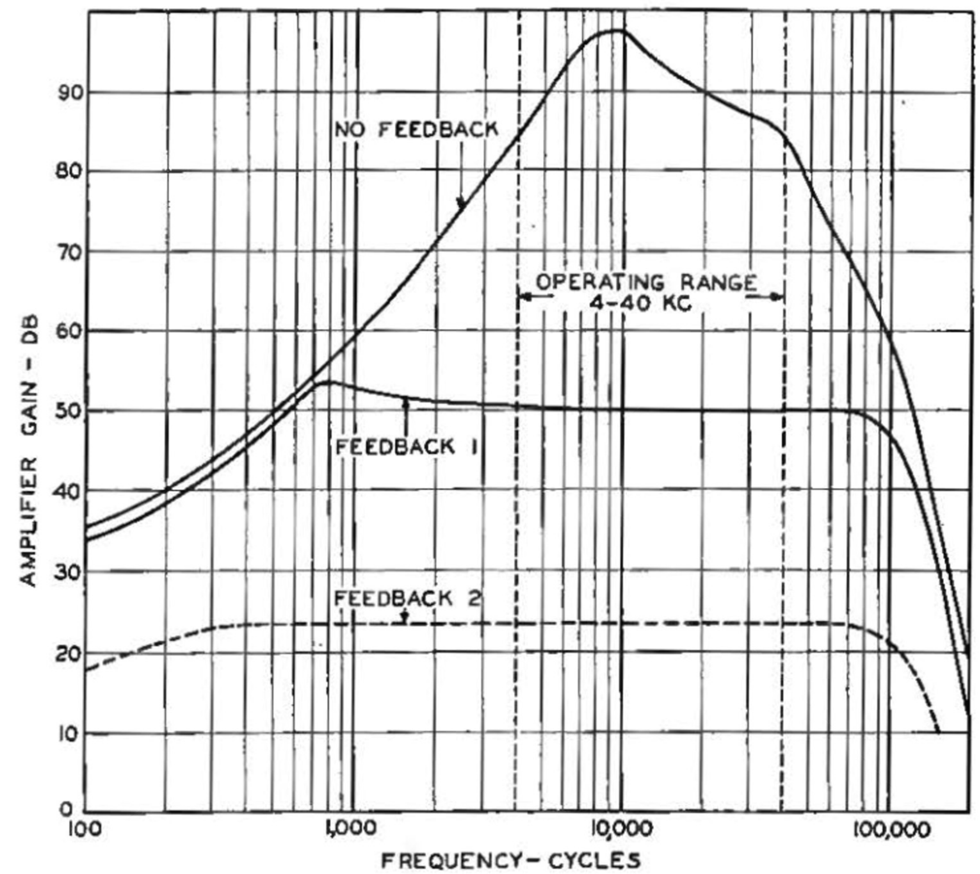
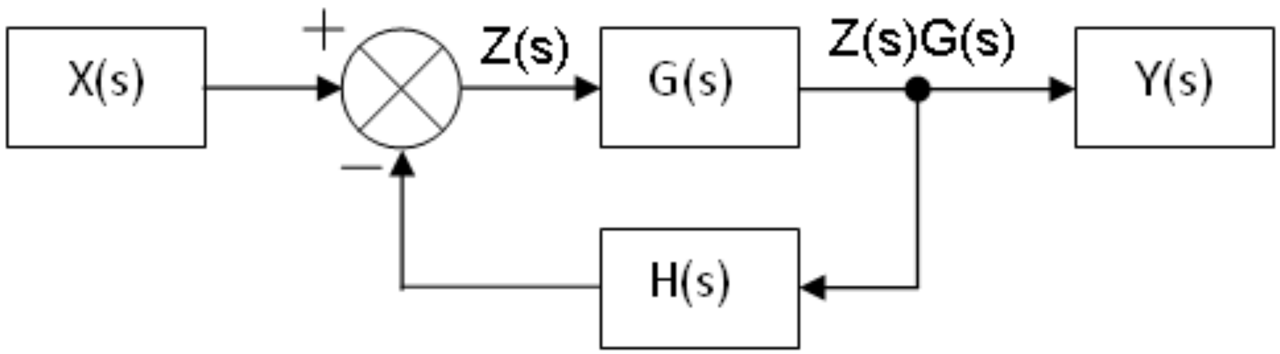


Fig. 6—Gain frequency characteristics with and without feedback of amplifier of Fig. 2.

H.S. Black, "Stabilized feed-back amplifiers", *Electrical Engineering*, vol. 53, pp. 114-120, Jan. 1934.

This result

- All modern control theory is built around the work of Black:



- As an EE or EECS person or whatever, this is one of the most fundamental and important concepts/achievements in existence

https://en.wikipedia.org/wiki/Closed-loop_transfer_function

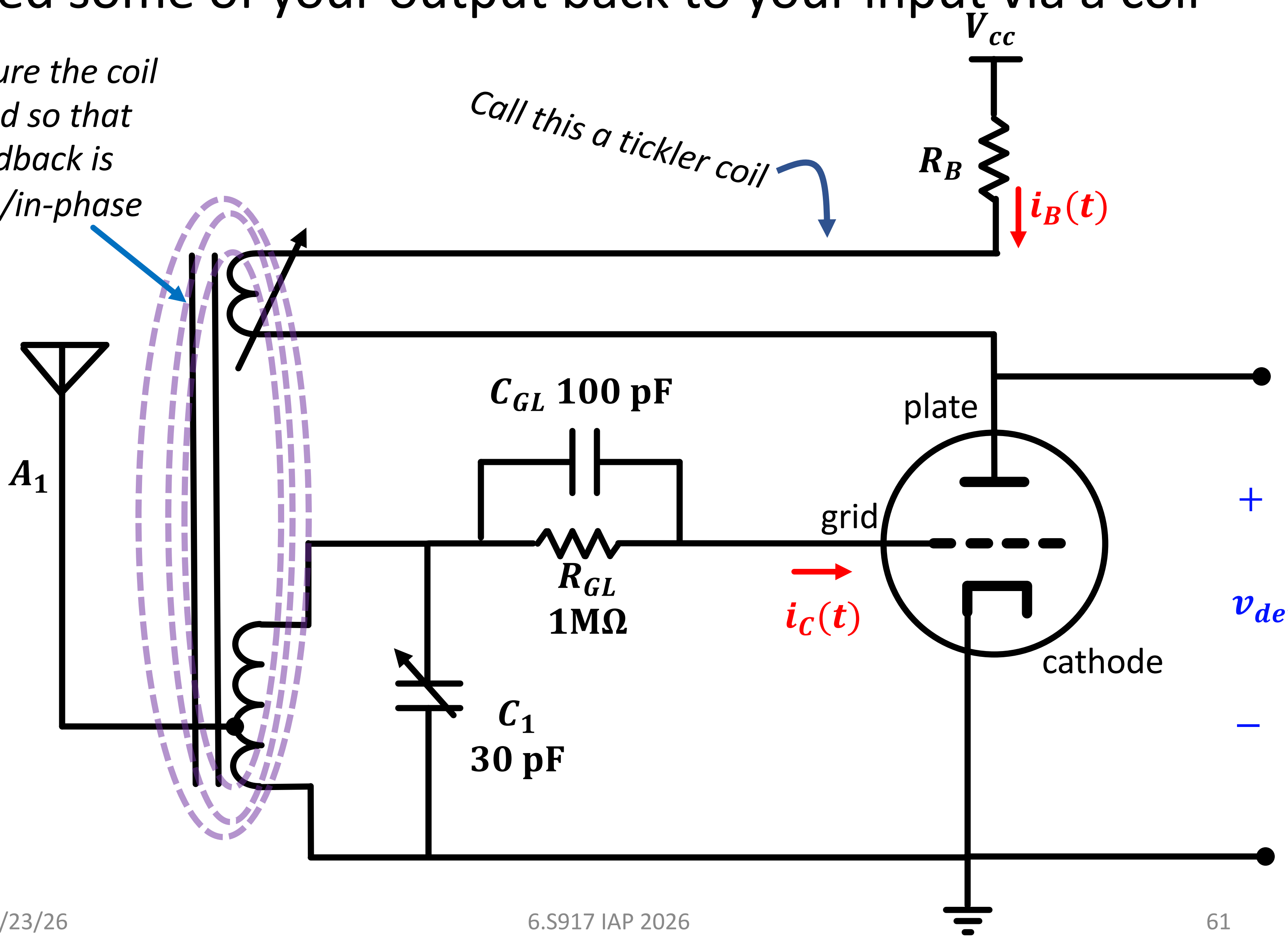
Now Let's Return to Armstrong and his circuits

- So…

Armstrong's Regeneration Receiver

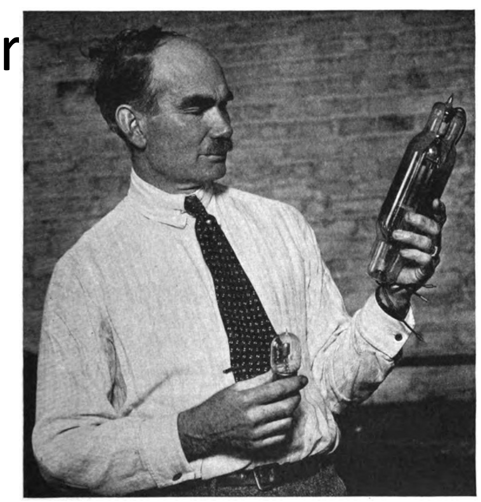
- Feed some of your output back to your input via a coil

Make sure the coil is flipped so that this feedback is positive/in-phase



~1914/5…

- Remember Lee de Forest?
- First person to put a third wire into a thermionic tube
- He had like a dozen companies that failed and always seemed to become friends with shysters scammers
- Sued lots of people
- Declared himself to be "father of radio" later in life
- But it is largely established that he invented the "triode" which he called the "audion"
- Had no idea really how it worked
- Patent Troll



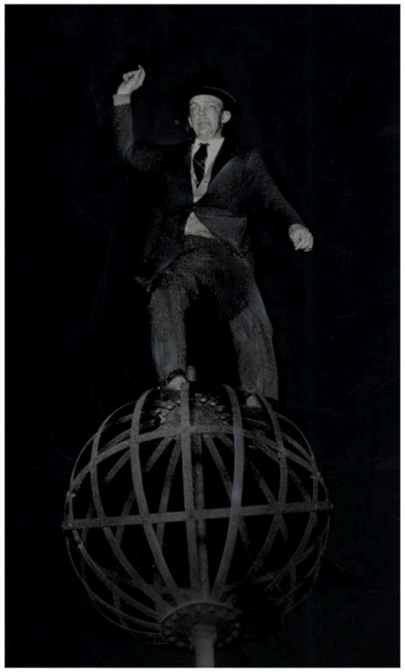
https://en.wikipedia.org/wiki/Lee_de_Forest

Well De Forest Sued Armstrong

- He claimed he had invented regeneration based on some unclear sketches from 1912, and he and Armstrong started fighting a very long drawn out legal battle that lasted ten years…well into the 1920s...
- AT&T had licensed some other patents from De Forest, so backed him (and AT&T was Google-like in size)
- Went all the way to the Supreme Court and in 1934 it sided with De Forest much to the surprise of the entire engineering field.
- Armstrong was bummed out, but by this time all the patents had been inter-licensed so it wasn't a huge loss.
- And by then other things were being designed

https://en.wikipedia.org/wiki/Lee_de_Forest

A Better Regenerative Receiver

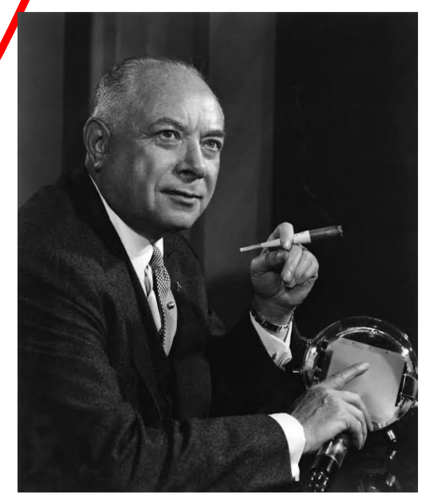


- Armstrong kept experimenting and developed a regenerative design that used a local oscillation to selectively filter and "quench" undesired feedback oscillations.
- As a result you could drive your receiver further into feedback and not "transmit"…gains of over 1 million were possible but circuit was very finicky
- Called it…
- The superregenerative receiver and patented in 1922.
- Sold it, made more moneyyyy

Armstrong Kept Doing Stuff

- He was in the signal corps during WW1. Made some more inventions
- Got married, made his wife the first known-portable radio (weighed 50 pounds) as a wedding present, lol
- Became very tight with RCA

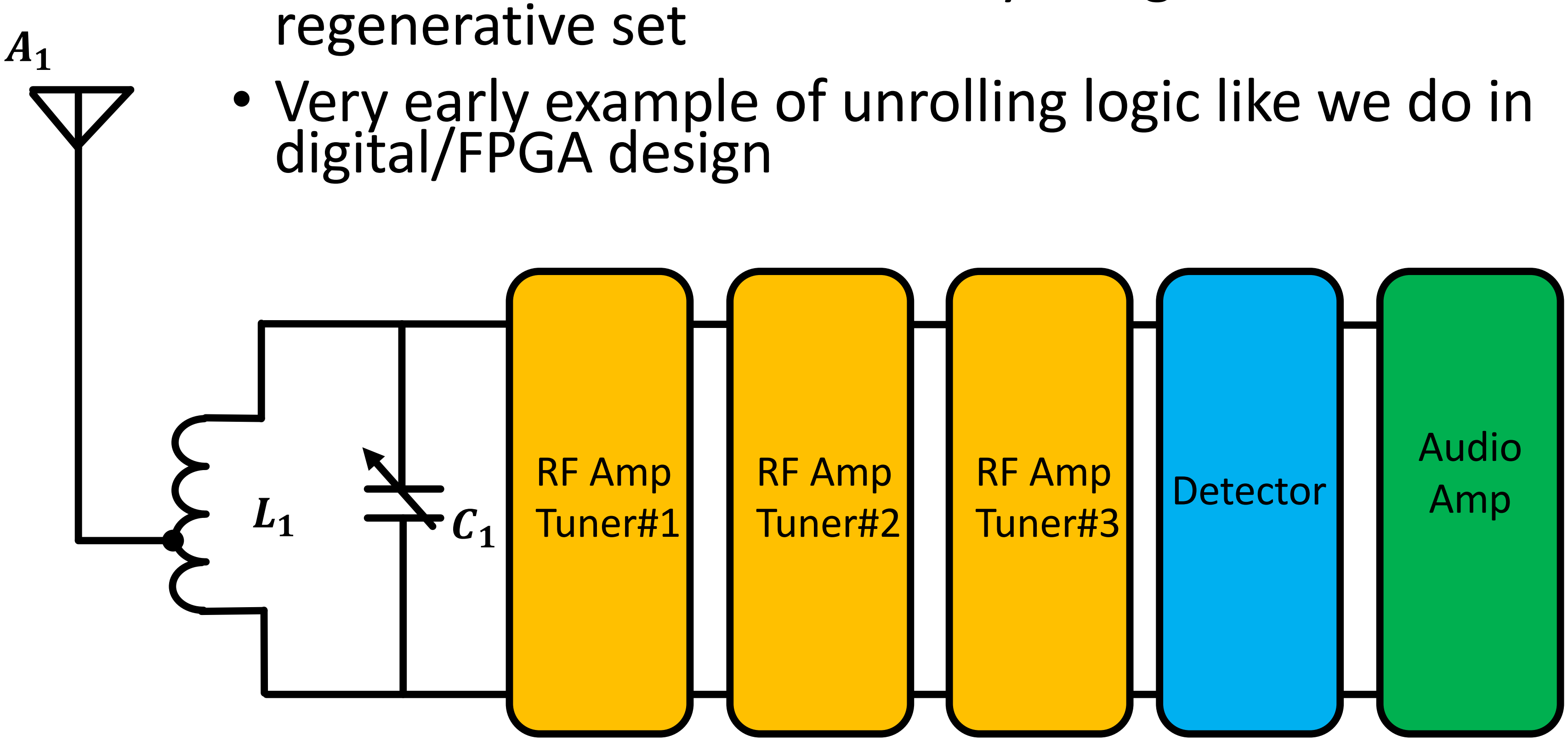
Radio Corporation of America



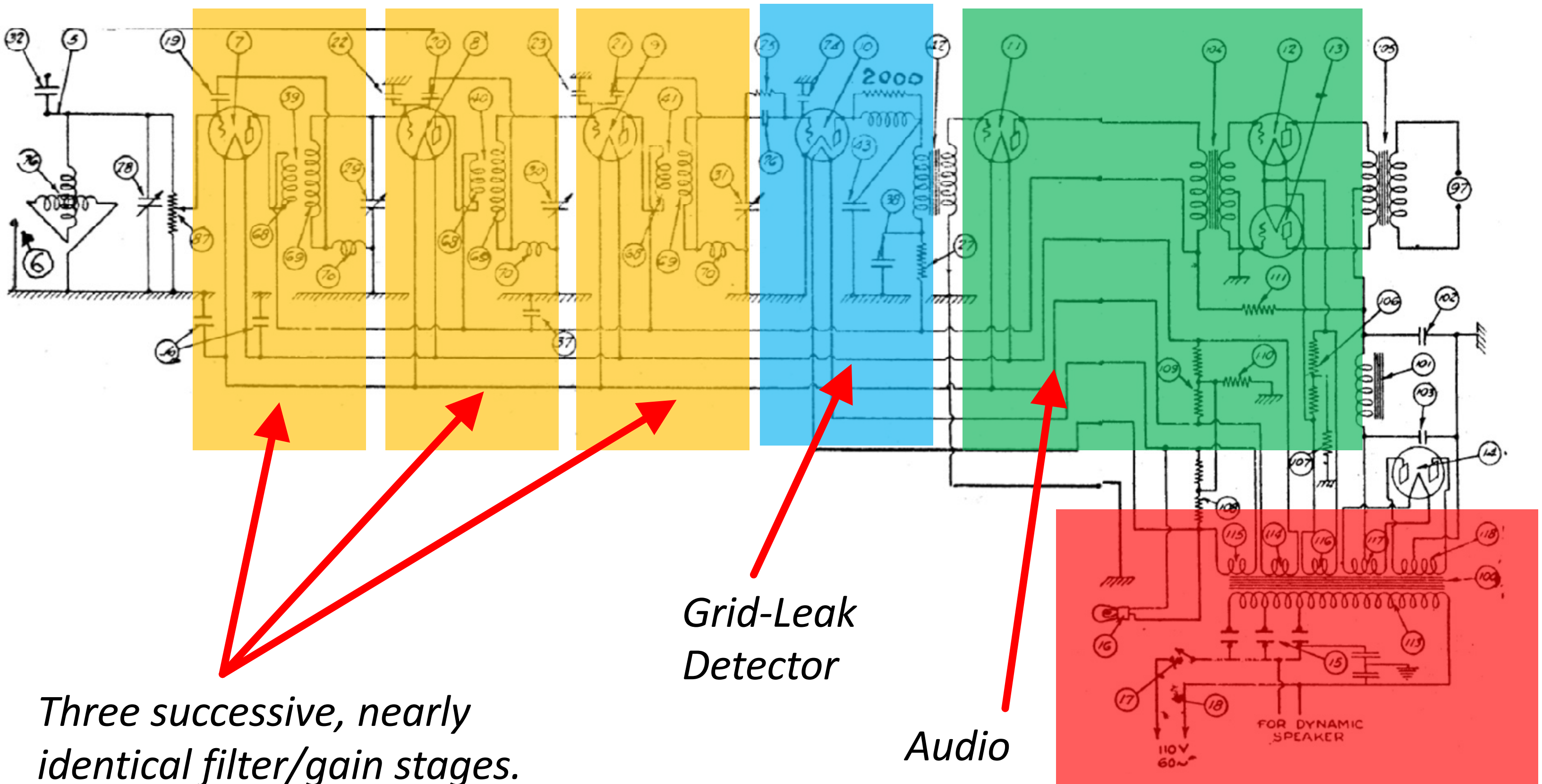
David Sarnoff, Leader of RCA

The Tuned Radio Frequency Receiver

- Instead of reusing the same tube, use multiple tubes in series, other designs came out…
- Got around regeneration patents and as tubes got cheaper this wasn't as absurd
- It was also far less of a finicky design than a regenerative set
- Very early example of unrolling logic like we do in digital/FPGA design



1928 Bosch Radio Receiver Schematic



Grid-Leak Detector

Audio Amps

Three successive, nearly identical filter/gain stages. Combined could have enough gain to compete with regenerative AND not have threat of oscillation!

Power Supply

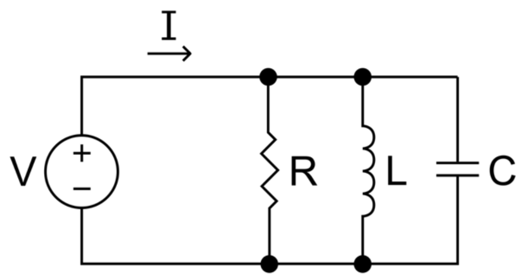
More Tubes != Better?

- The appearance of the TRF designs motivated the notion that more tubes implied a better set.
- If done correctly, there was merit to this:
  - A four-stage TRF was better than a two-stage TRF
  - Also doing your audio amplification with several layers of tubes could result in more, cleaner signal
- However some radio manufacturers started just putting random tubes into sets to convey that they were better.
- “12-tube-6-tube sets” appeared: only used 6 tubes, even though there were 12 in the design doing nothing but consuming power.
- Wasn’t always malicious, people were still figuring stuff out and there’d be weird trendy circuits that people thought were ”better” but really did nothing…or did the same thing less efficiently.
- Weird times.

Armstrong already coming up with even better solution

- Regenerative worked, but was finicky and dangerous
- The superregenerative worked but was even more complicated and finicky
- TRF worked pretty well, but needed a lot of tubes and wasn’t very amazing with selectivity:
  - It is very hard to have a variable filter maintain the exact same relative shape as you vary its resonant frequency
  - Also working at raw radio frequencies is hard…it would be nice if you could do your pre-demodulation work/filtering at lower frequencies

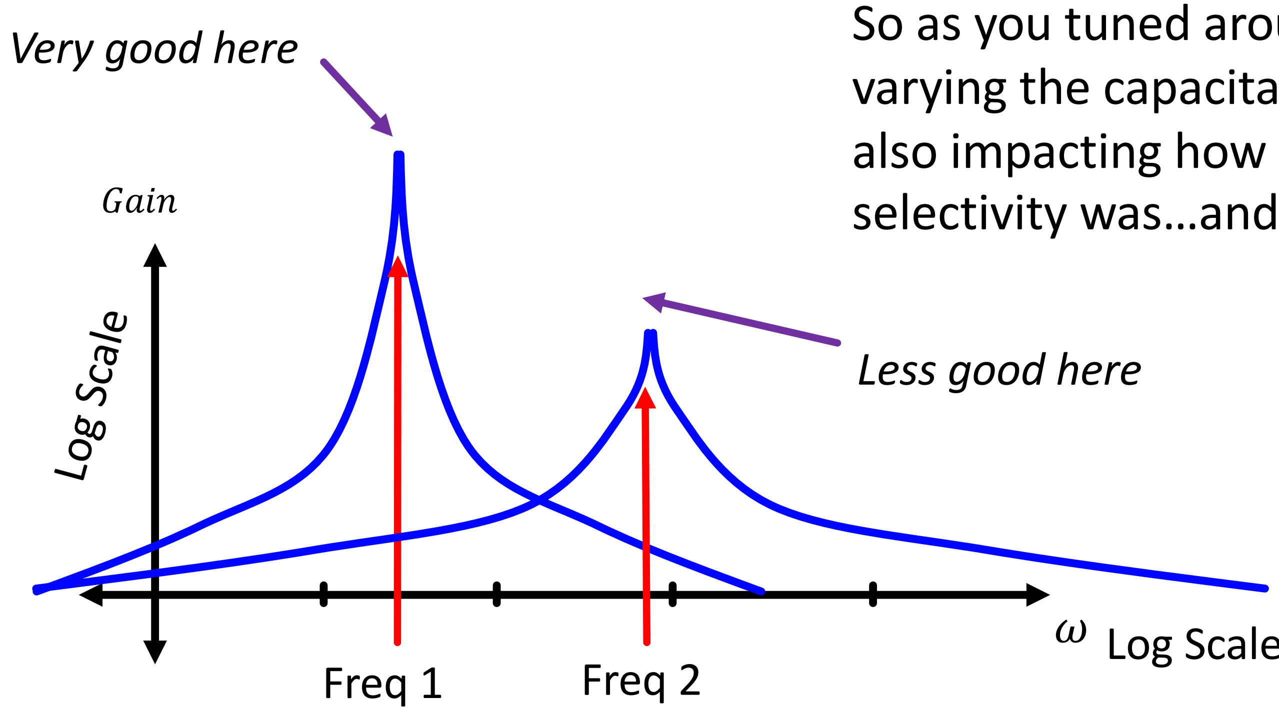
Having a Variable Tuner



ω_o is always going to $= {}^{1}/_{\sqrt{LC}}$

ω_o But the quality factor Q which relates to how selective a filter is is expressed with this: $\mathrm{Q} = \mathrm{R}\sqrt{\frac{C}{L}}$

So as you tuned around with your radio varying the capacitance (or L), you were also impacting how good/bad your selectivity was…and that's not ideal



Solution:

- Do all of the filtering at the same exact frequency regardless of what frequency your station is at.

- This way you could just have a bunch of unmovable filters targeting that fixed frequency that were perfectly calibrated.

- Seems simple, yes???

Are you crazy? "Do all of the filtering at the **same exact frequency** regardless of what **frequency** your station is at." Do you realize how crazy that sounds?

Mixing Signals (Down-Mixing)

- Based around multiplication of sine waves (remember from other week?)
- Let's say we have the following signal coming in:

$$v_c(t) = A_{s_1} \sin\left(2\pi f_{s_1} t\right)$$

- If we multiply that signal by a locally generated sine wave of frequency $f_{s_1} - f_{IF}$ where f_{IF} is some low frequency value (for AM let's say 455 kHz), we'd get:

$$A_{s_1} \sin\left(2\pi f_{s_1} t\right) \cdot \sin\left(2\pi\left(f_{s_1} - f_{IF}\right)t\right) =$$

$$A_{s_1} \cos\left(2\pi\left(2f_{s_1} - f_{IF}\right)t\right) + \cos(2\pi(-f_{IF})t)$$

Resulting frequencies

- We have two sinusoids as a result:

$$\cos(2\pi(2f_{s_1} - f_{IF})t) - \cos(2\pi(f_{IF})t)$$

This one is higher than starting radio signal. Ignore/filter it out

This one is at lower frequency. Keep it.

- What if we want a different signal at frequency f_{s_2}? Do same thing except this time multiply incoming signal of frequency $f_{s_2} - f_{IF}$ The result will be:

$$\cos(2\pi(2f_{s_2} - f_{IF})t) - \cos(2\pi(f_{IF})t)$$

This one is higher than starting radio signal. Ignore/filter it

This one is at lower frequency. Keep it. Also it is the same frequqency as first case!!!

The Superheterodyne Receiver

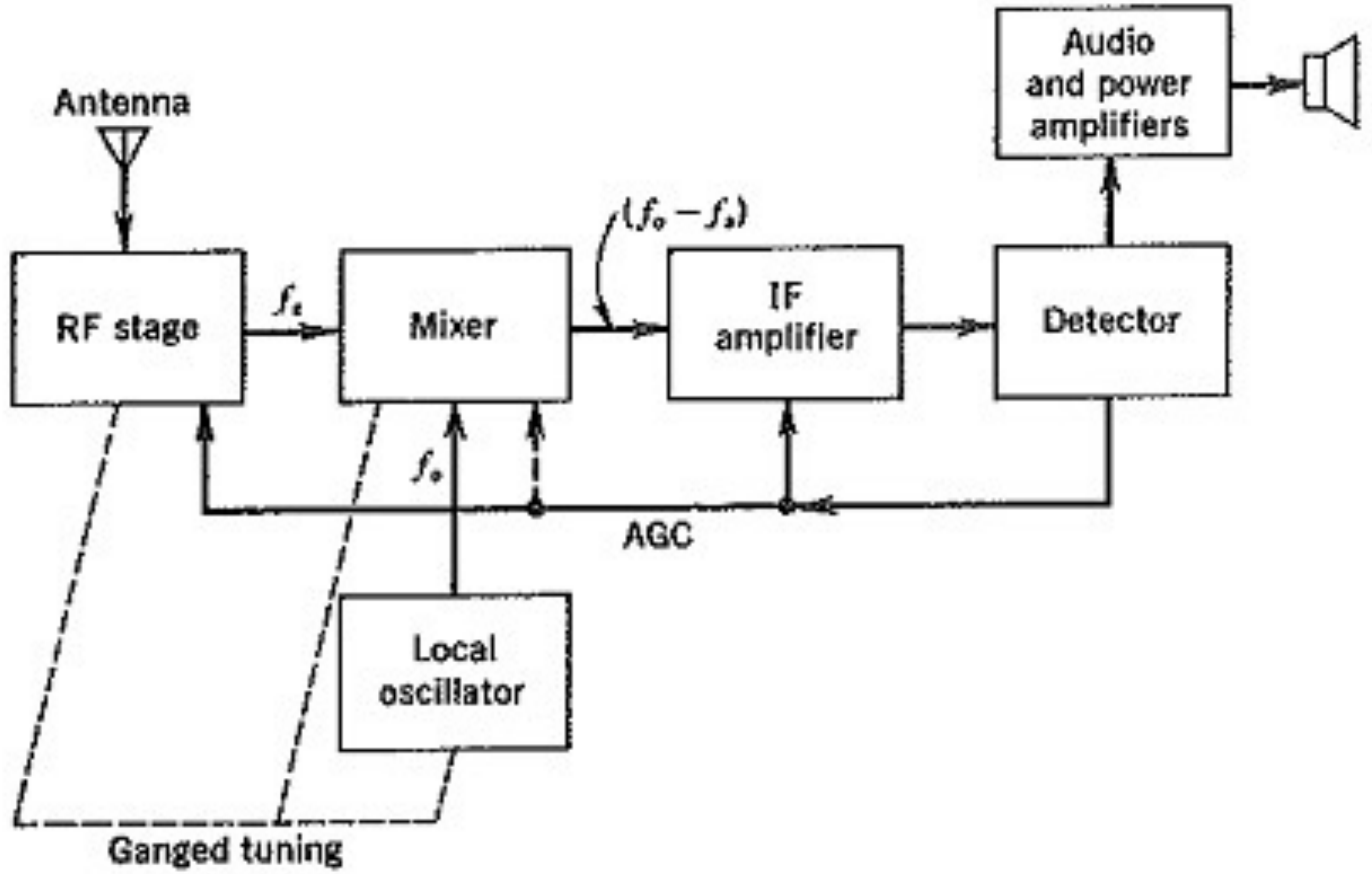


FIGURE 6-2 The superheterodyne receiver.

https://www.eeeguide.com/superheterodyne-principle/

The RF Stage

- Up front have a pentode that can work at high frequencies perform some initial amplification.

- Also have a broad selection filter that is tunable that can remove some out-of-signal junk

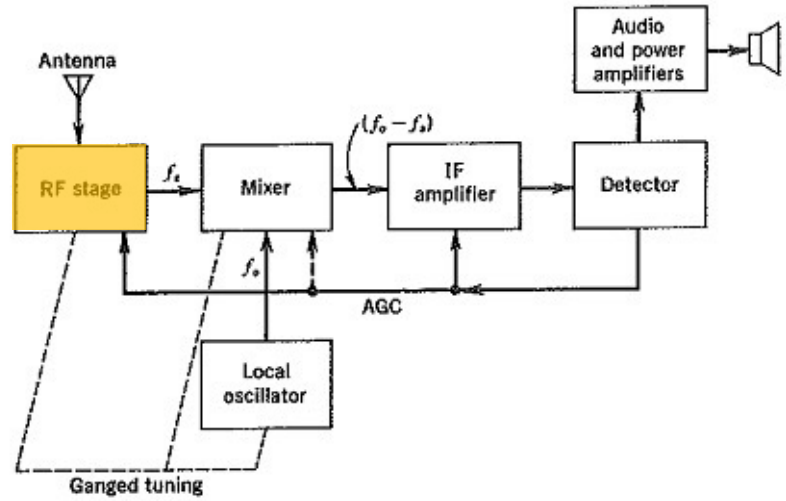


FIGURE 6-2 The superheterodyne receiver.

https://www.eeeguide.com/superheterodyne-principle/

The Local Oscillator (aka “LO”)

- Have a tube-driven local oscillator circuit that runs at a frequency f_{IF} *below* what we are trying to tune for

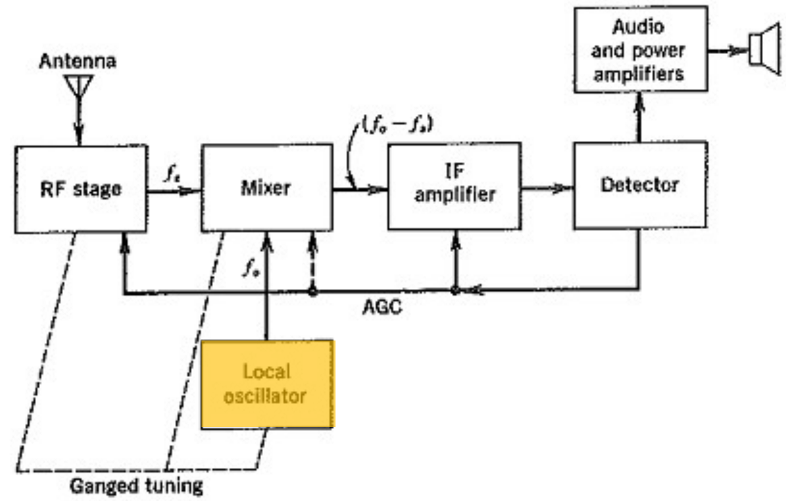


FIGURE 6-2 The superheterodyne receiver.

https://www.eeeguide.com/superheterodyne-principle/

The Mixer

- This is the stage that ”mixes” (multiply in this context) the two signals to get the IF out.
- If the RF stage and the LO are properly synchronized the output of the multiply will always be the same IF value (455 kHz in most American AM radios)
- IF stands for “Intermediate Frequency”

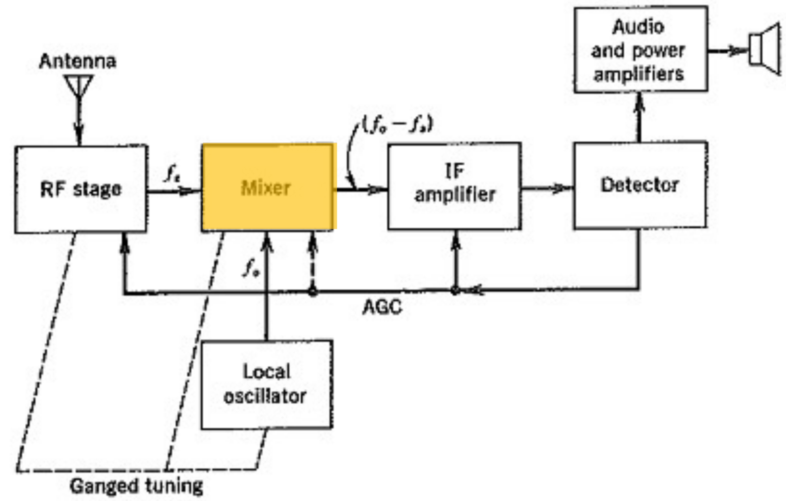


FIGURE 6-2 The superheterodyne receiver.

https://www.eeeguide.com/superheterodyne-principle/

How Do We Multiply?

- Silly question. We already went over this.

- We have amplifying devices that can be made to work in non-linear modes of operation. Add the signals you care about together, and run them through a tube in a particularly non-linear region and harvest the squaring signals (via F.O.I.L.) that come out and block with some filters!
- Profit
- Moving on…

The RF/Mixer/LO

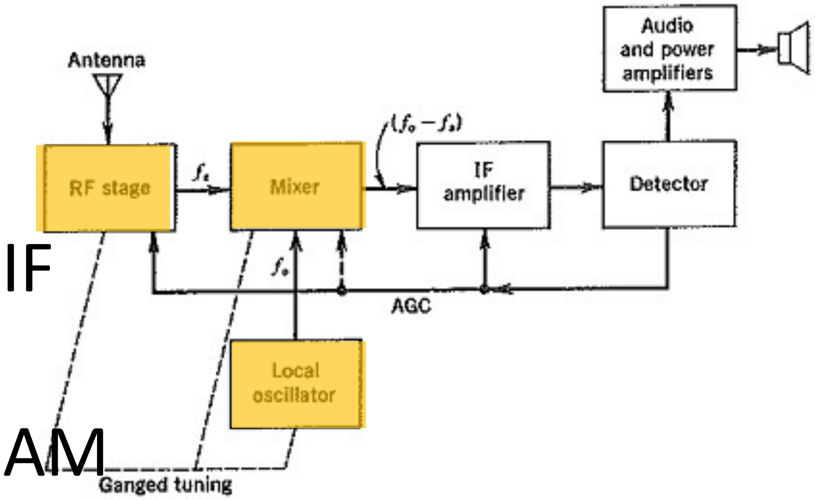


FIGURE 6-2 The superheterodyne receiver.

- For AM, sets usually targeted an IF of 455 kHz.
- So if you wanted 1080kHz in the AM band...
  - Your RF stage BPF set at 1080kHz
  - Your LO be set at: 625 kHz
  - Mixer/filter yields 1080-645=455 kHz
- If wanted 1500kHz in AM band...
  - Your RF stage BPF set to 1500 kHz
  - Your LO be set at 1.045MHz
  - Mixer/filter yields 1500-1045=455kHz

https://www.eeeguide.com/superheterodyne-principle/

Ganged Tuning

- Have the variable C's (or L's) "ganged" together so that when you vary the RF tuning filter, you also vary the LO so it remains at the correct frequency offset

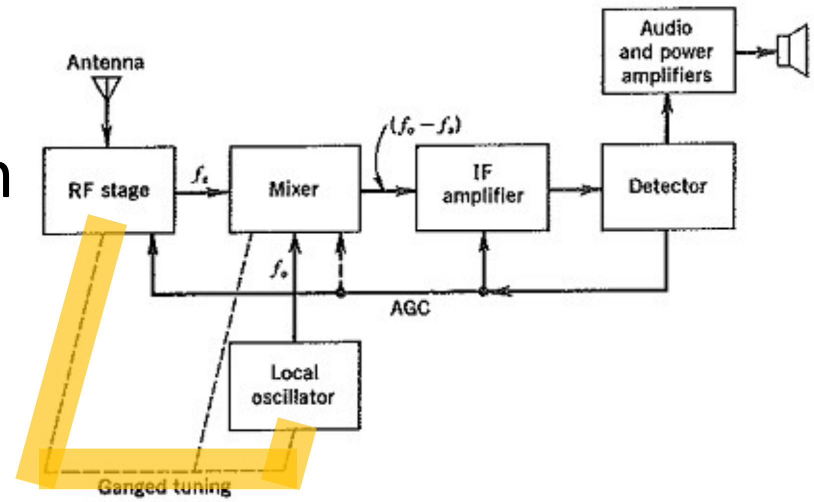
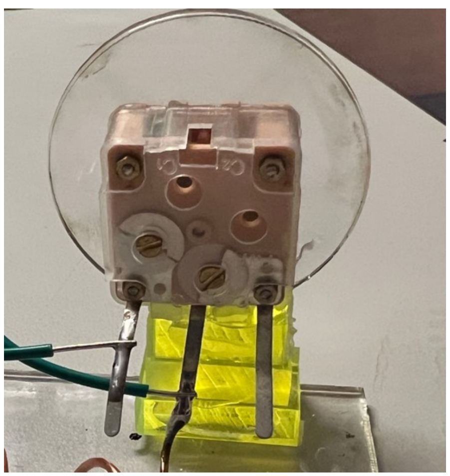
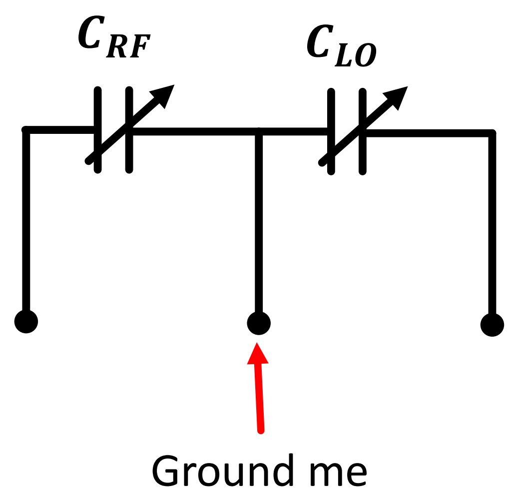


FIGURE 6-2 The superheterodyne receiver.



Schematic of lab 1 tuning cap



https://www.eeeguide.com/superheterodyne-principle/

The IF Amp

- This circuit can be special-made to work in and around the IF.
- This ability to not have to be flexible with center frequency can allow very nice tuning of the circuit overall (and very good filtering of signals outside our signal window)
- Note the signal is still modulated (AM…later FM or PM) in the IF circuit

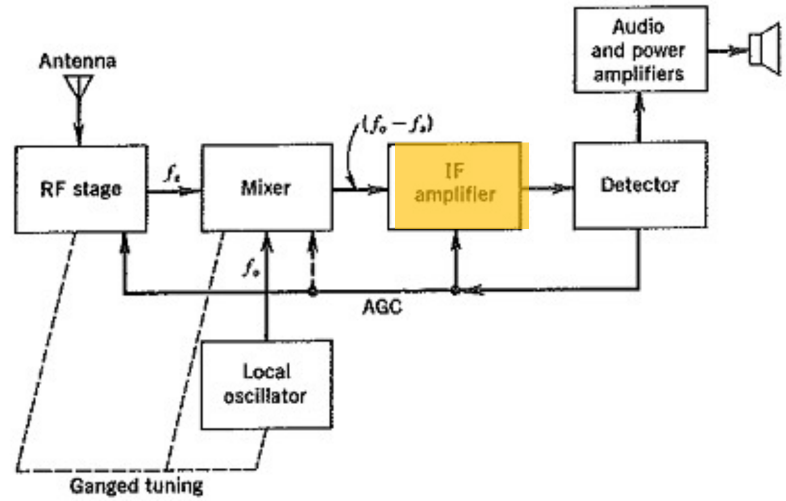


FIGURE 6-2 The superheterodyne receiver.

Intermediate Frequency is also similar to "base band" in modern radio tech

https://www.eeeguide.com/superheterodyne-principle/

The Detector

- Finally demodulate using the ways we've discussed.
- This stage isn't much different than other ways before
- But easier to build since it only had to demodulate at one specific frequency

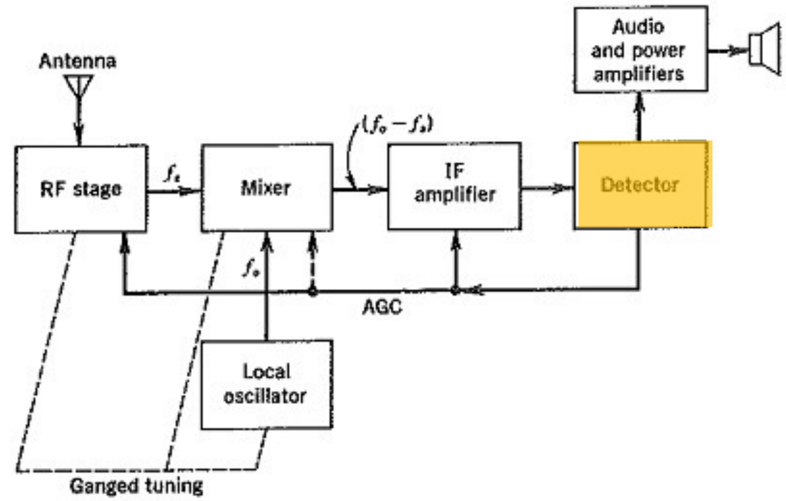


FIGURE 6-2 The superheterodyne receiver.

https://www.eeeguide.com/superheterodyne-principle/

The Audio Amplifier

- Just make the audio louder (scale in power)

- All good!

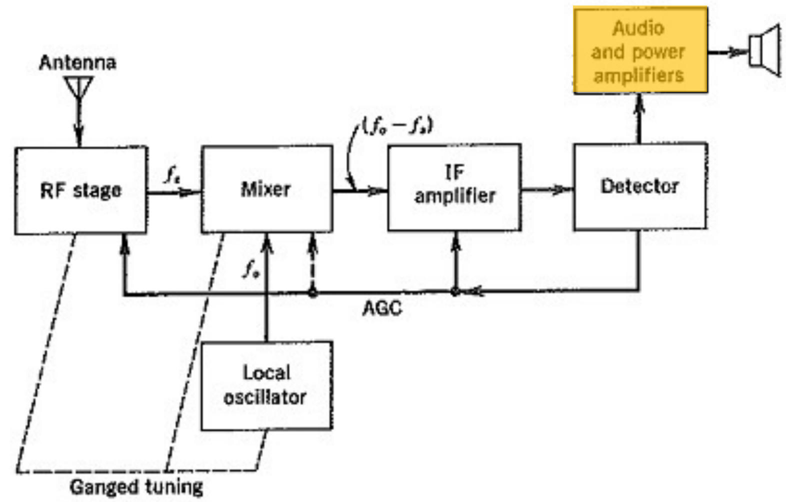


FIGURE 6-2 The superheterodyne receiver.

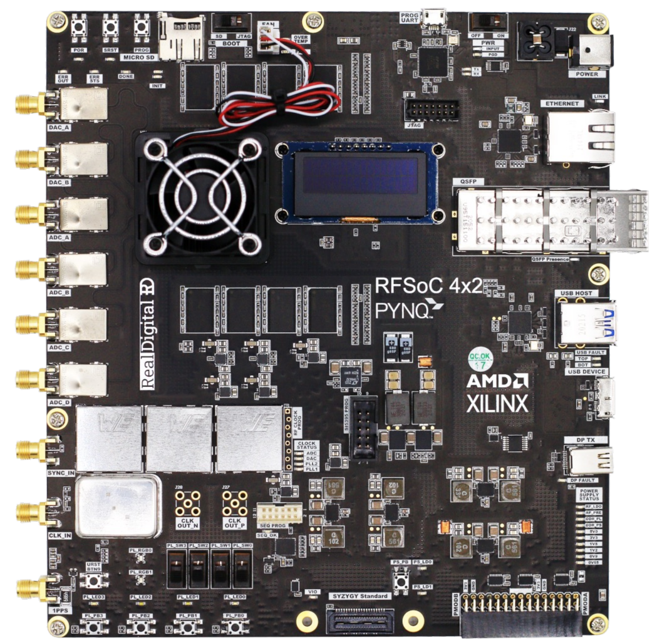
https://www.eeeguide.com/superheterodyne-principle/

The Superheterodyne

- Armstrong wasn't the only inventor of heterodyning, but he did have the dominant US patent and he did get the earliest versions of it working
- Sold that patent to RCA as well..made so much money that he basically set up his own privately funded research lab to keep working on stuff.
- *To this day*, most radio stuff (WiFi, etc…) utilizes some flavor of heterodyning in its signal path. It is a very important signal processing technique.

Even in modern systems...

- Still heterodyne
- The RFSoCs we use in 6.S965...
  - Sample at 5Gsps
  - Just do down conversion (heterodyne) digitally rather than in analog



RCA

- RCA dominated the radio ecosystem in the 1920s and 1930s…they were the *Radio* Corporation of America after all

- Had the Armstrong superheterodyne patent so RCA radios were very good compared to competitors that were mostly TRFs by this point (which needed a lot more tubes and could not compete with superheterodyne sets in terms of performance)
- RCA built and owned radio stations and networking.
- You listened to RCA content on RCA stations using RCA radio sets. Seems perfectly American.

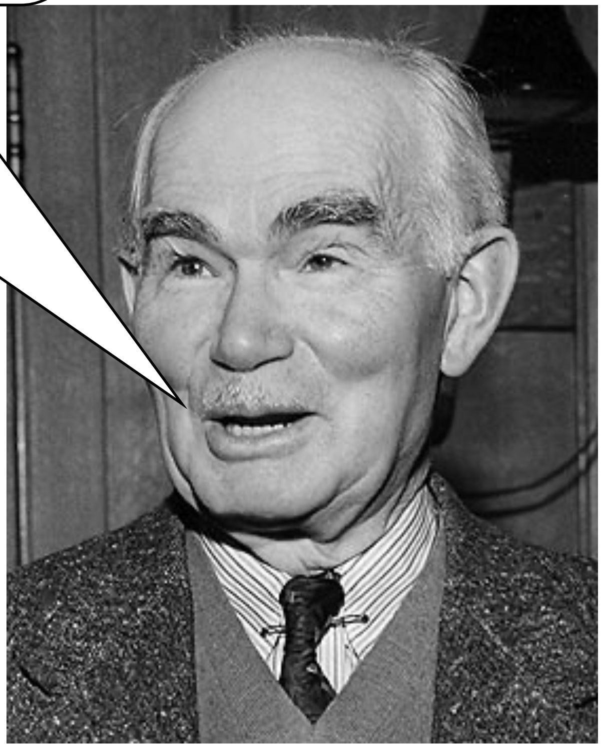
FM

- Armstrong got annoyed by the noise that AM radio was prone to so he invented FM (his greatest invention)
- RCA, who Armstrong was close with, did not like this because it endangered their monopoly on AM... So they set up competing patents, lobbied the FCC to change frequency/power rules that made Armstrong's patents less usable, all to basically block/take over FM and had money to litigate and stall Armstrong
- Huge patent fight…drawn out for decades.
- Armstrong lost all his money and jumped off a building in 1954…everyone blamed RCA/Sarnoff
- His wife continued the patent fight and eventually won 10-20 million in damages

DeForest…

“I have always taken the keenest delight in having beaten him so thoroughly on the feed-back question… after all, Armstrong has gone and I am alive, well and happy, and hope to live for many years more. What a contrast!”

- This guy was
- He died largely bankrupt in the late 1950s still claiming to have invented everything



https://kathylovesphysics.com/the-trials-of-howard-armstrong/#_edn24

Commodity Radios

- Superheterodyning enabled cheap, good radios.
- Radios proliferated.
- Even in the 1930's/depression, this was how people connected
- Radio was *the internet* of the 1920s-early 1950s before being supplanted by TV.

1929 Bosch Model 28

- About $135 without tubes in 1929...new car was about $300...that’s a lot of money

- Also 1929 was the....

- Stock Market Crash (beginning of Great Depression)

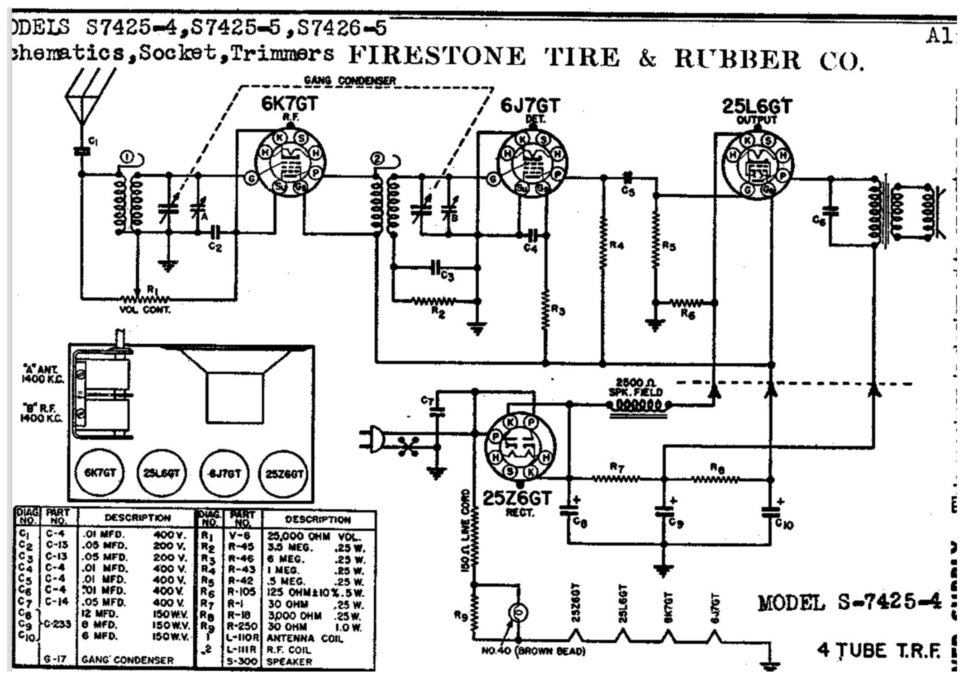
1939 Firestone Air Chief Radio Model No. S7425

- Pre-war *budget set*.
- Made by Firestone (yes the tire company)
- Was a TRF rather than superheterodyne to avoid paying patent royalties to RCA
- Extremely dangerous set
- But...cost **$19.95** with tubes in 1939

S7425

- Non-isolated chassis
- Uses curtain-burner cord to drop voltage (about 35W)...can't run on 120VAC right now...need to use variable transformer and drive on ~80Volts
- Not amazing reception...
- But it worked...

Originally used an Asbestos power cable to drop the voltage to save money by cutting transformer



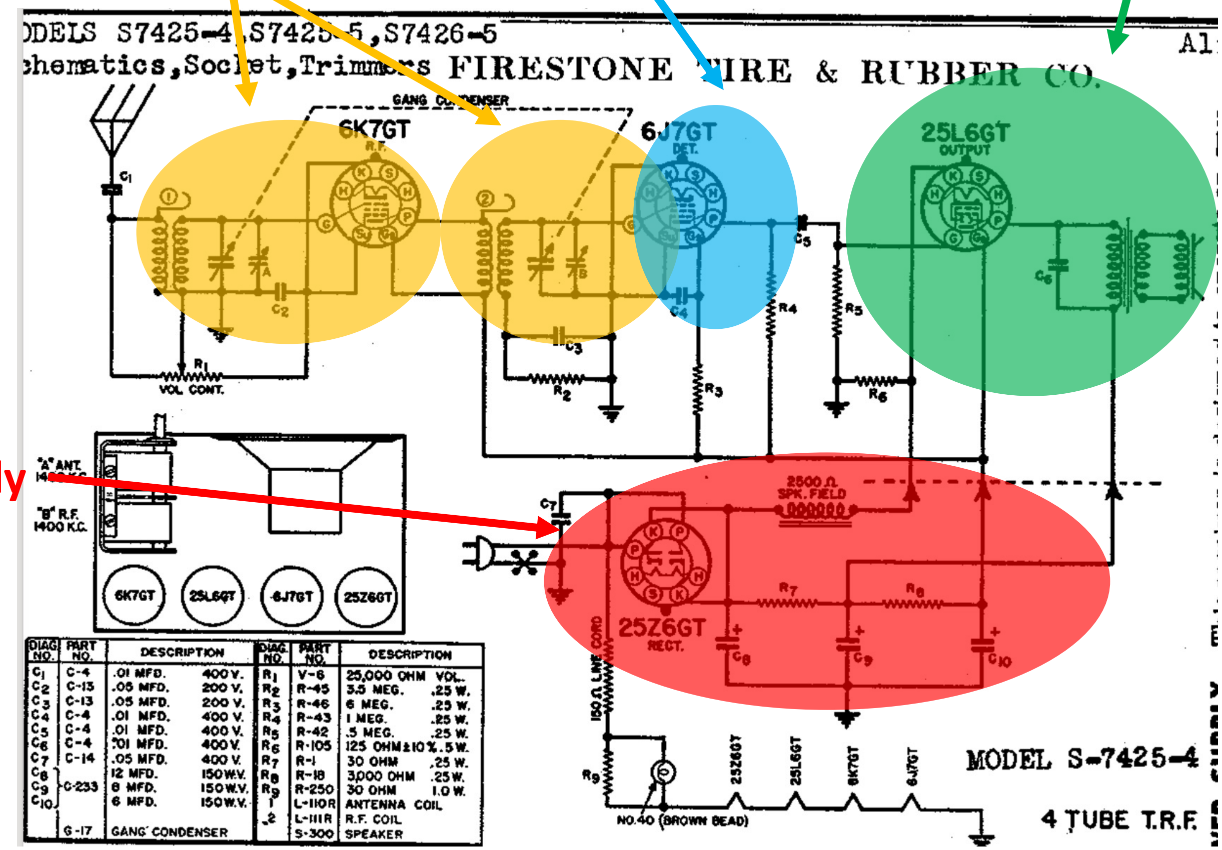
S7425

Detector/Demodulate
Use Pentode grid for nonlinearity

Audio Power Amp

Two stages of RF filtering

Power Supply



DIAG. NO.	PART NO.	DESCRIPTION		DIAG. NO.	PART NO.	DESCRIPTION	
C_1	C-4	.01 MFD.	400 V.	R_1	V-6	25,000 OHM	VOL.
C_2	C-13	.05 MFD.	200 V.	R_2	R-45	3.5 MEG.	.25 W.
C_3	C-13	.05 MFD.	200 V.	R_3	R-46	6 MEG.	.25 W.
C_4	C-4	.01 MFD.	400 V.	R_4	R-43	1 MEG.	.25 W.
C_5	C-4	.01 MFD.	400 V.	R_5	R-42	.5 MEG.	.25 W.
C_6	C-4	.01 MFD.	400 V.	R_6	R-105	125 OHM±10%	.5 W.
C_7	C-14	.05 MFD.	400 V.	R_7	R-1	30 OHM	.25 W.
C_8	C-233	12 MFD.	150 W.V.	R_8	R-18	3,000 OHM	.25 W.
C_9	C-233	8 MFD.	150 W.V.	R_9	R-250	30 OHM	1.0 W.
C_{10}	C-233	6 MFD.	150 W.V.	1	L-110R	ANTENNA COIL	
				2	L-111R	R.F. COIL	
	G-17	GANG CONDENSER			S-300	SPEAKER	

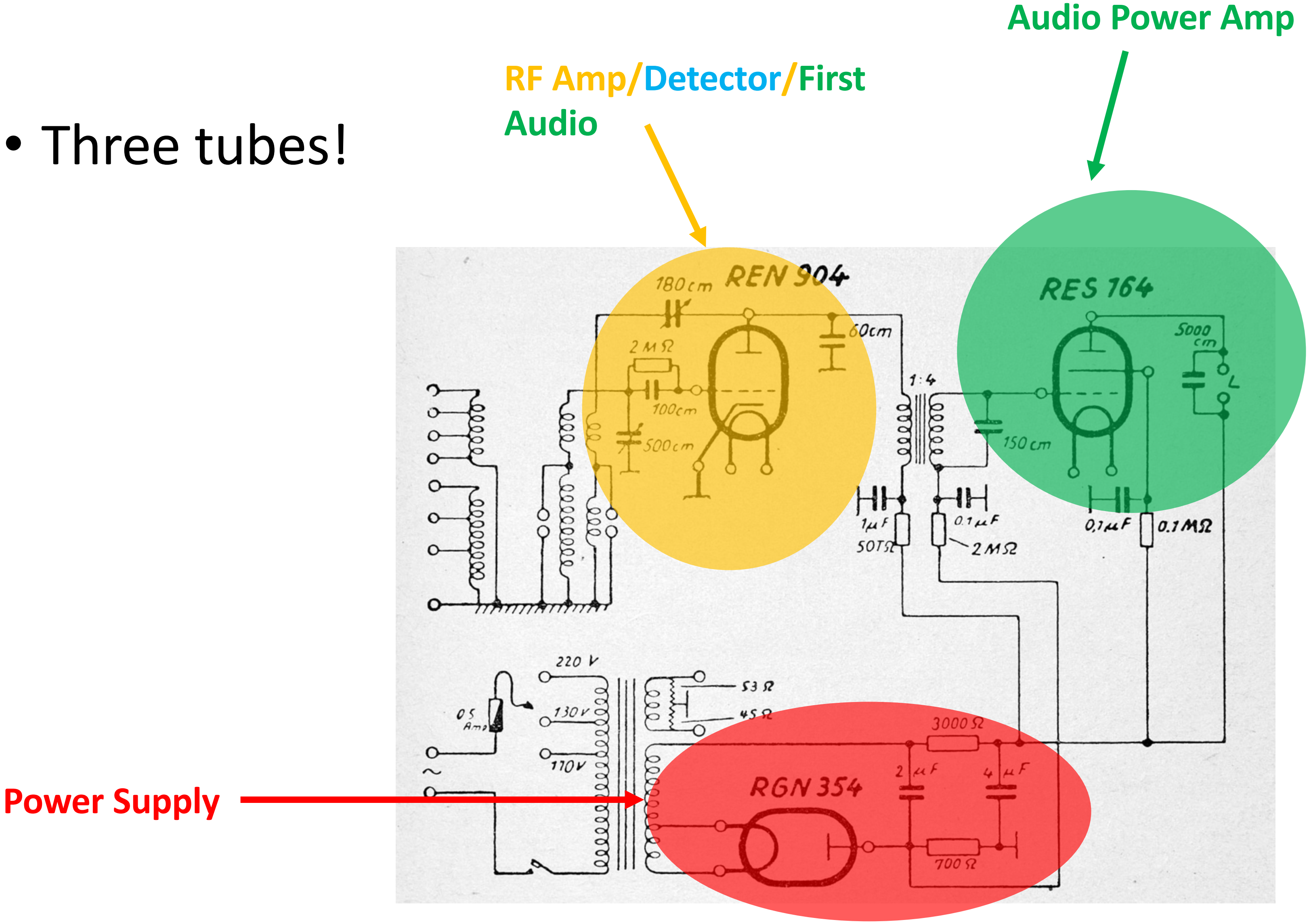
Radio/Broadcast Audio Everywhere

- By 1930's, cheap, robust sets changed the world. Its impact cannot be understated
- Radio shows were listened to by millions
- Real-time news
- Society became synchronized at many levels never before achieved
- People got to hear leaders speak

Fireside Chats by FDR

German Volksempfanger Radio

- Three tubes!



The People's Radio: Nazi Germany

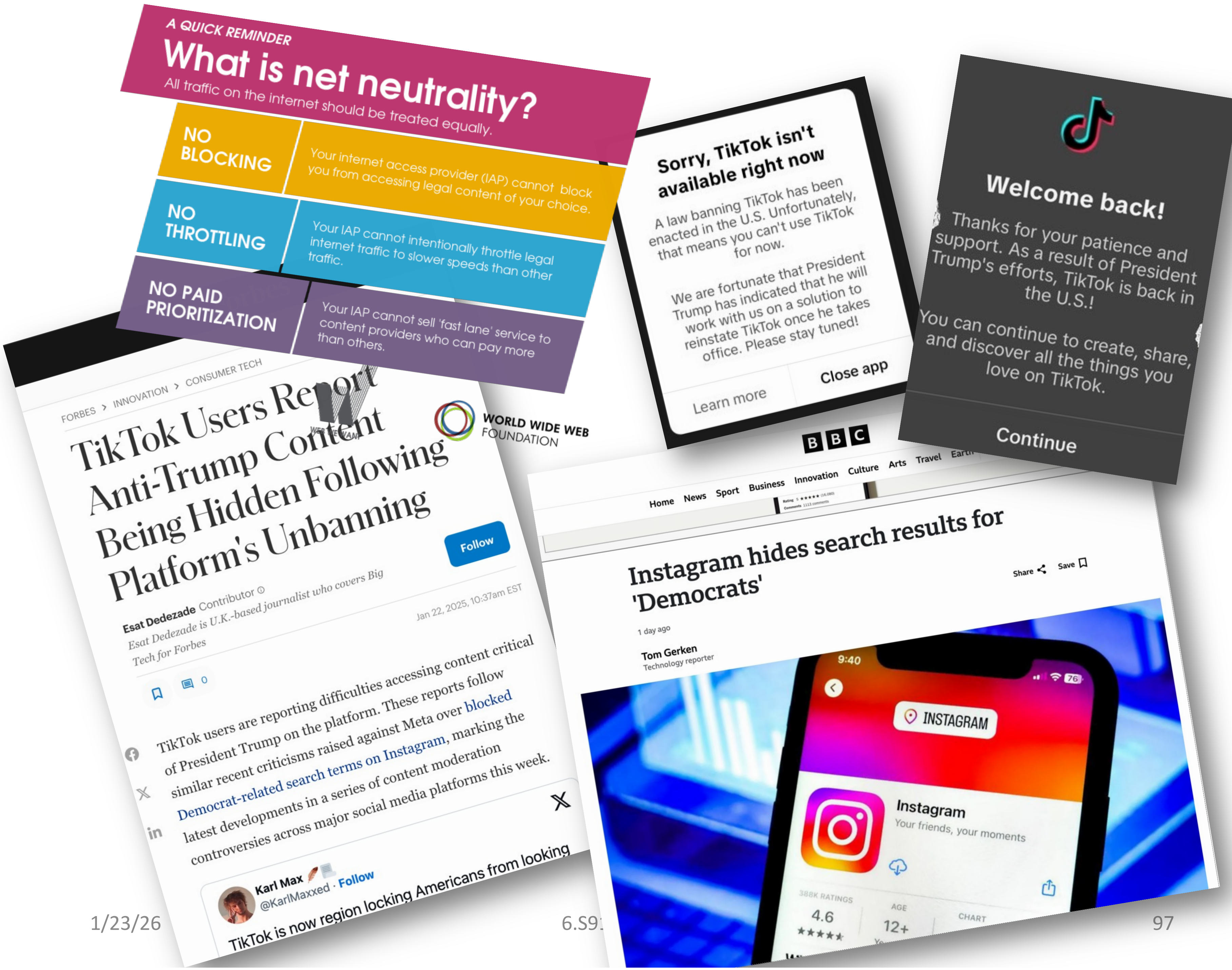
- Hitler and Goebbels assigned engineers to design an extremely simple and affordable tube radio
- Called *Volksempfanger*
- Millions of these sets sold…enabled propaganda to be blasted into everyone's houses

Hitler's dictatorship differed in one fundamental point from all its predecessors in history. His was the first dictatorship in the present period of modern technical development, a dictatorship which made the complete use of all technical means for domination of its own country. Through technical devices like the radio and loudspeaker, 80 million people were deprived of independent thought. It was thereby possible to subject them to the will of one man...

-Albert Speer
Nuremburg Trials 1946

https://en.wikipedia.org/wiki/Volksempf%C3%A4nger

http://oz6gh.byethost33.com/Volksempfanger.htm


A QUICK REMINDER
What is net neutrality?
All traffic on the internet should be treated equally.
NO BLOCKING
Your internet access provider (IAP) cannot block you from accessing legal content of your choice.
NO THROTTLING
Your IAP cannot intentionally throttle legal internet traffic to slower speeds than other traffic.
NO PAID PRIORITIZATION
Your IAP cannot sell 'fast lane' service to content providers who can pay more than others.
Sorry, TikTok isn't available right now
A law banning TikTok has been enacted in the U.S. Unfortunately, that means you can't use TikTok for now.
We are fortunate that President Trump has indicated that he will work with us on a solution to reinstate TikTok once he takes office. Please stay tuned!
Learn more
Close app
Welcome back!
Thanks for your patience and support. As a result of President Trump's efforts, TikTok is back in the U.S.!
You can continue to create, share, and discover all the things you love on TikTok.
Continue
FORBES > INNOVATION > CONSUMER TECH
TikTok Users Report Anti-Trump Content Being Hidden Following Platform's Unbanning
WORLD WIDE WEB FOUNDATION
Follow
Esat Dedezade Contributor
Esat Dedezade is U.K.-based journalist who covers Big Tech for Forbes
Jan 22, 2025, 10:37am EST
TikTok users are reporting difficulties accessing content critical of President Trump on the platform. These reports follow similar recent criticisms raised against Meta over blocked Democrat-related search terms on Instagram, marking the latest developments in a series of content moderation controversies across major social media platforms this week.
Karl Max @KarlMaxxed · Follow
TikTok is now region locking Americans from looking
BBC
Home News Sport Business Innovation Culture Arts Travel Earth
Instagram hides search results for 'Democrats'
Share Save
1 day ago
Tom Gerken
Technology reporter
9:40
INSTAGRAM
Instagram
Your friends, your moments
388K RATINGS
4.6
AGE
12+
CHART

History Reminder

- The world was at war from 1937-1945. This was really the first techno-centric war. Vacuum tubes and radio were at the heart of it
- Much of our modern understanding of all of EECS was accelerated during this time period because governments basically gave blank checks to researchers.
- MIT really, really, really expanded during WW2 in terms of research

Radio in WW2

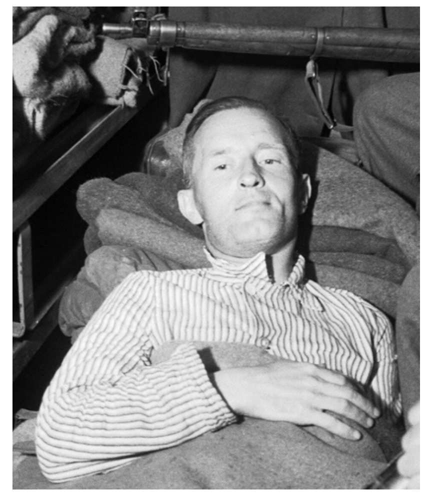
- Direction Finding
- RADAR
- SONAR
- Electronic Warfare
- Countermeasures
- Early computer development...

https://en.wikipedia.org/wiki/List_of_World_War_II_electronic_warfare_equipment

Radio Propaganda

- During the Occupation of France by Nazi Germany, England right across the channel would broadcast messages meant to coordinate the Resistance and other things.

- Battle of propaganda:
  - Germany broadcast to England
  - England to Germany/France
  - US to Japan
  - Japan to US



Lord Haw Haw

WW2 Jamming

- Radios in German-occupied Europe would either be collected/confiscated or have their tuning capacitors/inductors fixed in place...varying them could lead to imprisonment/death...just listening to another station could be punished.

- Each side would jam the other

"Wound my Heart with a Monotonous Langour"

- The BBC would routinely broadcast radio over Europe even while the Germans occupied countries during WW2.
- They'd intersperse messages for the Resistance in it.
- Verlaine's *Chanson d'automne* ("Autumn Song") was used to indicate the Allied invasion of France was about to begin to soon so the resistance could prepare...
  - *Les sanglots longs des violons de l'automne* meant the invasion was coming within two weeks
  - *Blessent mon cœur d'une langueur monotone* meant the invasion was happening within 48 hours (broadcast on June 5, 1944)

WW2

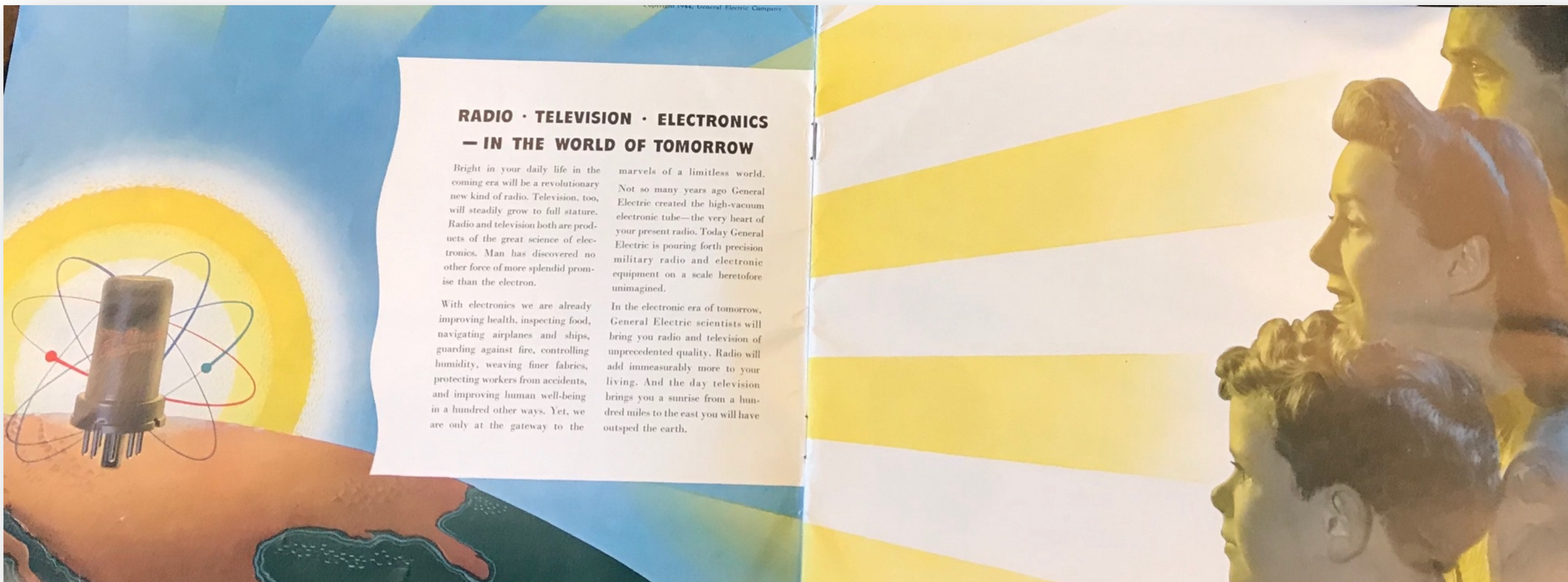

UNITED WE WIN


THE SATURDAY EVENING
POST
MAY 29, 1943
10¢
ROSIE
Norman Rockwell


BUY WAR BONDS

Obsession, Hope?

- US stopped production of most consumer electronics (mostly radios) ~1941 for WW2…became item of longing/black marketing in US



1944 GE teaser advertisement…they couldn't sell stuff but they sent out alluring images about future consumerism once Axis was beaten.

Interesting Aside

- Good NYTimes article today...(1/23/26)


IDEAS

It Makes Sense That People See A.I. as God

A religious fervor surrounds our relationship with technology.

Photo illustration by Alex Merto

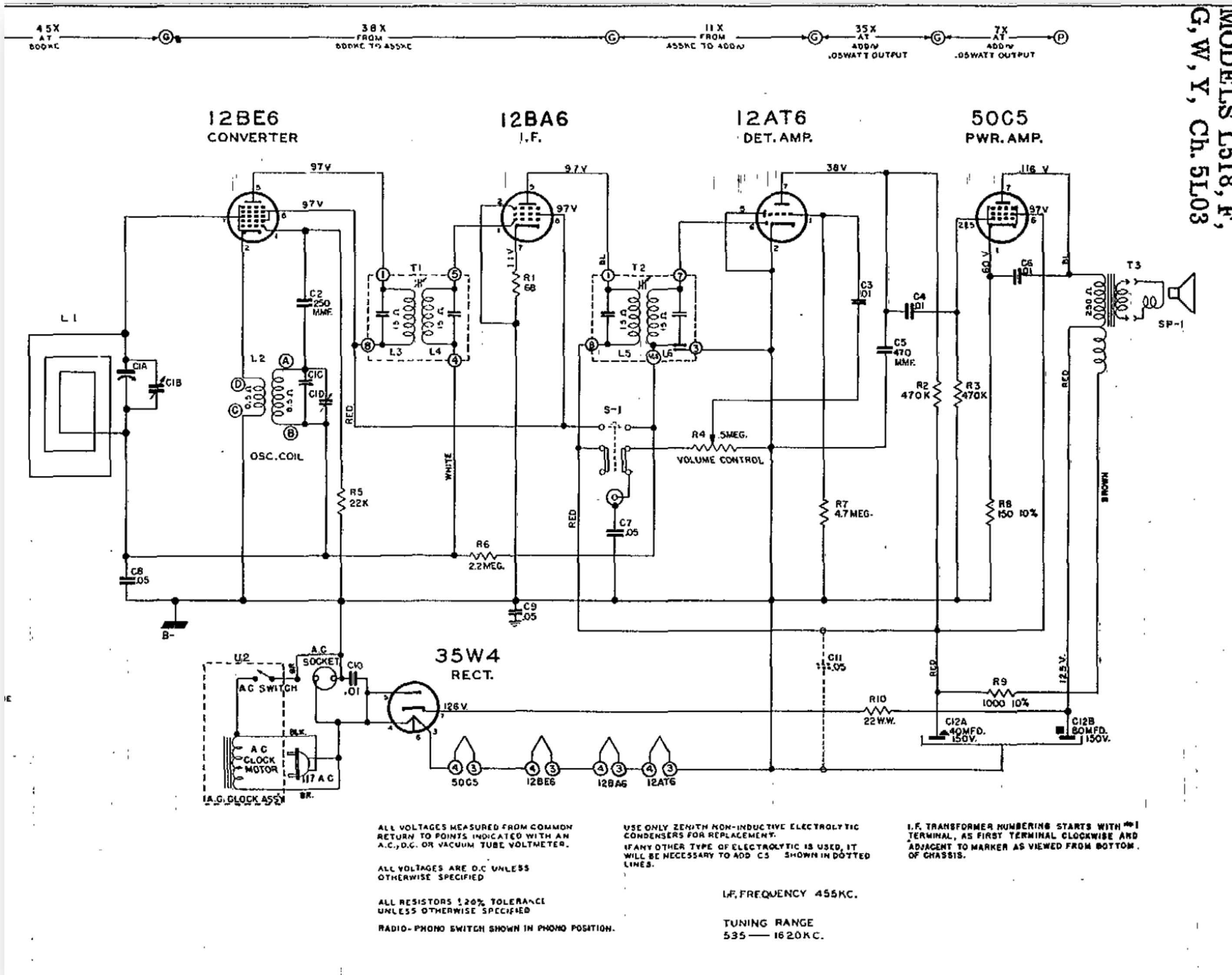
1953 Zenith L518

- Things went crazy after WW2 ended in 1945
- Postwar radio set, but still uses tubes in a superheterodyne configuration
- Not that different from prewar commodity sets

- An example of an

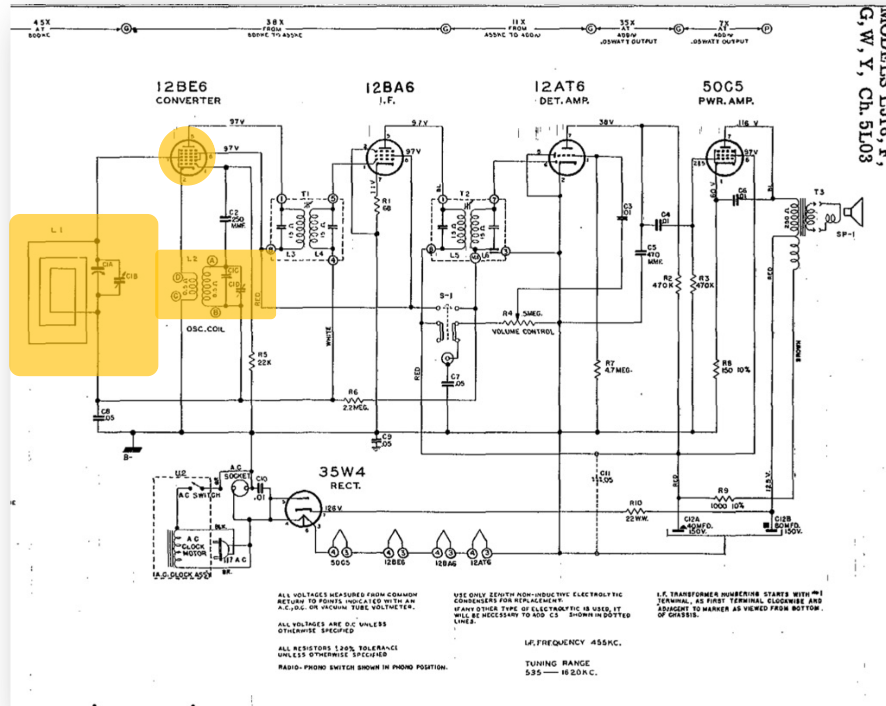
"All American Five" set

Zenith L518


MODELS L518, F, G, W, Y, Ch. 5L03
12BE6
CONVERTER
12BA6
I.F.
12AT6
DET. AMP.
50C5
PWR. AMP.
35W4
RECT.
OSC. COIL
VOLUME CONTROL
ALL VOLTAGES MEASURED FROM COMMON RETURN TO POINTS INDICATED WITH AN A.C., D.C. OR VACUUM TUBE VOLTMETER.
ALL VOLTAGES ARE D.C UNLESS OTHERWISE SPECIFIED
ALL RESISTORS ±20% TOLERANCE UNLESS OTHERWISE SPECIFIED
RADIO-PHONO SWITCH SHOWN IN PHONO POSITION.
USE ONLY ZENITH NON-INDUCTIVE ELECTROLYTIC CONDENSERS FOR REPLACEMENT.
IF ANY OTHER TYPE OF ELECTROLYTIC IS USED, IT WILL BE NECESSARY TO ADD C5 SHOWN IN DOTTED LINES.
I.F. FREQUENCY 455KC.
TUNING RANGE
535 — 1620KC.
I.F. TRANSFORMER NUMBERING STARTS WITH #1 TERMINAL, AS FIRST TERMINAL CLOCKWISE AND ADJACENT TO MARKER AS VIEWED FROM BOTTOM OF CHASSIS.

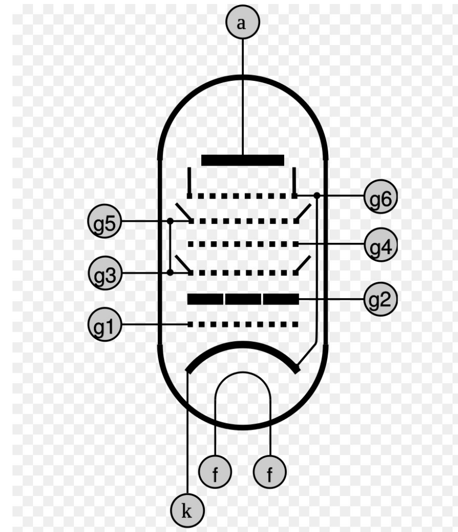
RF/Mixer/LO

- A single 12BE6 tube is used to do all the RF/mixing/LO stuff
- This was very common by the 1940s
- Woah…how did a tube do that?



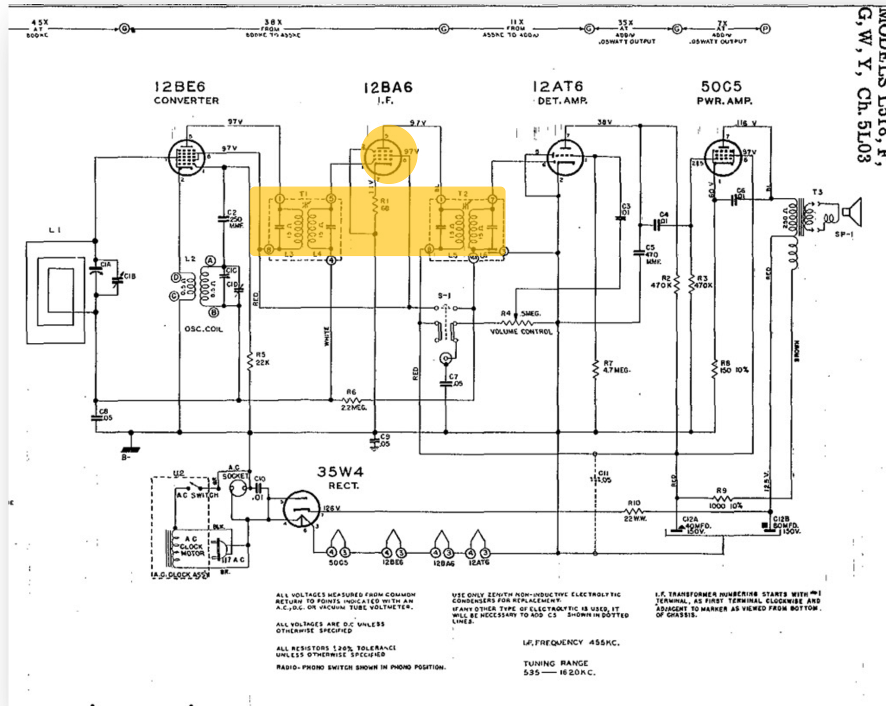
The Pentagrid Converter

- A heptode tube (seven electrodes) or a octode tube that was used to do the following all in one package:
  - RF Amplification
  - Manage the Local Oscillator
  - Mix the two signals and output on IF
- Still a tube, but a tube that had a lot more functionality built in.
- You could think of this an early form of integrated circuit maybe



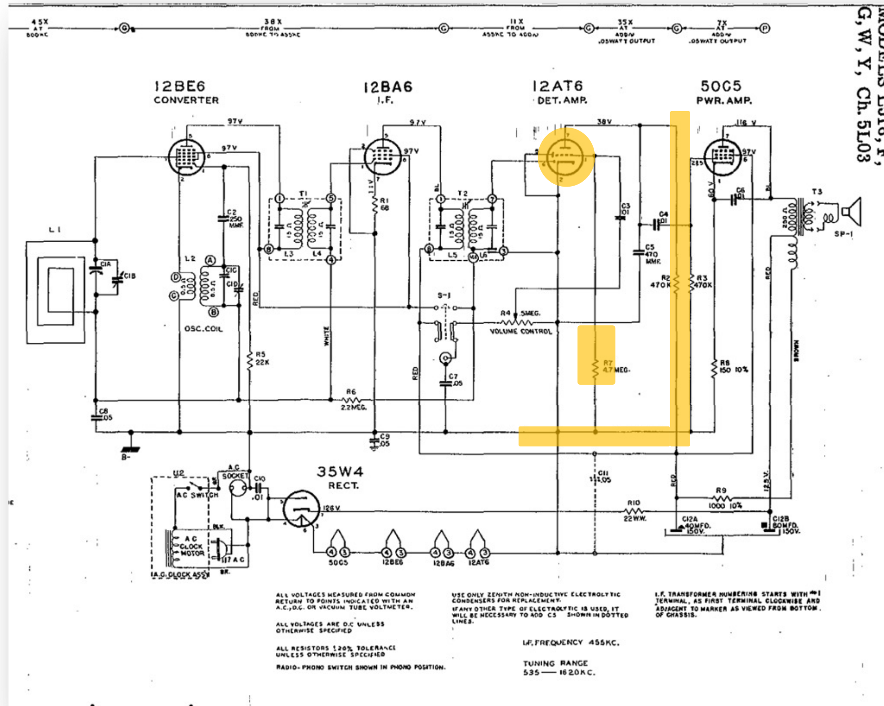
IF Amp

- A 12BA6 pentode was used to amplify and filter at the IF of 455 kHz



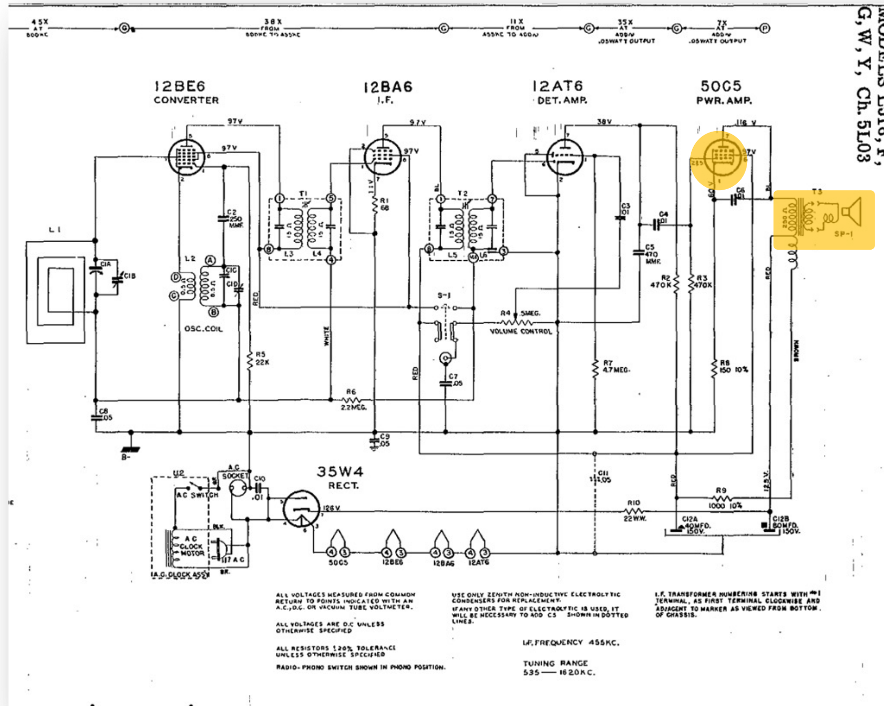
Detector

- A 12AT6 Double-diode triode was used for detection, audio amplification, and automatic gain control
- Triode used for low noise



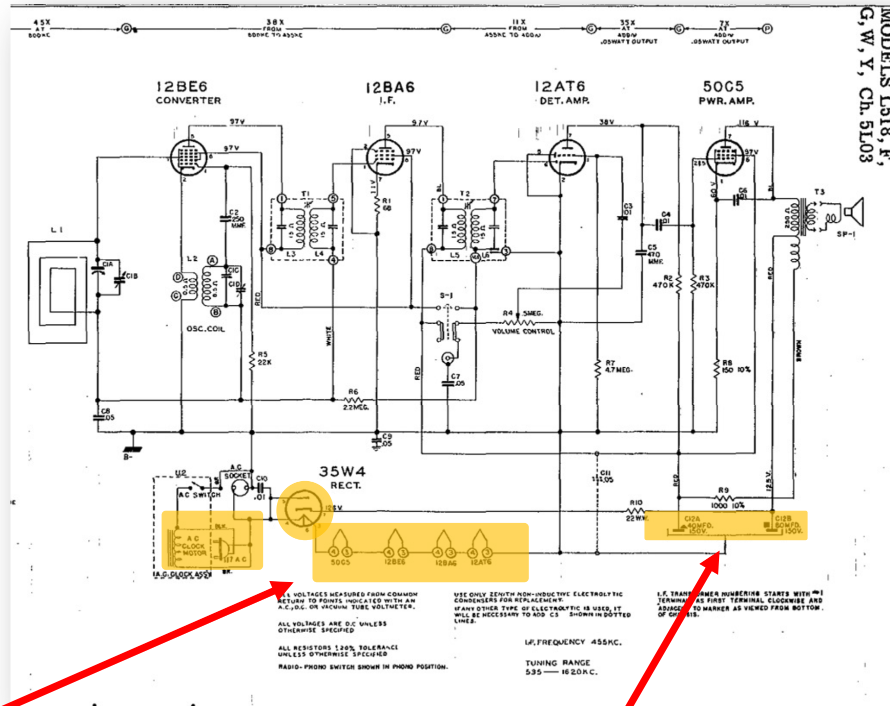
Audio Amp

- Big Beefy 50C5 Pentode used as power amplifier
- Speaker driven through coil for load matching



Power Supply

- 35W4 used for converting 120 VAC into about 150 VDC
- *No transformer.* This set was a hot-chassis (could get electrocuted opening touching the back side
- Notice how the filaments are all strung in series. Their filament voltages are:
  - 35+50+12+12+12 = 121V …$120V_{RMS}$?
  - Coincidence? Nope!

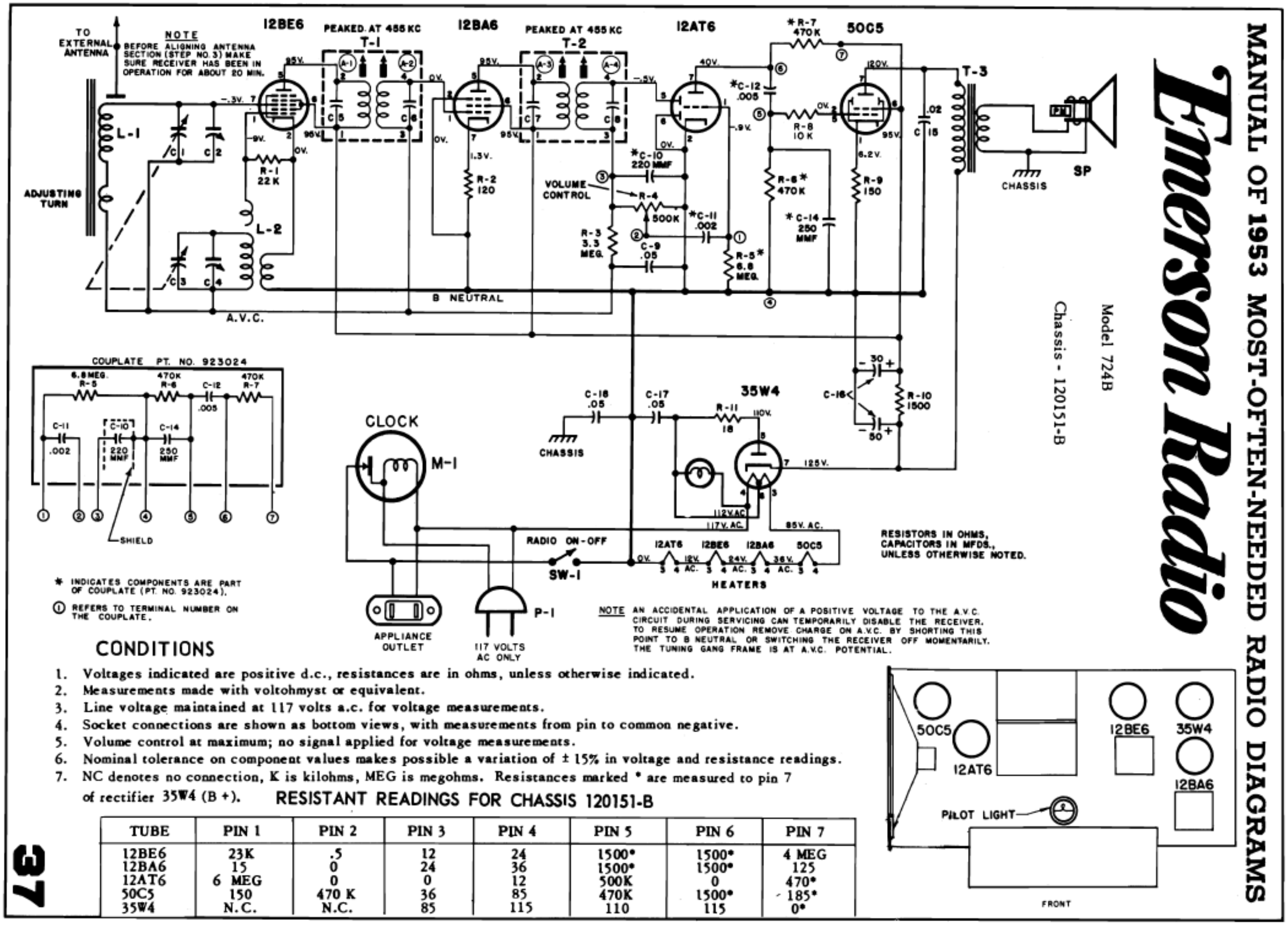


Big juicy caps to absorb the ripple from AC-DC conversion

1953 Emerson 724

- Another All-American-Five set also from 1953.
- Looks so different!
- So much better!!!

Emerson 724



CONDITIONS

1. Voltages indicated are positive d.c., resistances are in ohms, unless otherwise indicated.
2. Measurements made with voltohmyst or equivalent.
3. Line voltage maintained at 117 volts a.c. for voltage measurements.
4. Socket connections are shown as bottom views, with measurements from pin to common negative.
5. Volume control at maximum; no signal applied for voltage measurements.
6. Nominal tolerance on component values makes possible a variation of ± 15% in voltage and resistance readings.
7. NC denotes no connection, K is kilohms, MEG is megohms. Resistances marked * are measured to pin 7 of rectifier 35W4 (B +).

RESISTANT READINGS FOR CHASSIS 120151-B

TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7
12BE6	23K	.5	12	24	1500*	1500*	4 MEG
12BA6	15	0	24	36	1500*	1500*	125
12AT6	6 MEG	0	0	12	500K	0	470*
50C5	150	470 K	36	85	470K	1500*	185*
35W4	N.C.	N.C.	85	115	110	115	0*

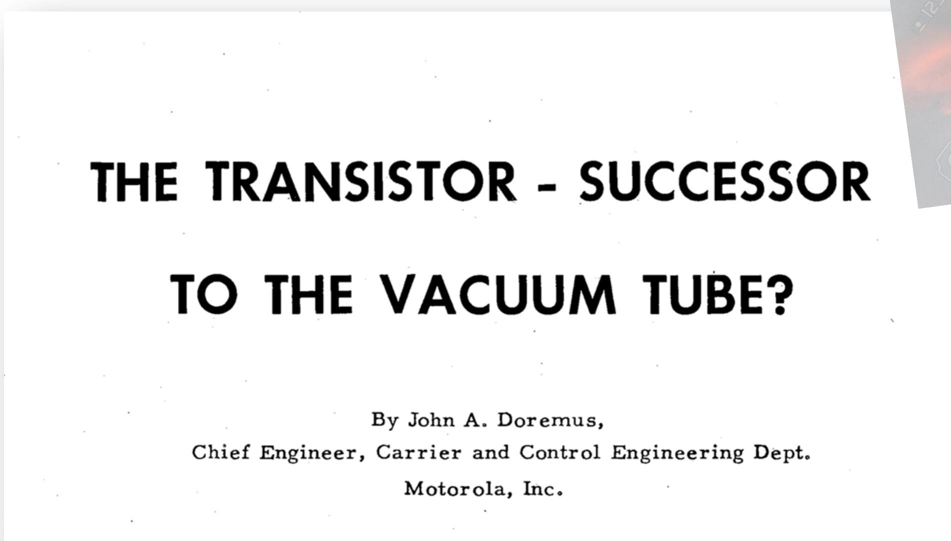
Basically exactly the same as L518

- Both sets use the same set of tubes:
  - 12BE6 Pentagrid converter (oscillation/heterodyning)
  - 12BA6 IF amplifier
  - 12AT6 Detector/first stage AF amp (pre-amp)
  - 50C5 power amp tube driving audio-transformer matched speaker
  - 35W4 for AC-DC conversion
- All the companies had nearly identical models at similar price points...you were mostly buying different cases and brands.

Next Time

- Solid-state triodes appear

Step aside, BoOmEr.
Low Key.



THE TRANSISTOR - SUCCESSOR TO THE VACUUM TUBE?

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