Lecture 6

Tube Electronics

Last Time

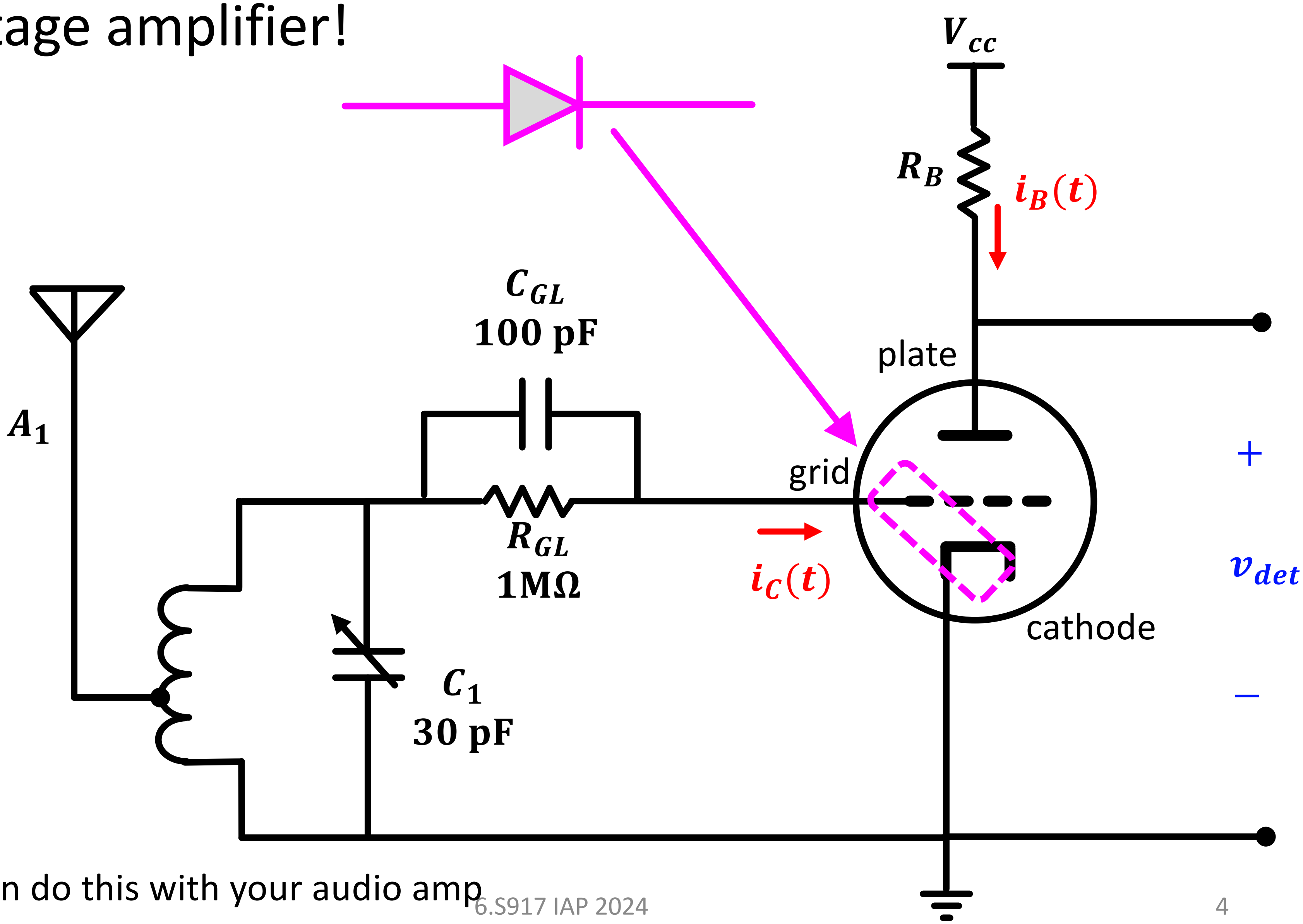
- Saw the appearance of feedback onto the scene and how it could be harnessed to our benefit.
- Also saw the evolution and development of the pentode.
- The pentode was a very transistor-like device in terms of its IV relationships and working with it was about as complicated as the triode (in terms of load-line analysis).

Other Uses

- In Lab 2 you built/are building an amplifier
- The tube was the first purely electronic amplifying and non-linear device that was reasonably robust. The floodgates opened in terms of developments as a result:
  - Detectors
  - Oscillators
  - Feedback Theory
  - Mixers
  - Memory/Digital Logic
  - Etc..
- While tubes are largely a dead tech now they were the stuff upon which all modern EECS was prototyped.

The Grid Leak Detector

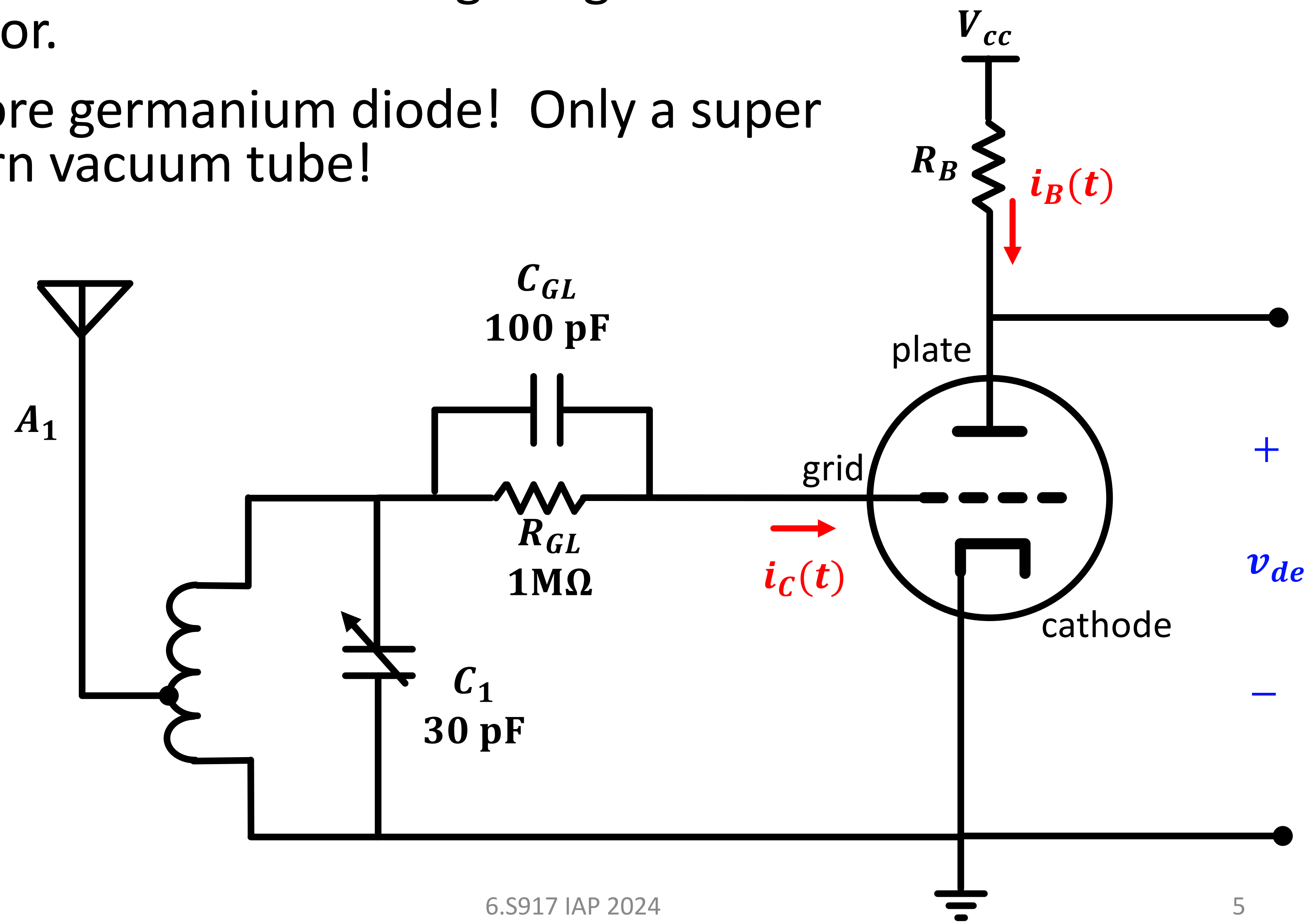
- The Tube pulled double duty as both a detector and first-stage amplifier!



BTW you can do this with your audio amp

The Grid Leak Detector

- Also btw in lab02, you can use the first 12AT7 triode like this and get a grid leak detector.
- No more germanium diode! Only a super modern vacuum tube!

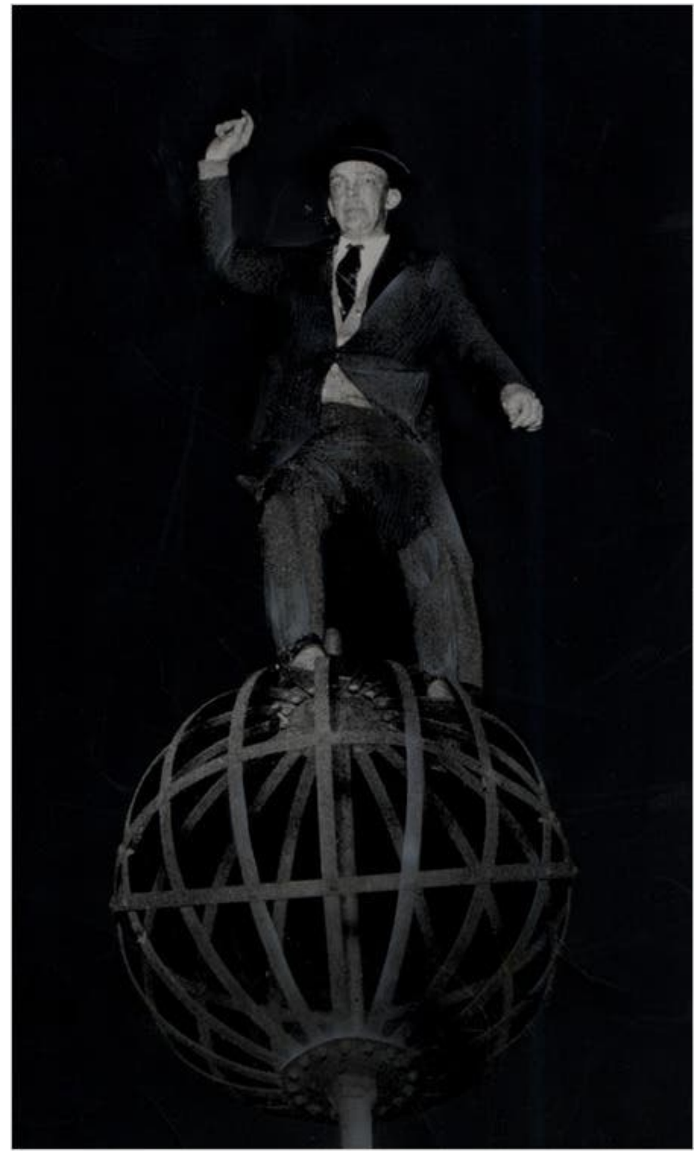


An Interesting Early Circuit Using Grid Leak Detector as Starting Point

- In the 1910's triodes were *just* getting figured out.
- Triodes also didn't have very high gain (that wouldn't come for almost 15 more years).
- Triodes were also very expensive
- Early wireless receivers couldn't amplify the received signal much
- They also weren't very selective (stations would bleed into one another…as you saw in lab01)
- In to solve this problem is…

Edwin Howard Armstrong

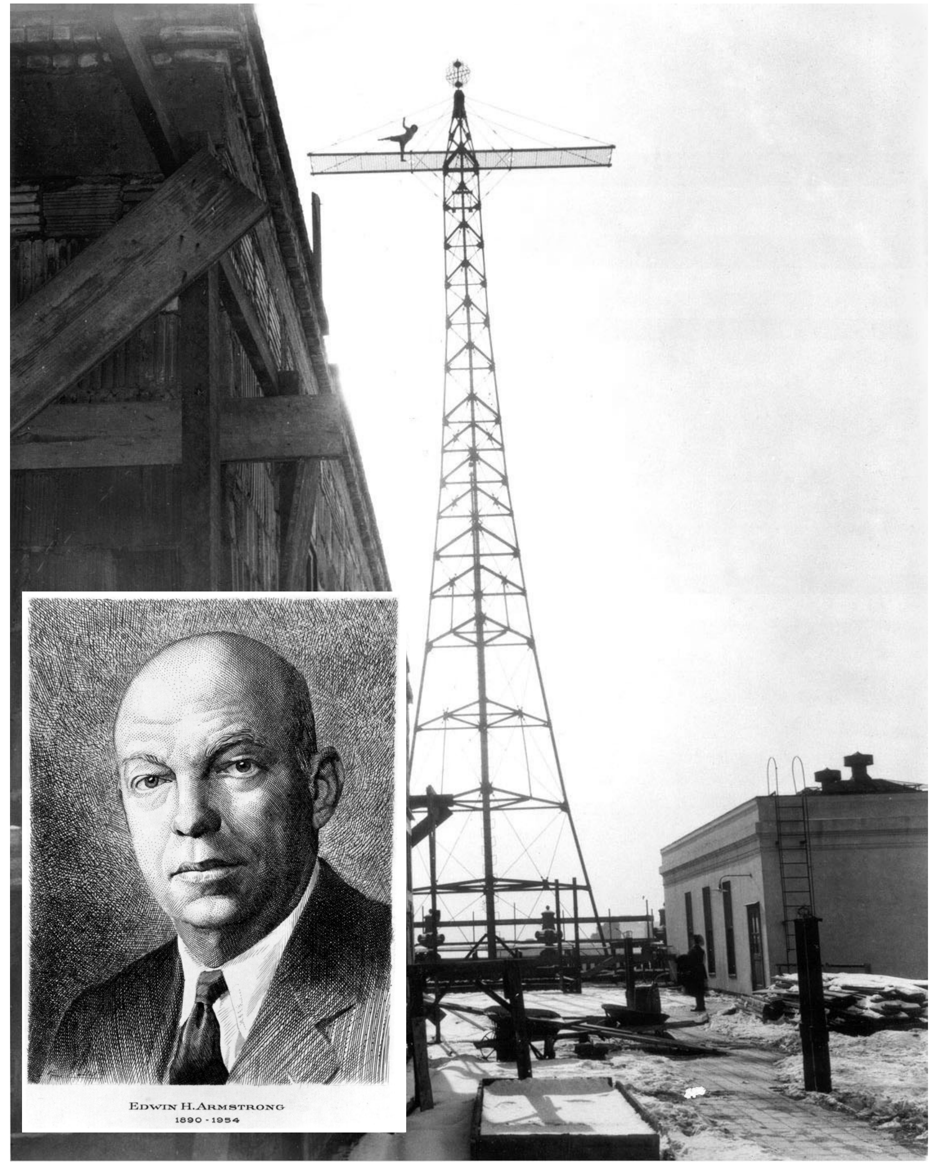
- An early 20th century EE who developed some of the most influential circuits of the last 100 years.
- The man worked in vacuum tube electronics the way other artists might work in oils or clay. It was his true medium, a master.
- His designs still have impact today.



Edwin H. Armstrong, on top of the WJZ station's antenna tower in New York in 1923, several hundred feet in the air.Credit...*Edwin H. Armstrong Papers, Rare Book and Manuscript Library, Columbia University*

Armstrong

- Born in 1890
- In 1913, while a senior at Columbia Engineering in NYC he solved the problem we're talking about (getting more gain out of early tubes)



Here's Edwin again dancing on that antenna on another day.

http://www.theradiohistorian.org/wjzgallery/images/wjz_armstrong.jpg

Aside:

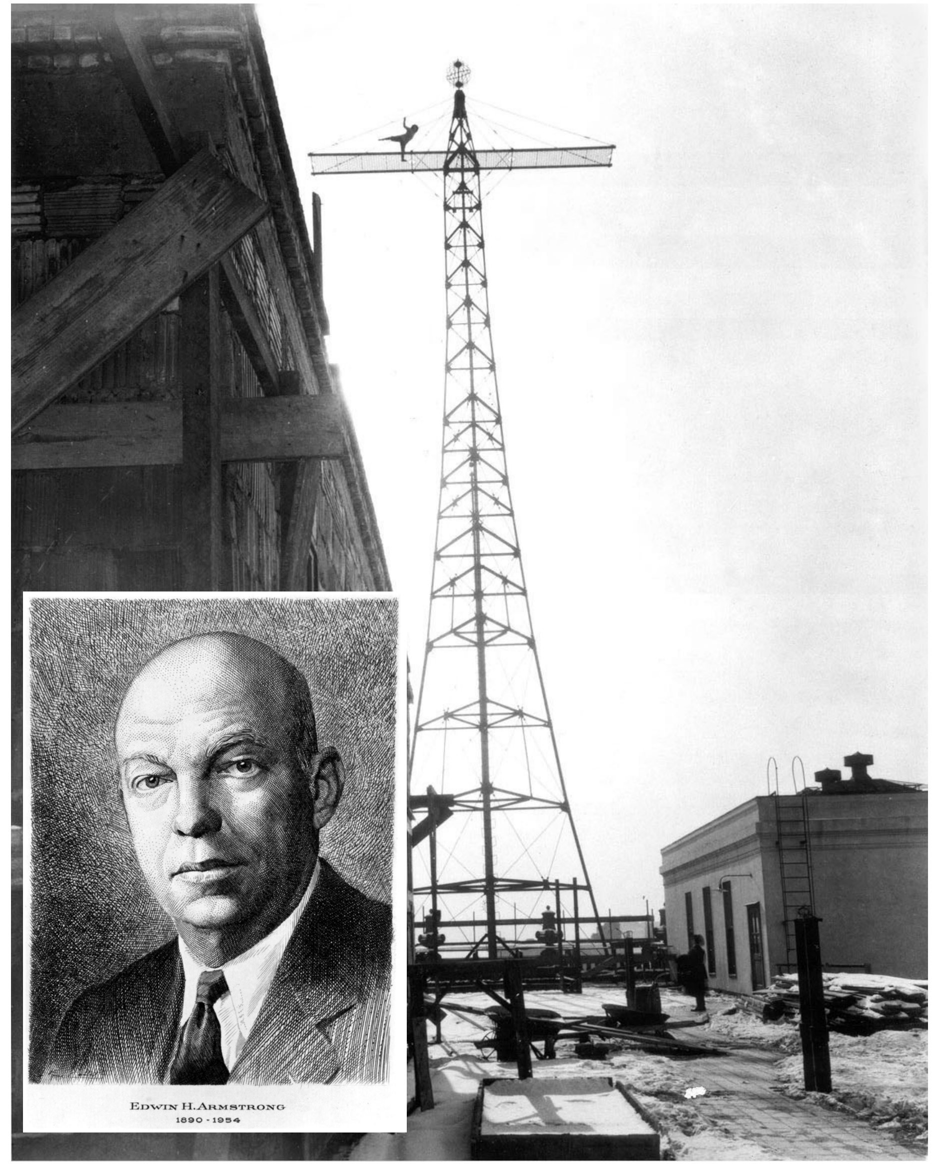
- Humans really got into doing things way up in the sky in the 1920s for some reason The obvious answer is skyscrapers and radio towers were shooting up in some cities and were unliked anything ever seen before.
- As a result people were like, :
  - what if I balanced chairs at the top of that building
  - Or sit on a flagpole for 20 hours?
  - These were all the tiktok challenges of the day
- So Edwin was not *that* weird considering the fads of the time

https://viewing.nyc/vintage-photograph-shows-nyc-daredevil-balancing-on-a-stack-of-chairs-20-stories-up-circa-1920/

https://vintagenewsdaily.com/the-flagpole-sitting-trend-of-the-1920s-was-widely-popularized-in-the-u-s-by-alvin-shipwreck-kelly/

Armstrong

- Born in 1890
- In 1913, while a senior at Columbia Engineering in NYC he solved the problem we're talking about (getting more gain out of early tubes)
- …so back to the problem…

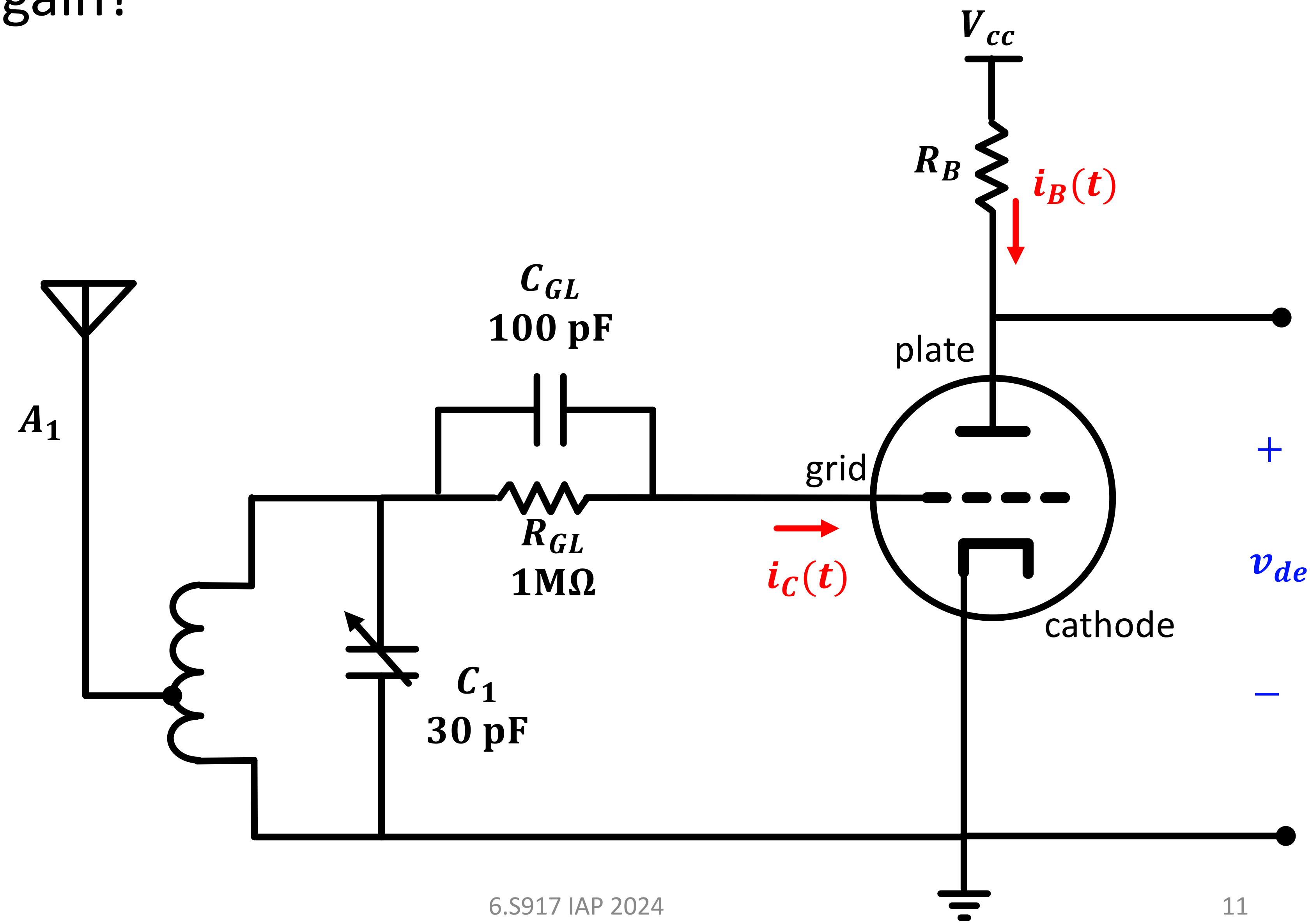


Here's Edwin again dancing on that antenna on another day.

http://www.theradiohistorian.org/wjzgallery/images/wjz_armstrong.jpg

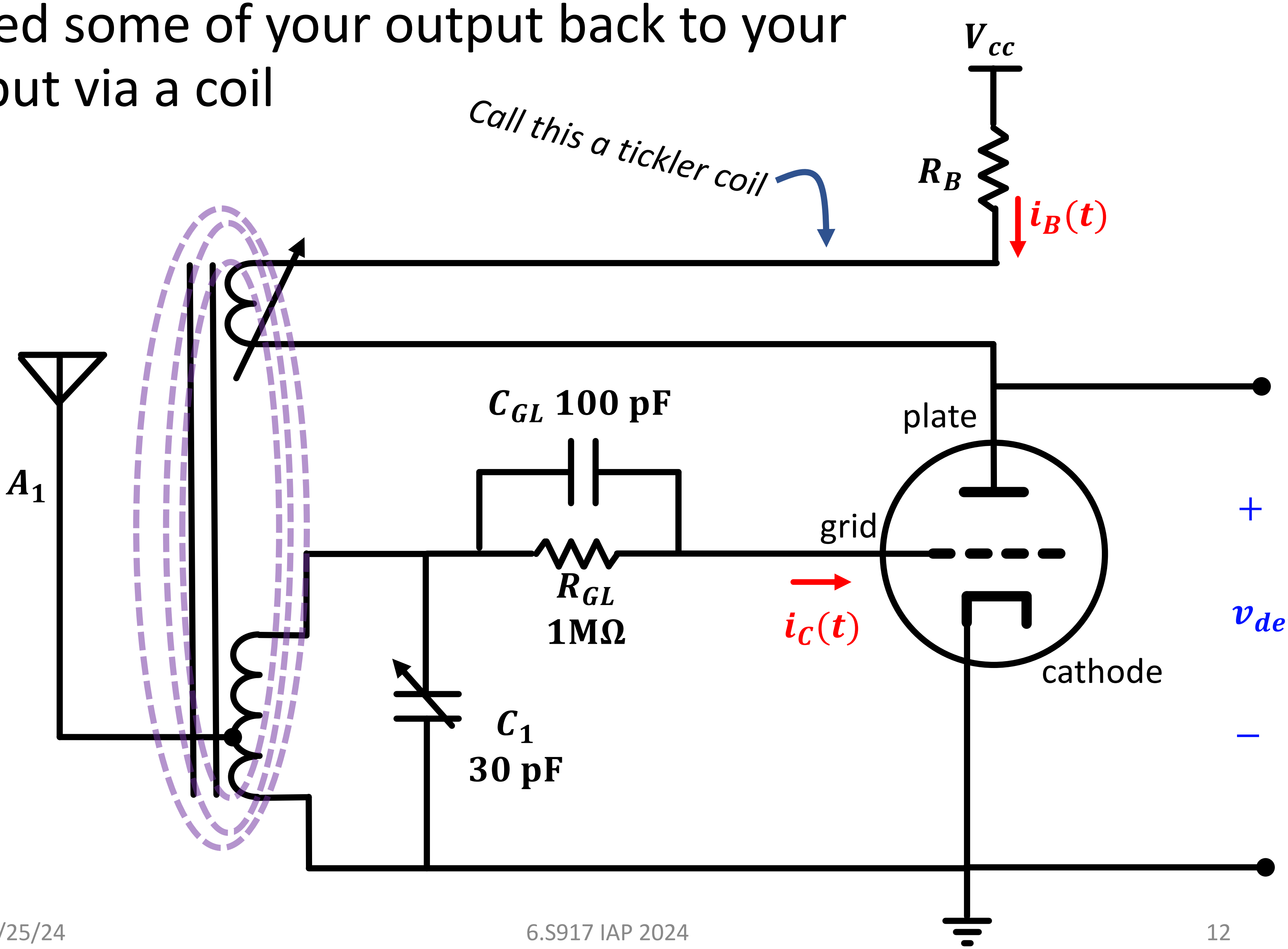
The Grid Leak Detector

- So we got this circuit…How can I get more gain?



The Fix

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



Wait a Second…feedback linearizes at the expense of gain…this is not doing that. Something's wrong

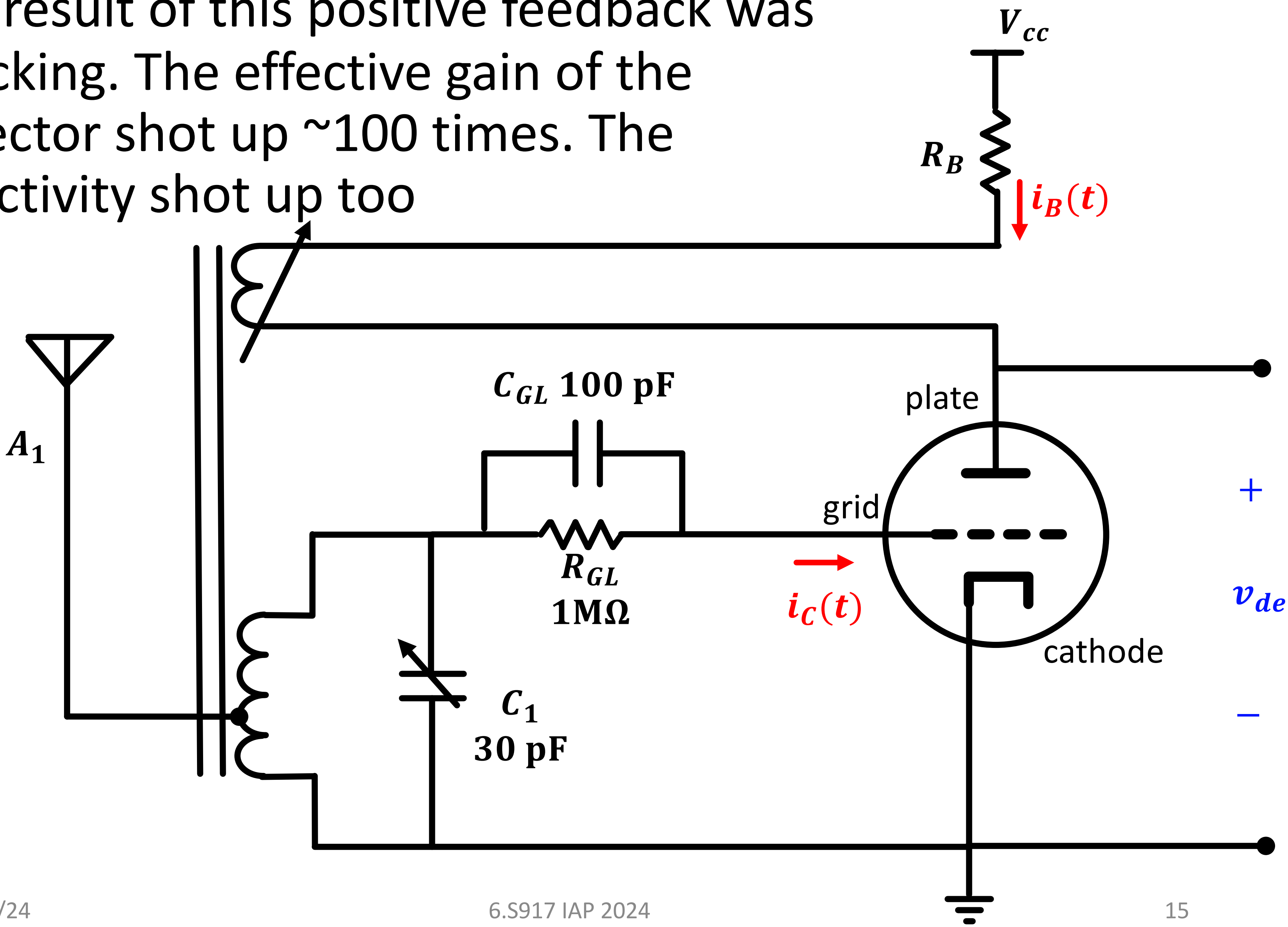
- That's correct…if it were negative feedback.
- But we're not
- In fact at that time, all people saw with negative feedback was it makes your signal go away (Black was 15 years away)
- Armstrong decided to take some output and instead of feeding it back with negative phase (like lec05), he fed it back with ***in-phase*** instead.
- So we had positive feedback going on here

Positive Feedback

- As engineers we often seek out negative feedback in designs. Negative feedback is stabilizing and makes things work reliably.
- There are times and places where positive feedback is what we want:
  - Nuclear weapons for example
  - Modern digital electronics use it in certain spots
  - In teaching we often give students “positive feedback” but this is a misnomer…positive feedback in education would be telling a student to fail/suck harder and blow up or something. Teachers actually give students negative feedback to stabilize their behavior
- But positive feedback is finicky and you have to be careful.

Feeding/Refeeding a Signal Repeatedly

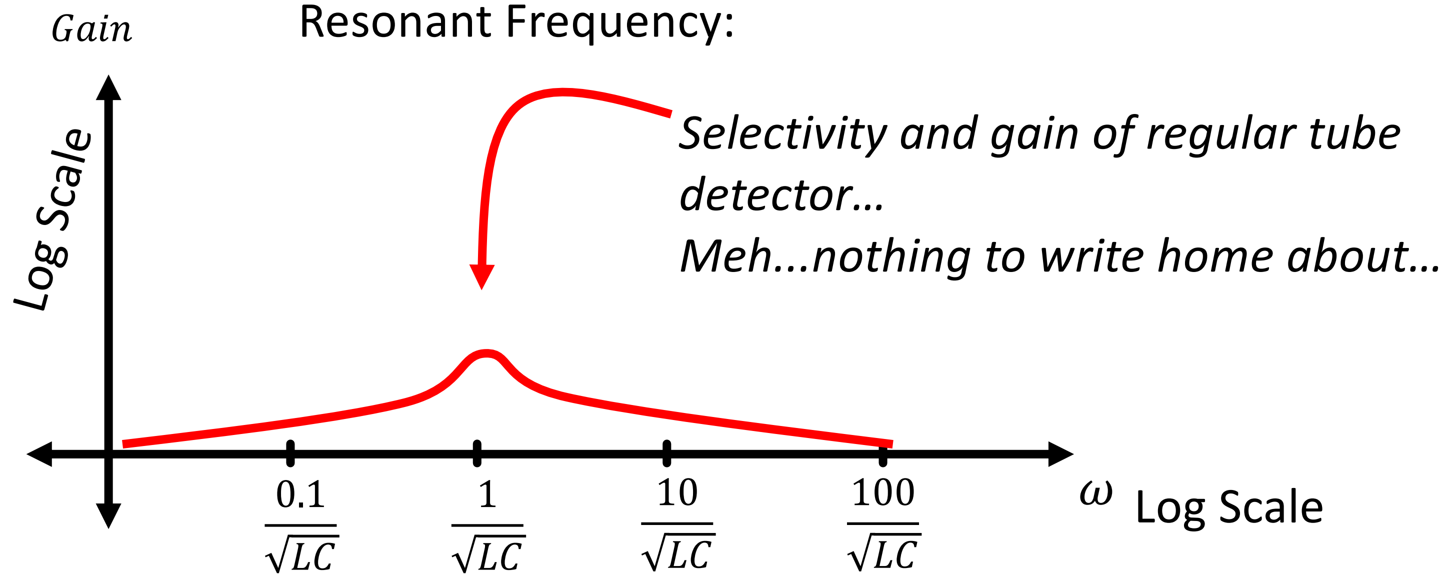
- The result of this positive feedback was shocking. The effective gain of the detector shot up ~100 times. The selectivity shot up too

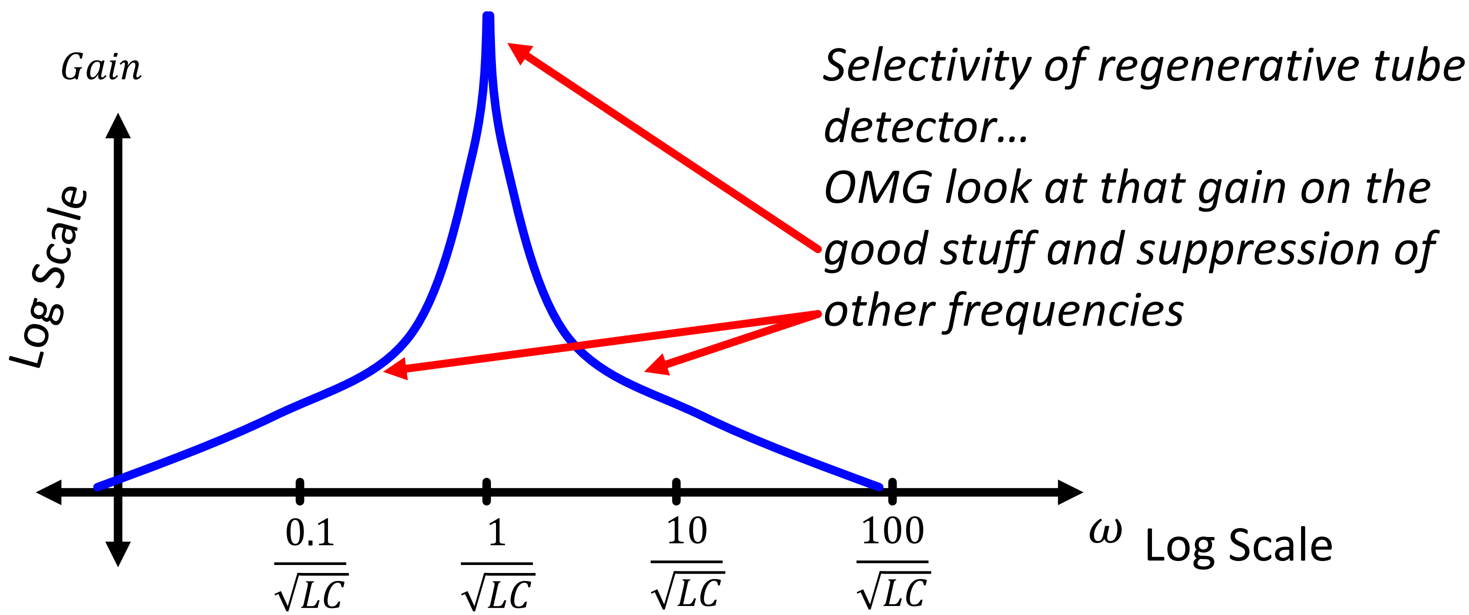


The LC (+parasitic R) tuner

One way to think of the regenerative circuit is that it is reusing the circuit for multiple passes. Run the signal through once to filter/amplify it…then run it through again…and again…and again.

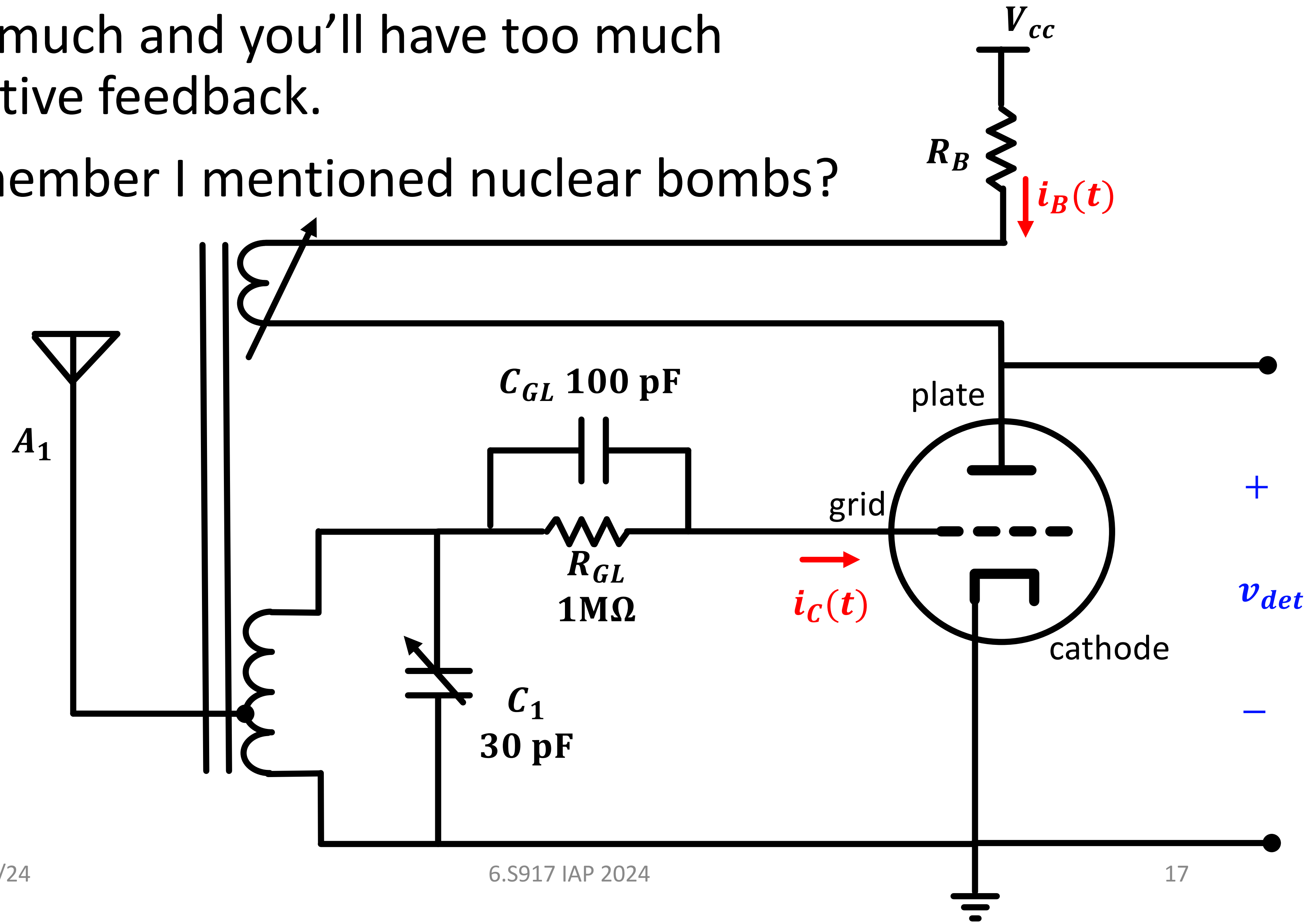
Resonant Frequency:





Of Course…this is Positive Feedback

- You tune the tickler coil so that it couples too much and you'll have too much positive feedback.
- Remember I mentioned nuclear bombs?



Regenerative Receivers

- When tuned well were amazing! Great selectivity and gain (for the time)
- Became dominant receiver design up through early 1920s…
- BUT…
- If too much positive feedback showed up though, the circuit would turn into an oscillator, and at the very frequency you were trying to listen at….and the thing was connected to an antenna…
- As a result a receiver could very quickly switch from receiving into transmitting and jam everyone nearby

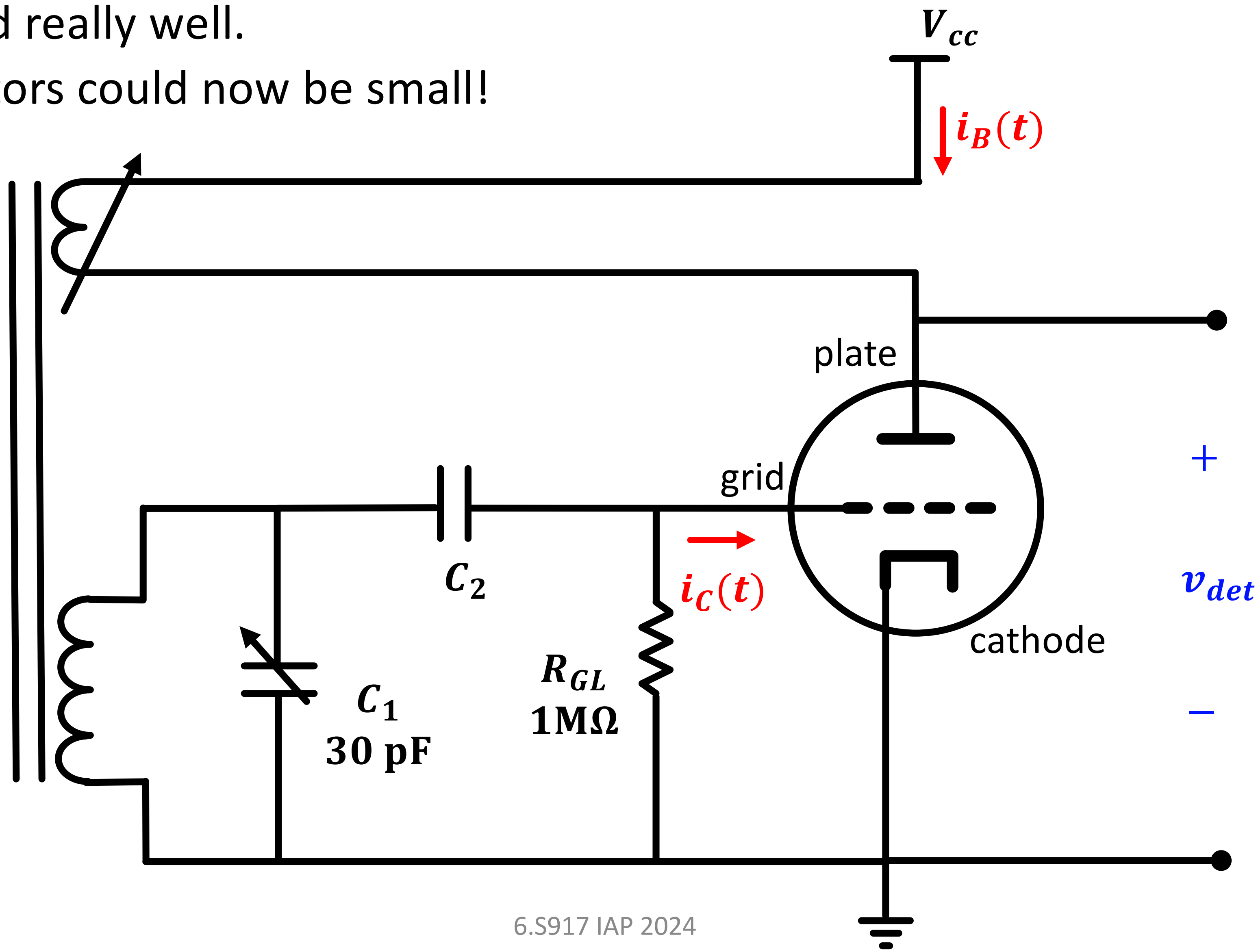
When Life Gives you Oscillators, Make Oscillade

- The regenerative receiver was step in the right direction. So Armstrong patented it. Made 500K USD off it (1920 money)…
- The fact that it could turn into a transmitter wasn't awful either. In fact it was a useful discovery in its own right…Armstrong had developed the first tube-based electrical oscillator.*
  - Before that, they'd been electromechanical/spark-wheel based.

**In fact Armstrong had the oscillator part figured out first, documenting it in 1912, months before regeneration.*

The Armstrong Oscillator

- Basically the same circuit. Still had the tickler coil for positive feedback!
- First fully-described electronic oscillator
- Worked really well.
- Oscillators could now be small!

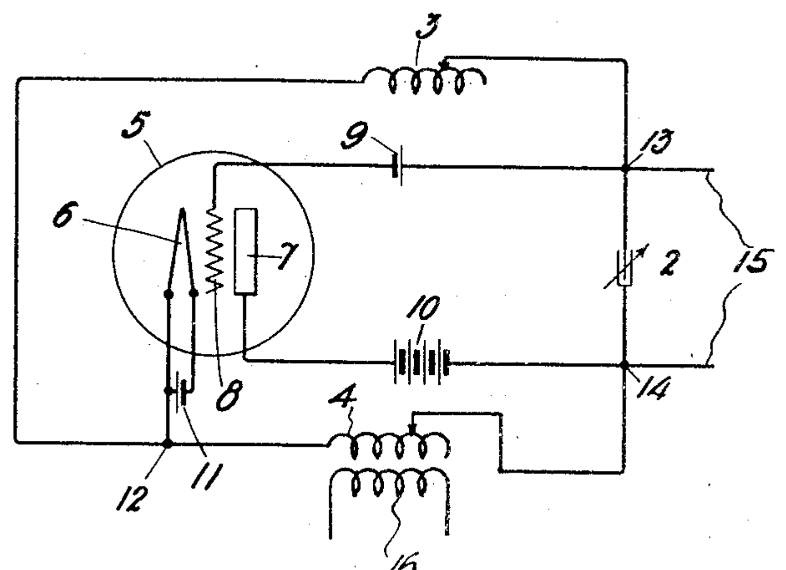


Start of Aside

- …We will return to Armstrong

Other Oscillators soon followed

- Ralph Hartley developed one in 1915:
- Using a LC tank with a tapped L (and positive feedback ofc)

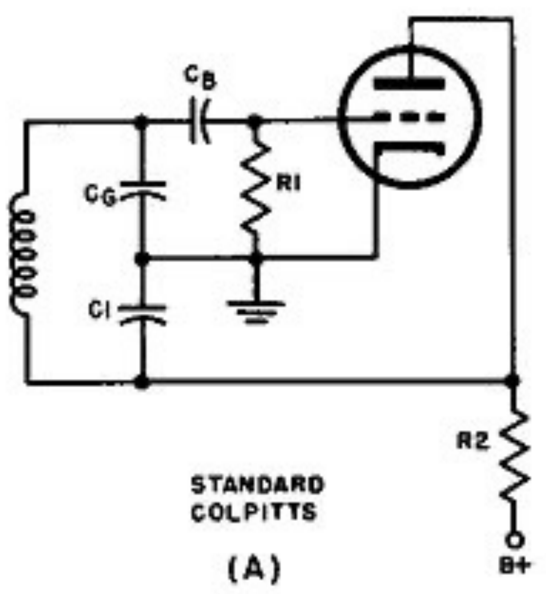


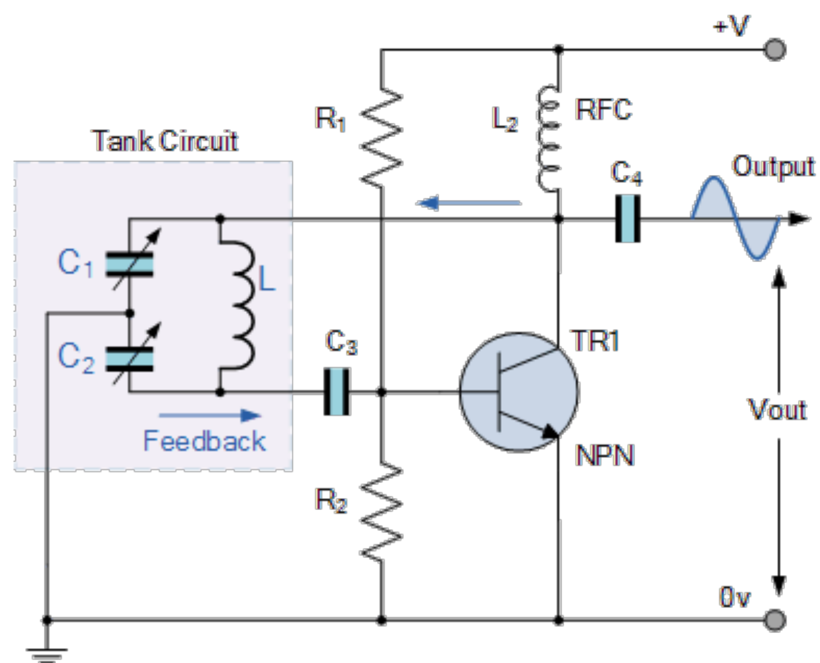
US Pat. 1,356,763

https://circuitdigest.com/tutorial/hartley-oscillator

Others soon followed

- Colpitts developed one in 1919:
- Using a LC tank with a "tapped" C (and positive feedback ofc)





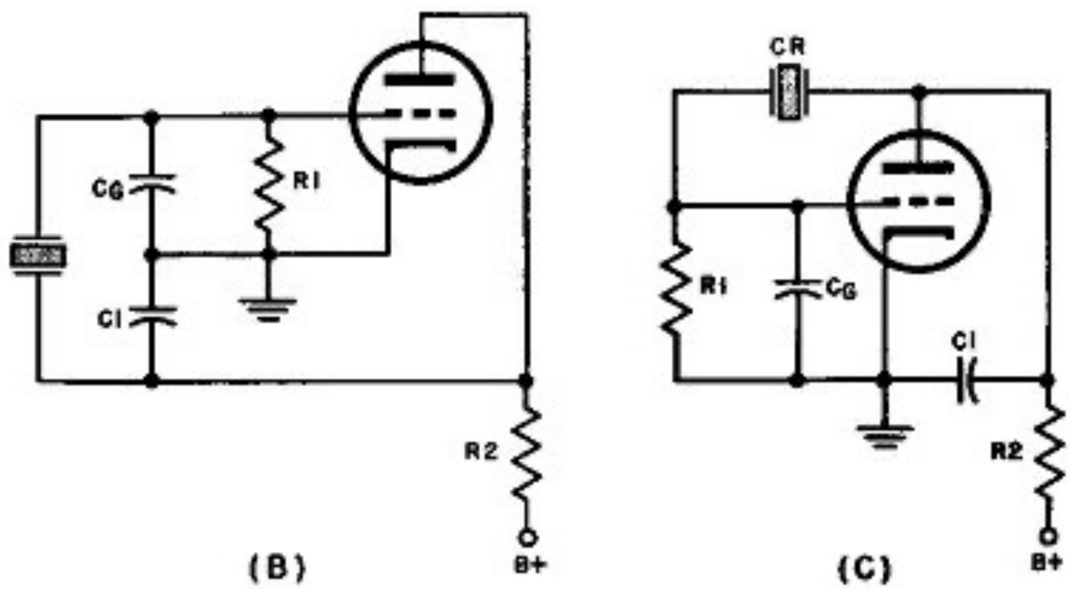
"modern" transistorized Colpitts Oscillator

https://www.industrial-electronics.com/crystal_osc_4.html

https://www.electronics-tutorials.ws/oscillator/colpitts.html

Others soon followed

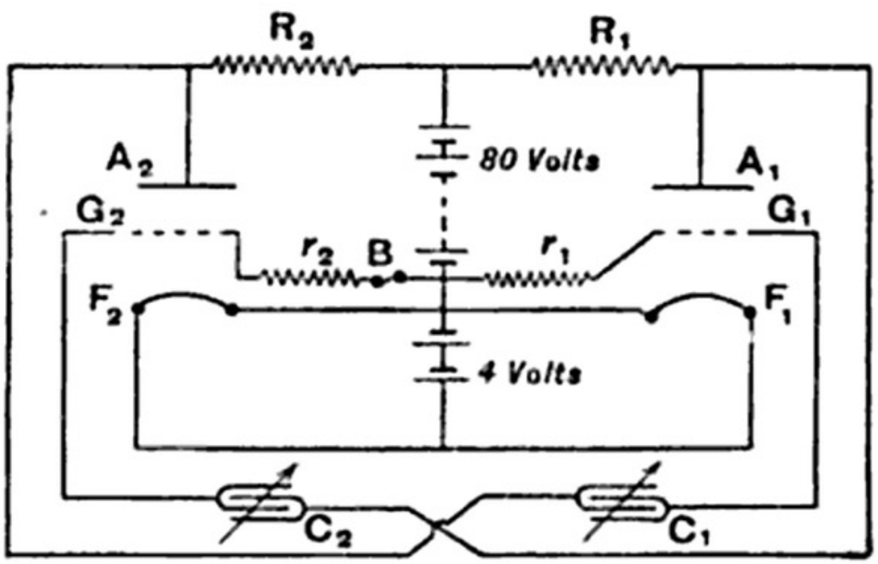
- Miller (of Miller capacitance fame) developed one in 1919:
- Early experimentation with quartz crystals (which act like LC tanks) and positive feedback



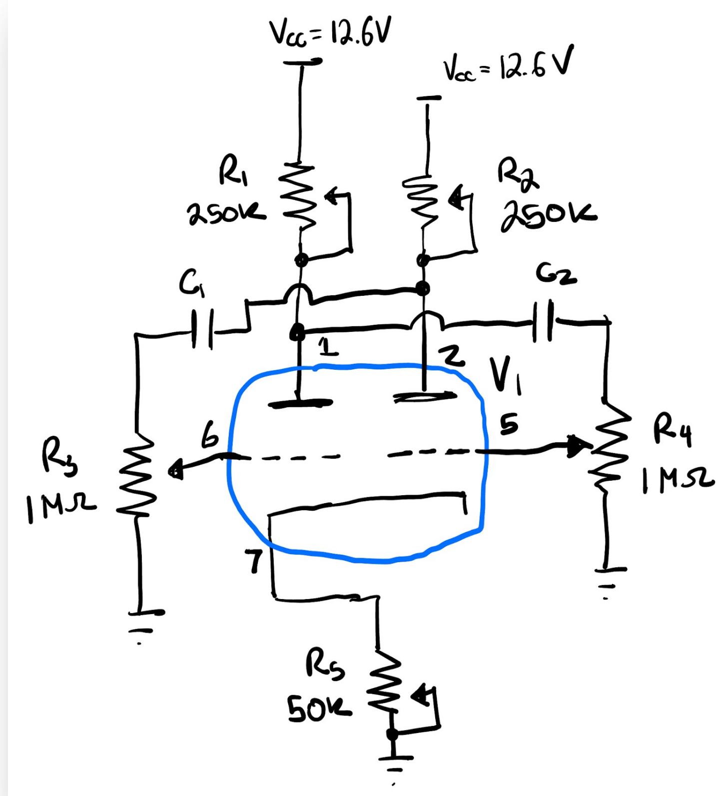
https://www.industrial-electronics.com/crystal_osc_4.html

Others soon followed

- Abraham and Bloch found out that with two tubes, they could get oscillations



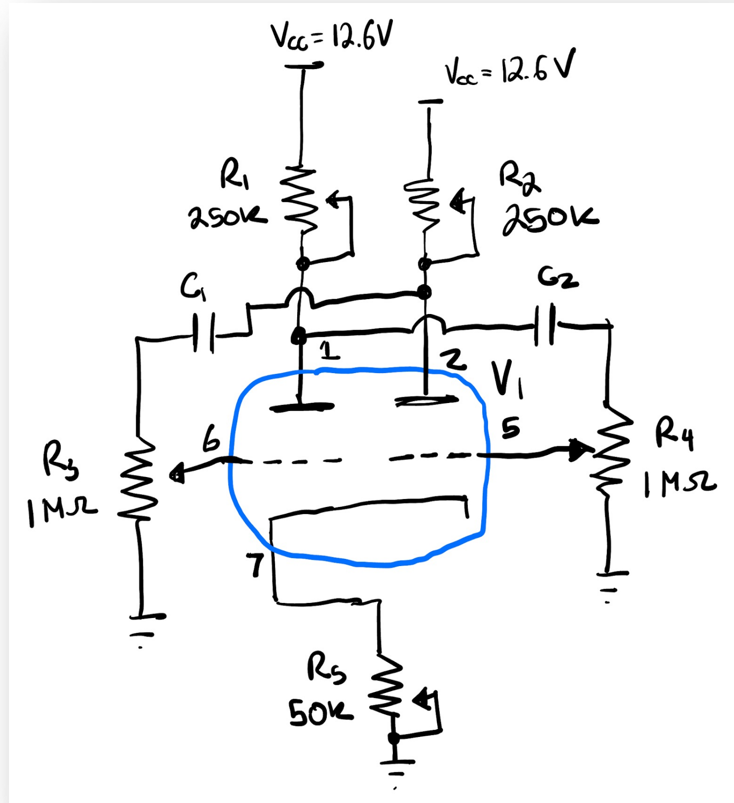
Original 1919 Circuit



Circuit to build in Lab 03

Two Active Devices in a Feedback Chain

- This circuit formed what is now known as a **multivibrator**
  - With Caps for feedback paths it is **astable**….meaning it will oscillate
  - Having predominantly resistive feedback paths, the circuit can become **bistable**

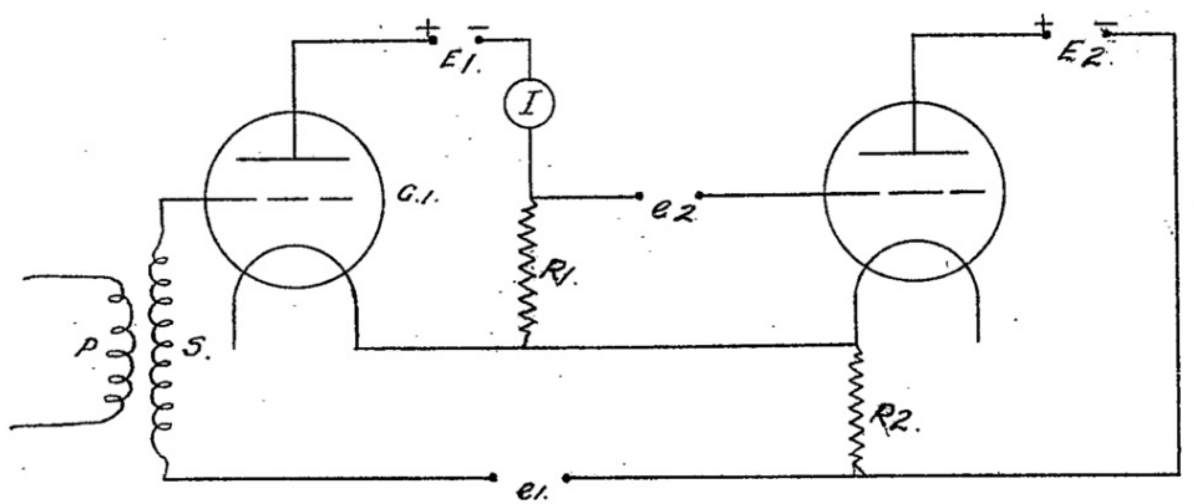


Circuit to build in Lab 03

Come back to that at end of class…

The Bistable Multivibrator

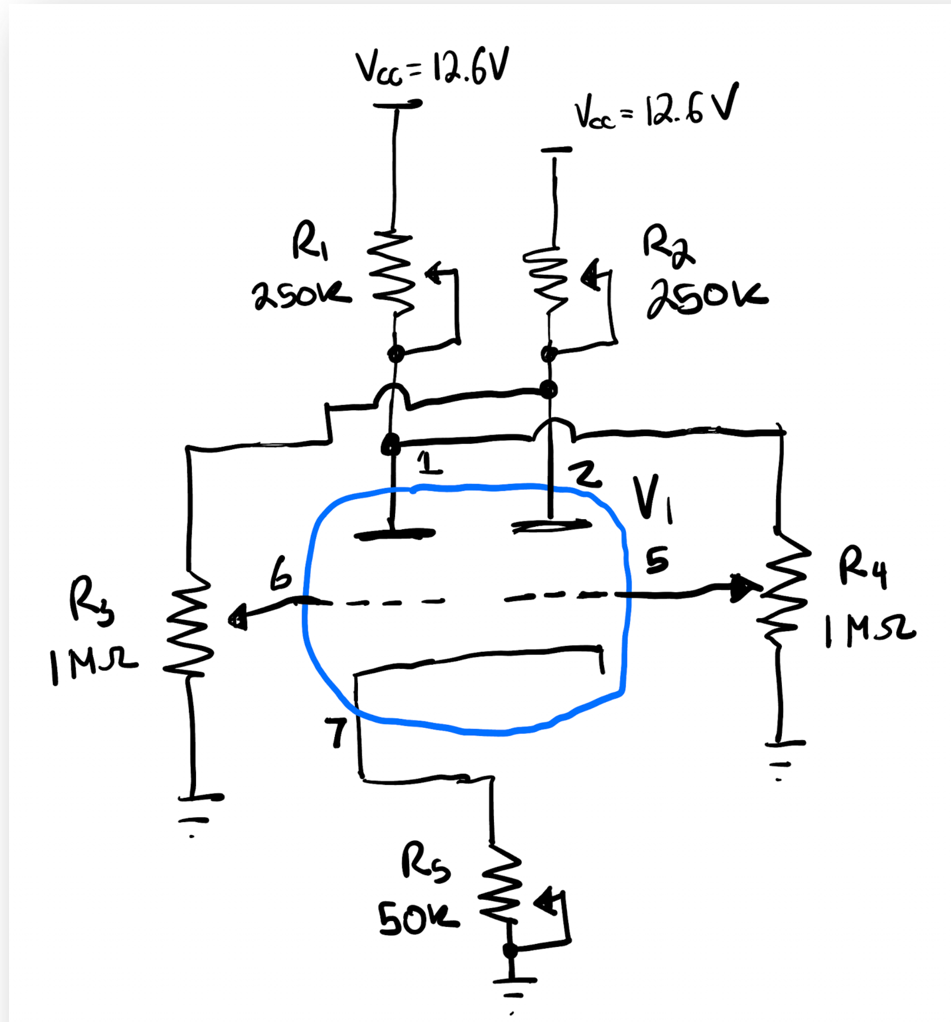
- This was also discovered/developed right around 1919 by Eccles and Jordan
- Originally termed “trigger circuits” but they eventually became known as flipflops



The original Eccles Jordan

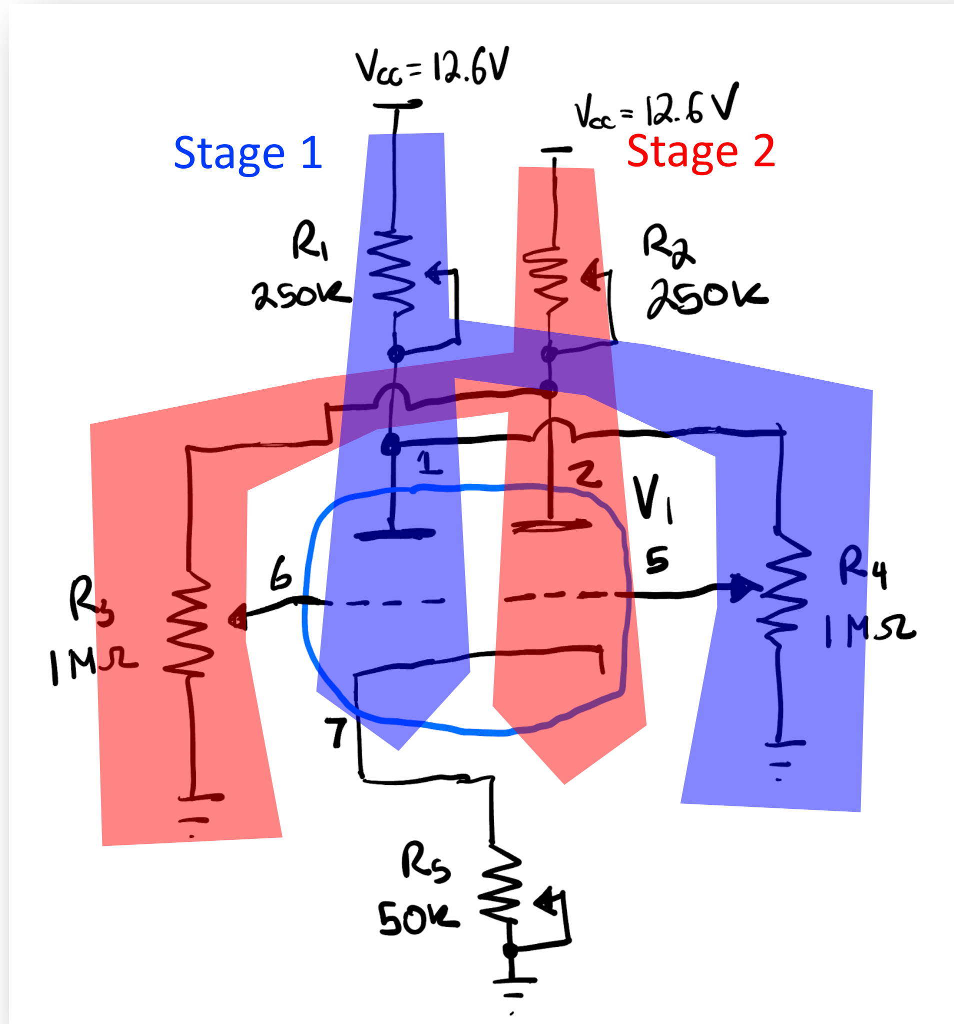
Can we do this with our Triodes?

- Remove the two capacitors basically have the Eccles Jordan circuit



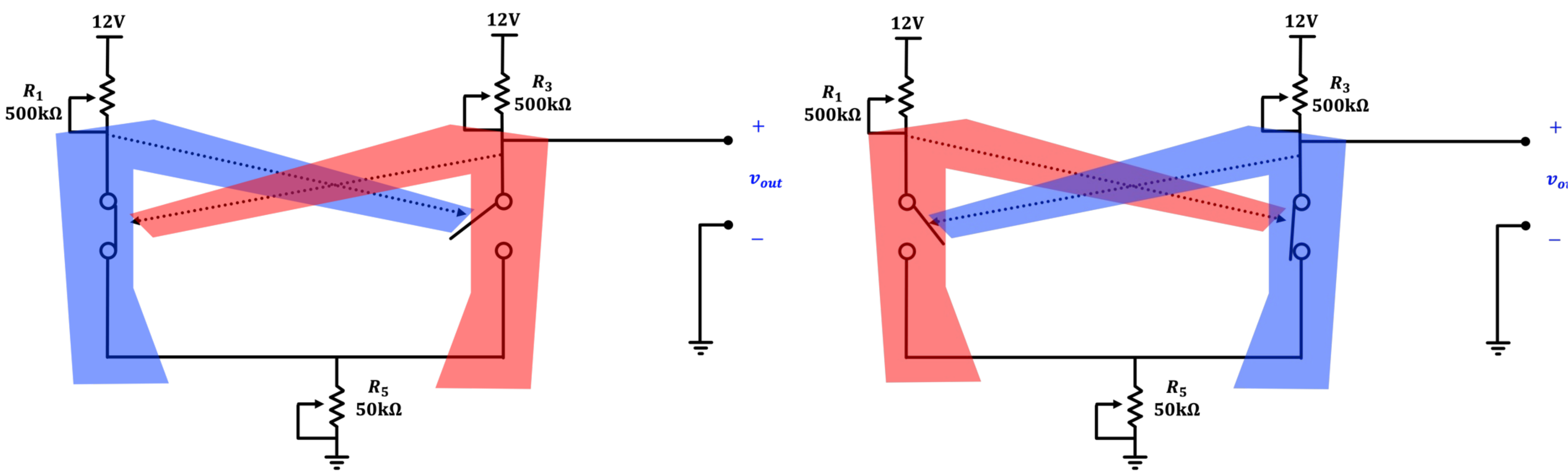
In theory should be relatively easy to implement something like this:

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…



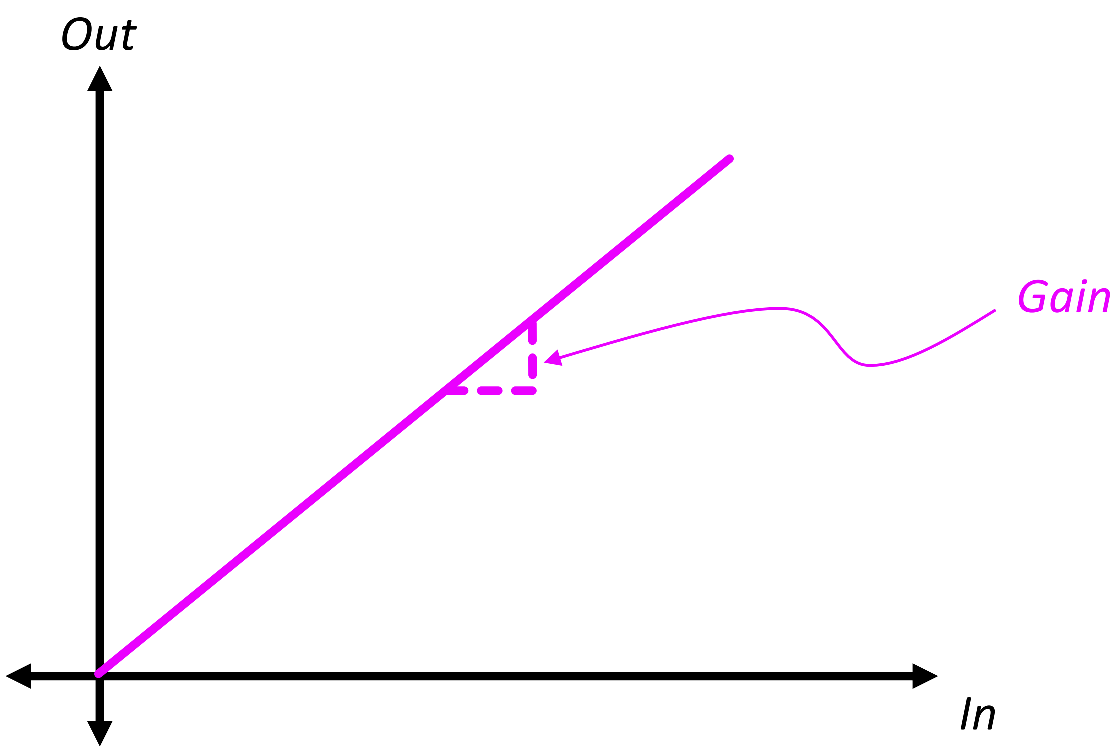
A Bistable Circuit

- 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:



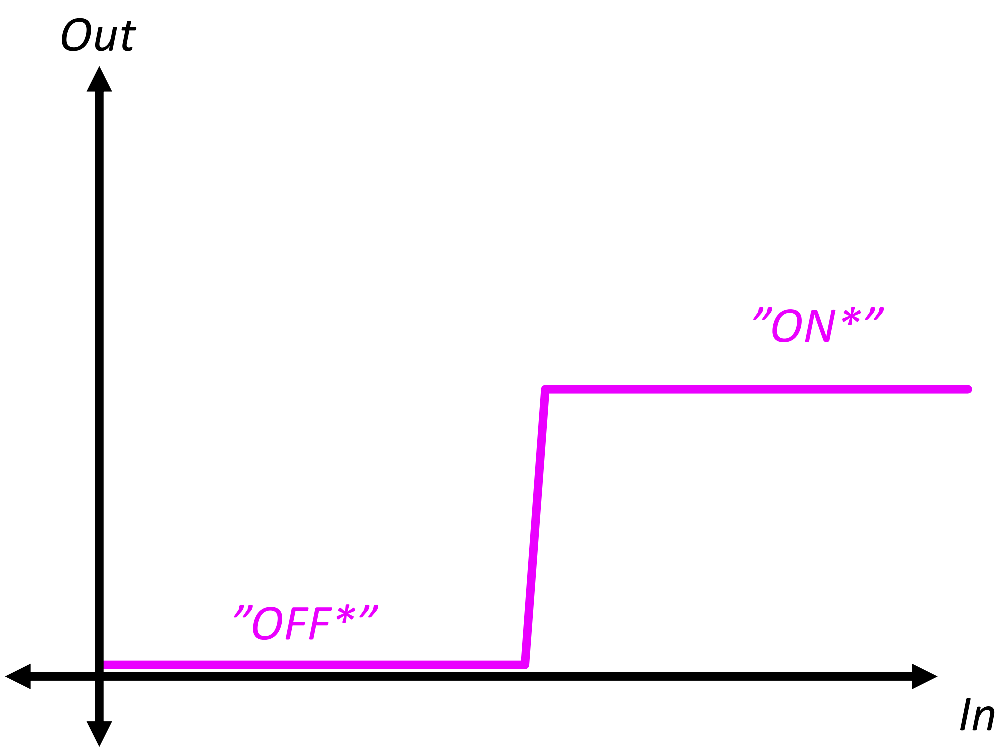
For a Analog Amplifier…

- 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

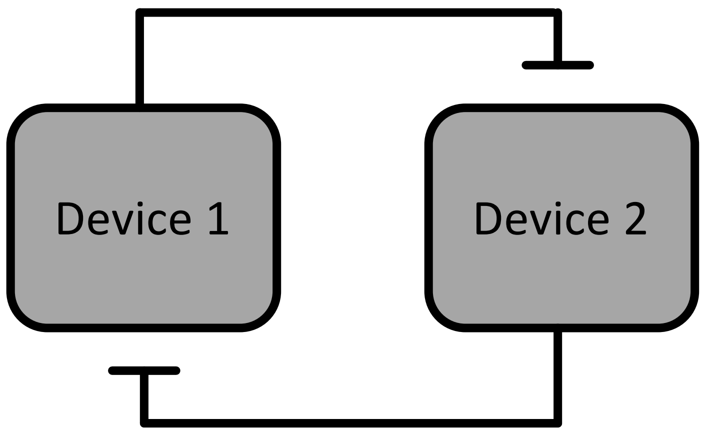


- In the case of a flip-flop we really want something to work that way
- The more non-linear, the better and more stable it will be

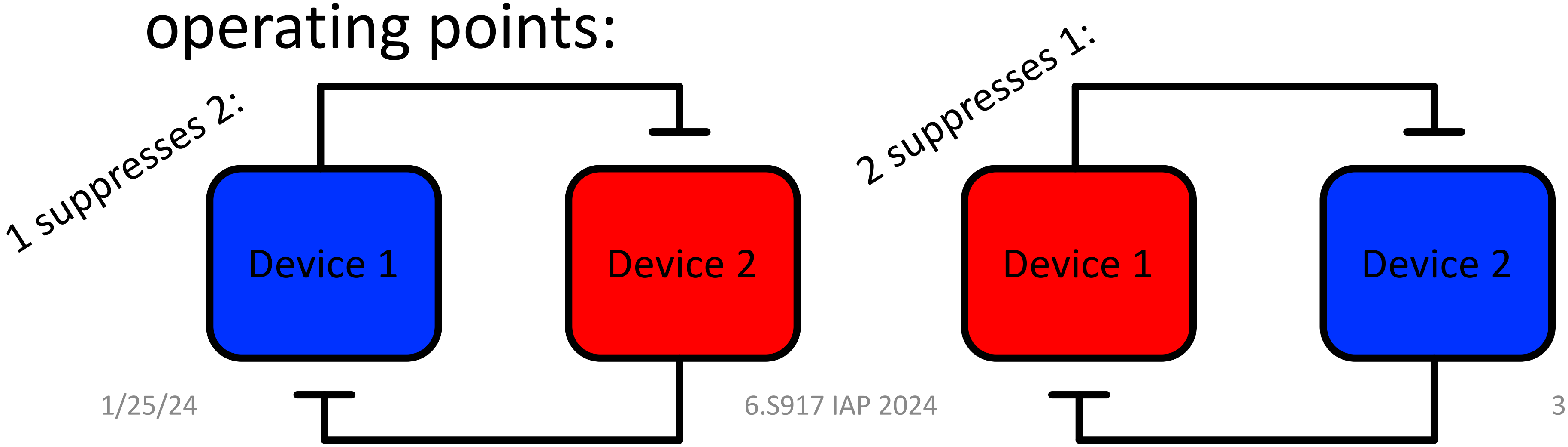
** Or some other descriptive name*

A Jordan-Eccles Circuit (Bistable Flip-flop)

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

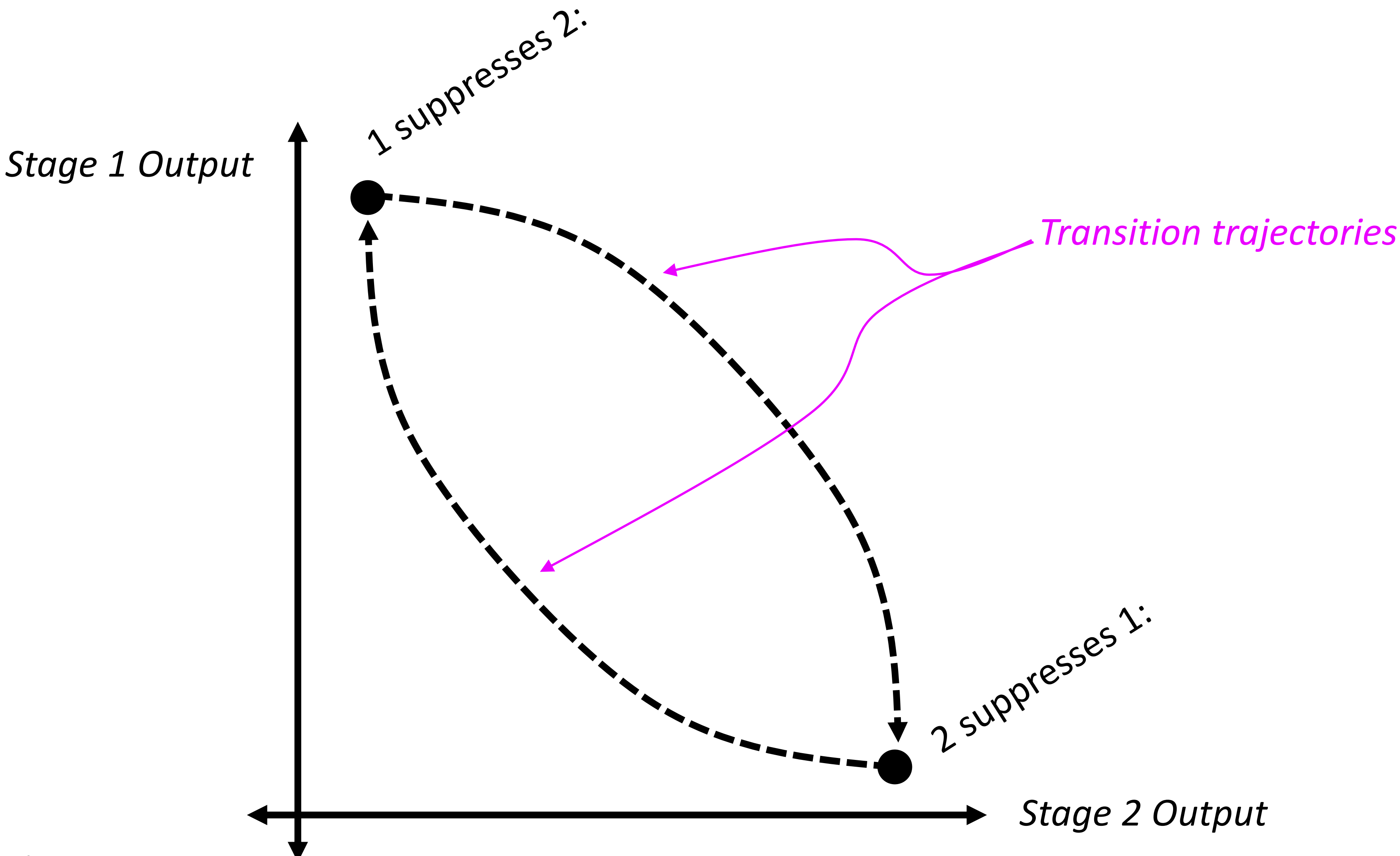


- When tuned, the circuit will stabilize to one of two operating points:

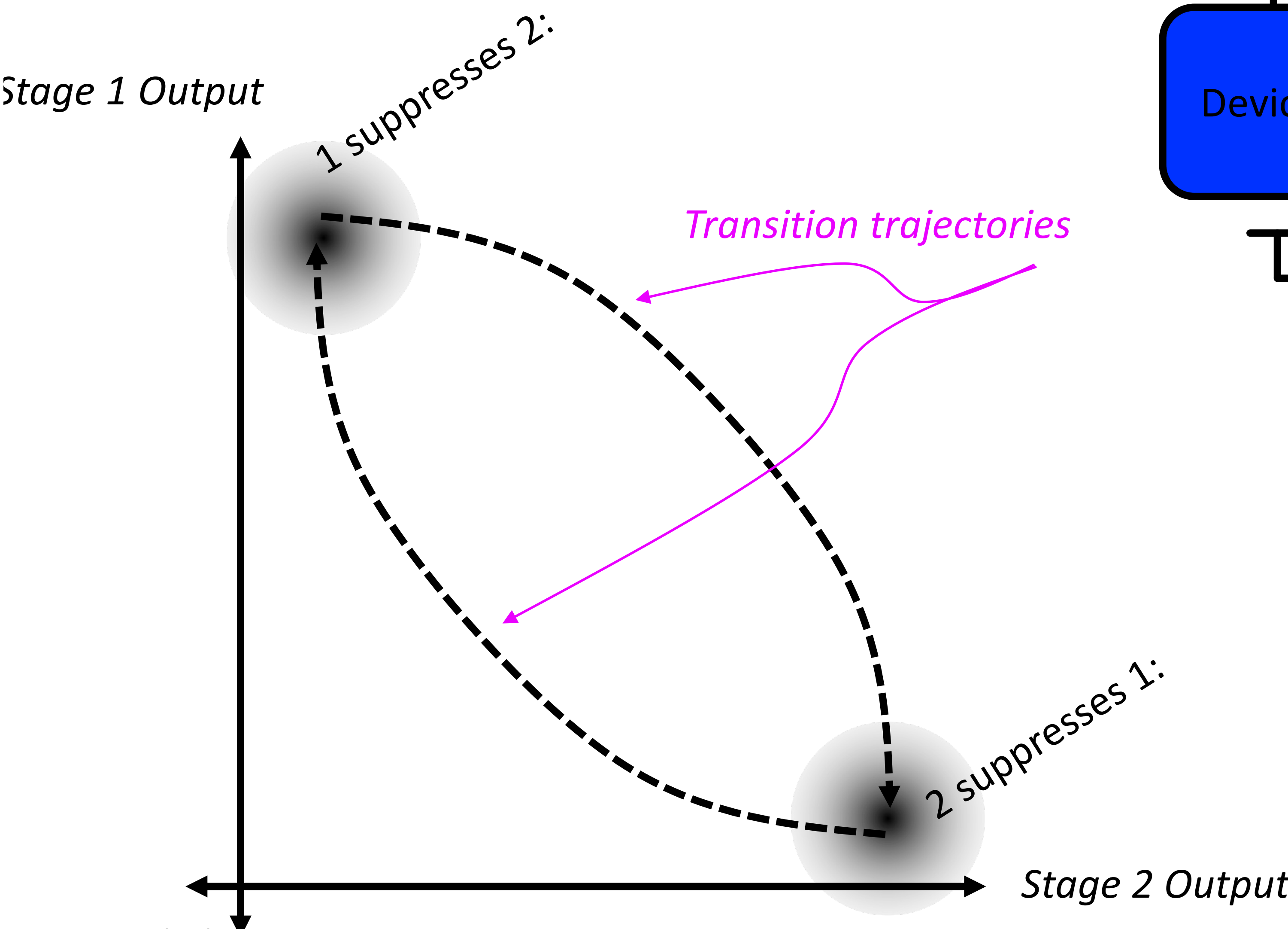


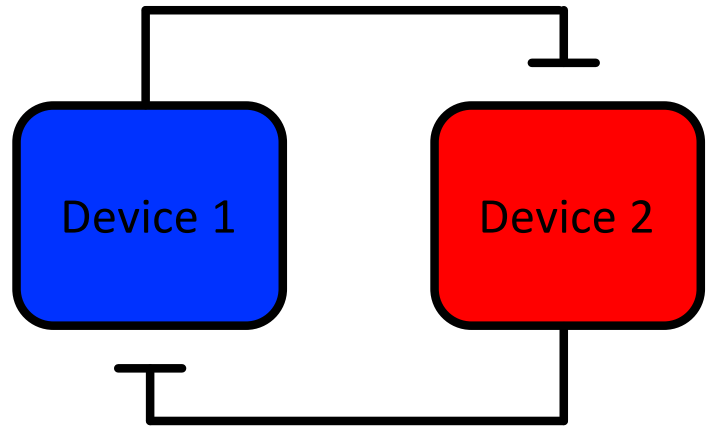
Map of Stability

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

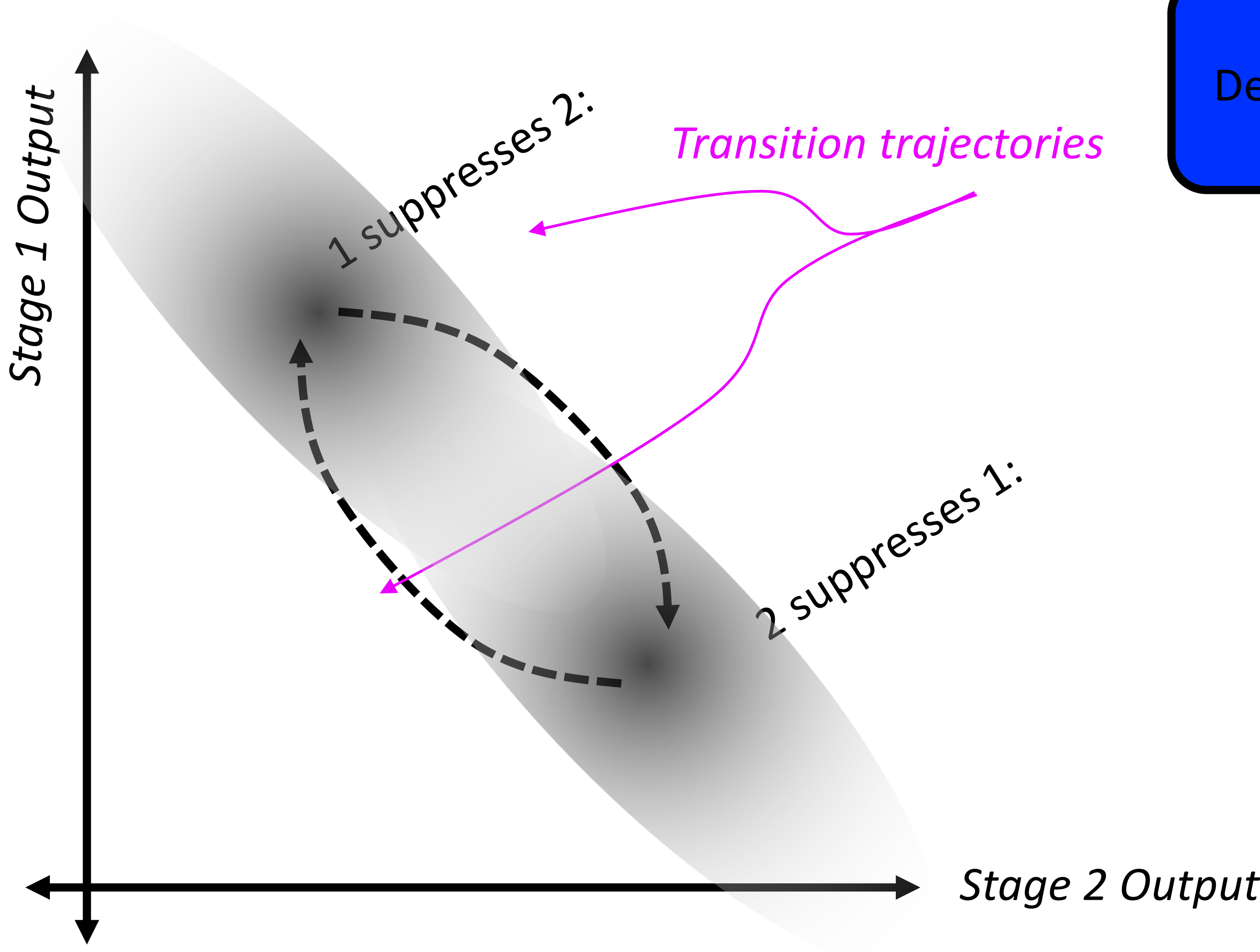


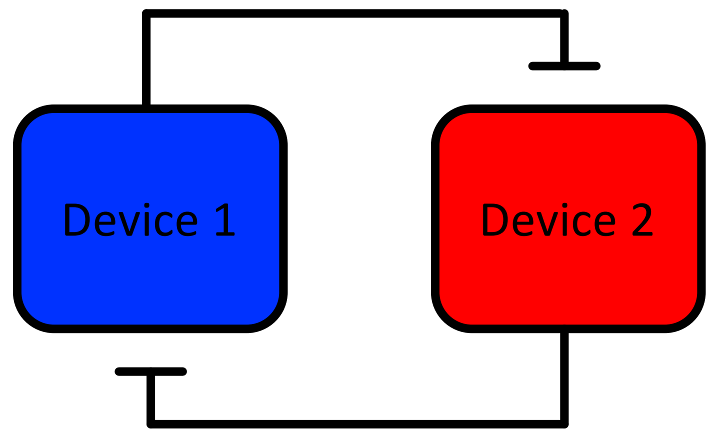
The Less Switch-Like Our Amplifiers Look, the Less Ideal Our Stability Map Will Become…



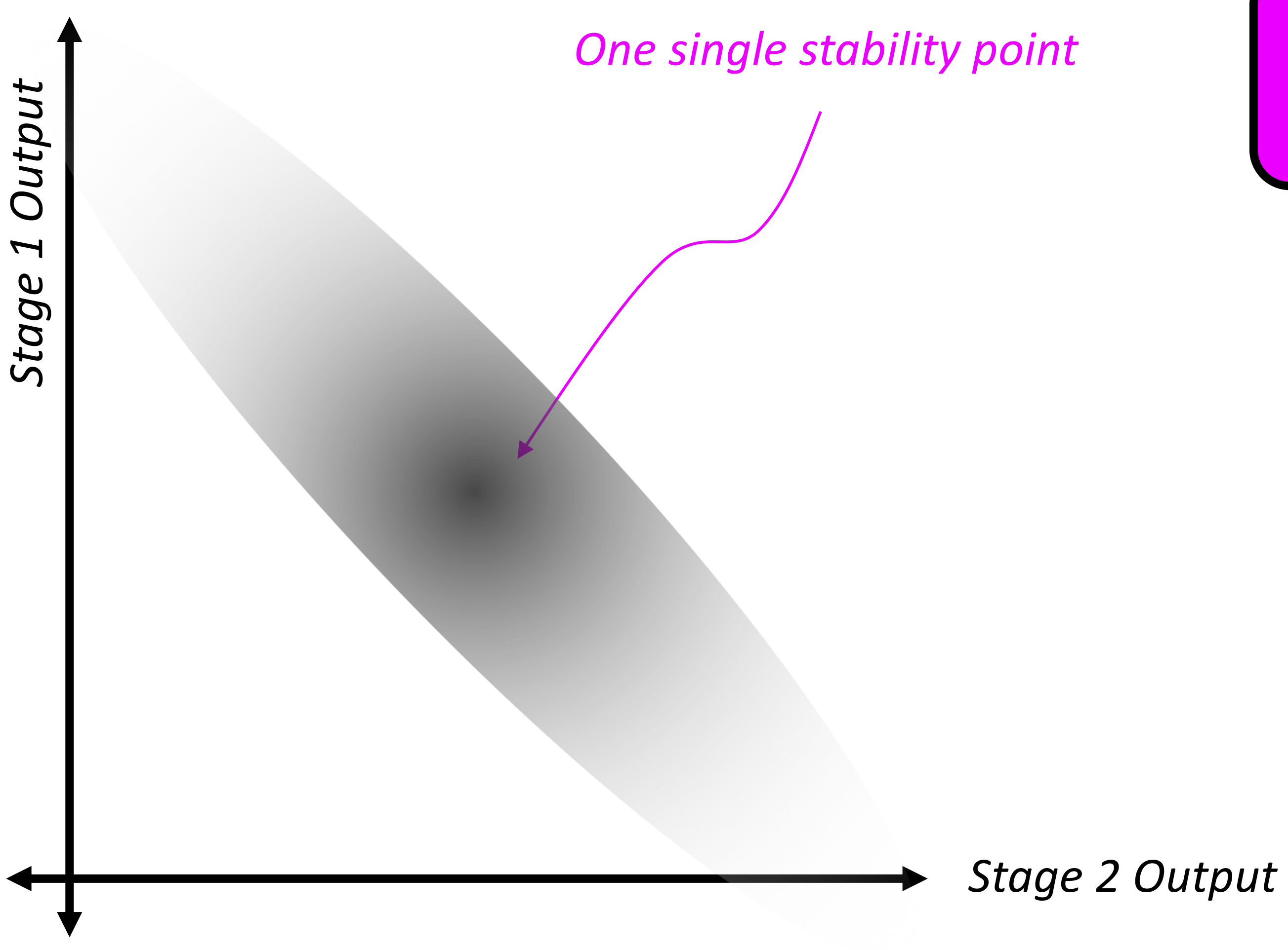


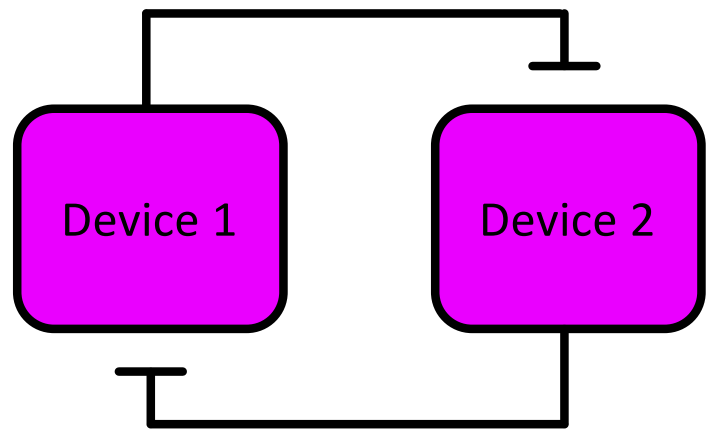
If Our amplifiers *really* can't act like switches, then…





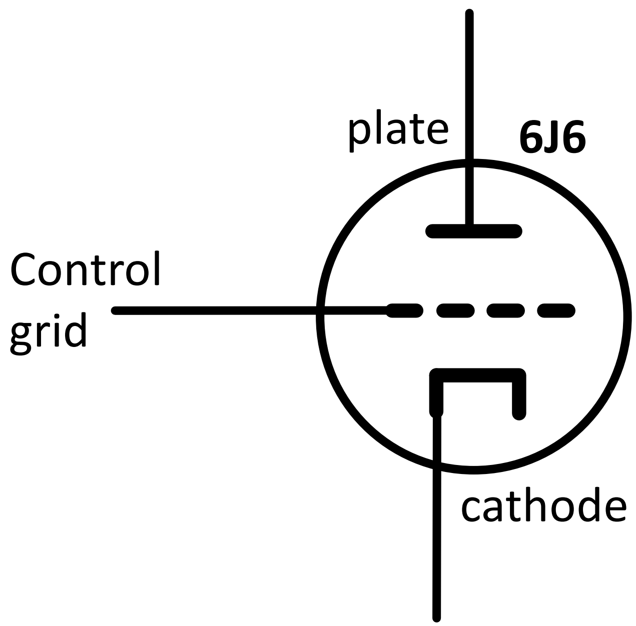
If they really really can't act as switches, then…

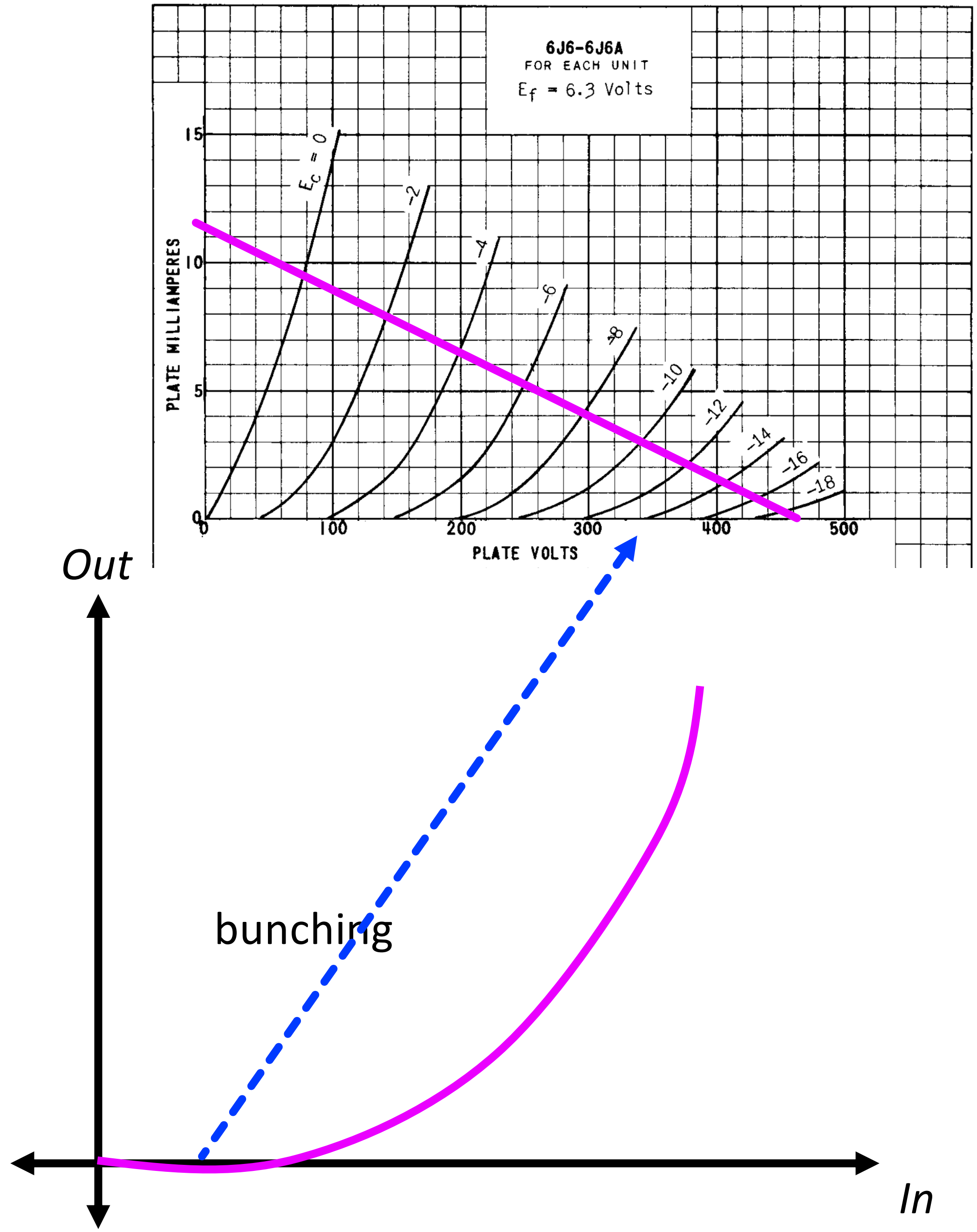




Can Our Amplifiers Act as Switches?

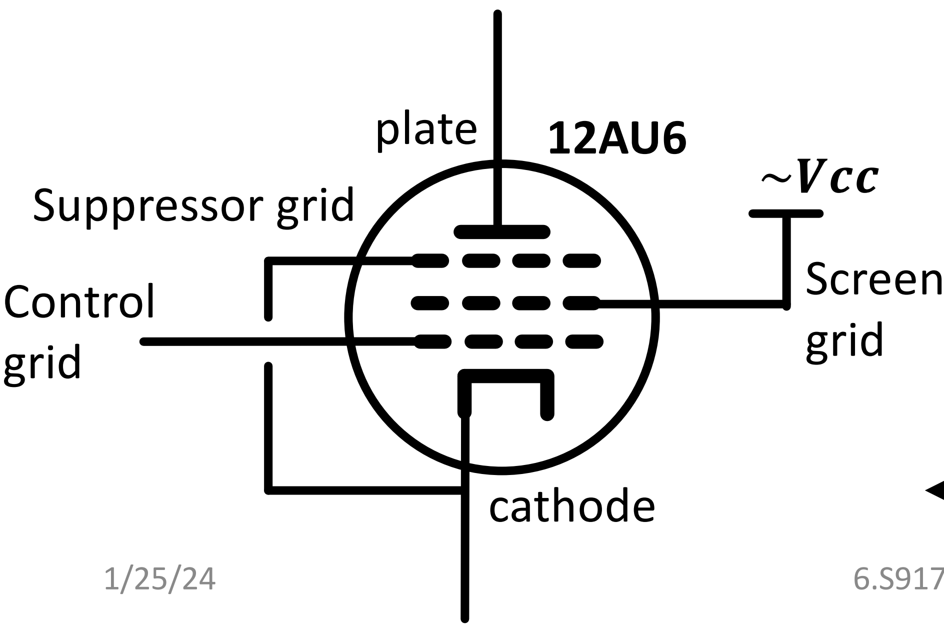
- Consider the Triode:

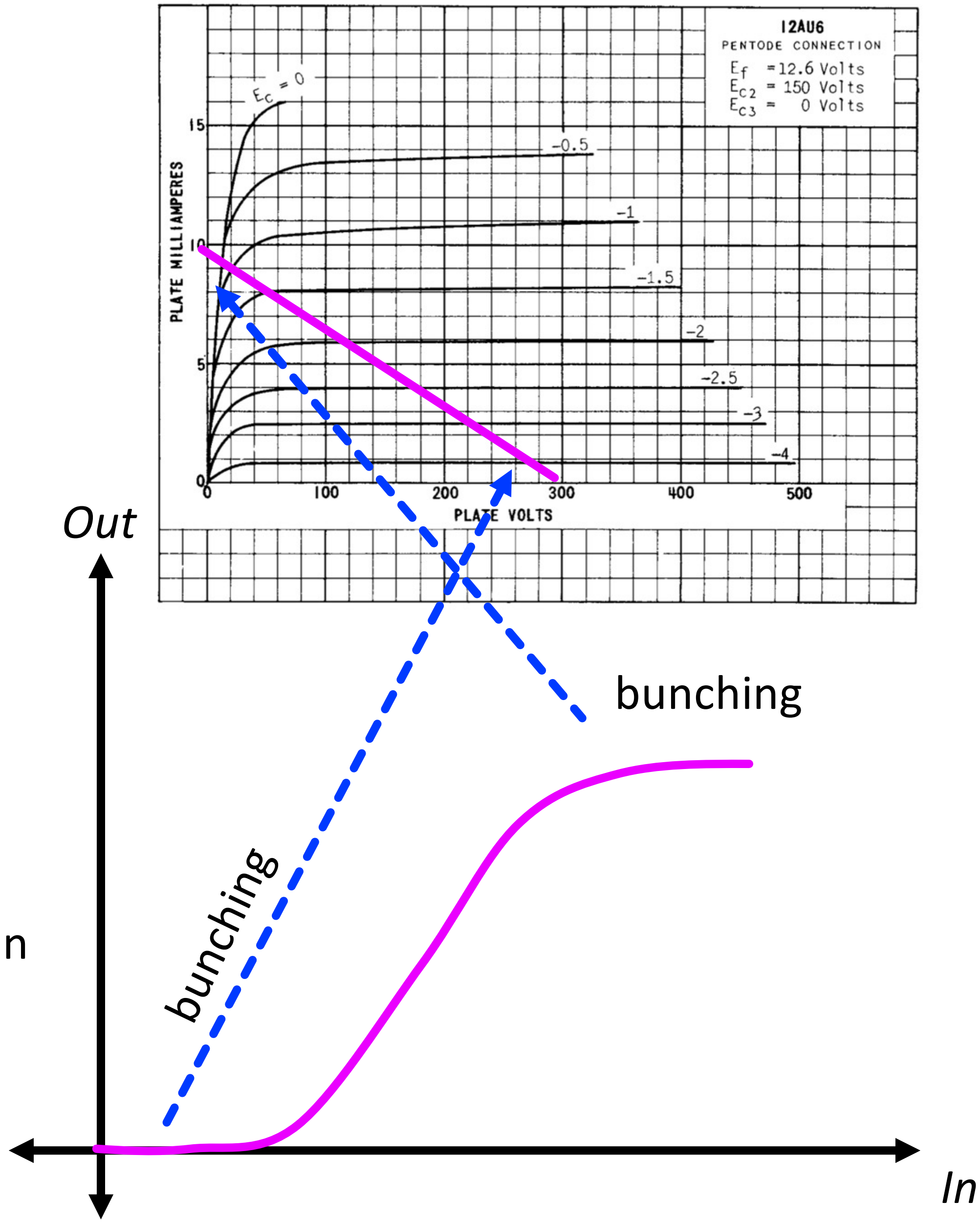




Can Our Amplifiers Act as Switches?

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

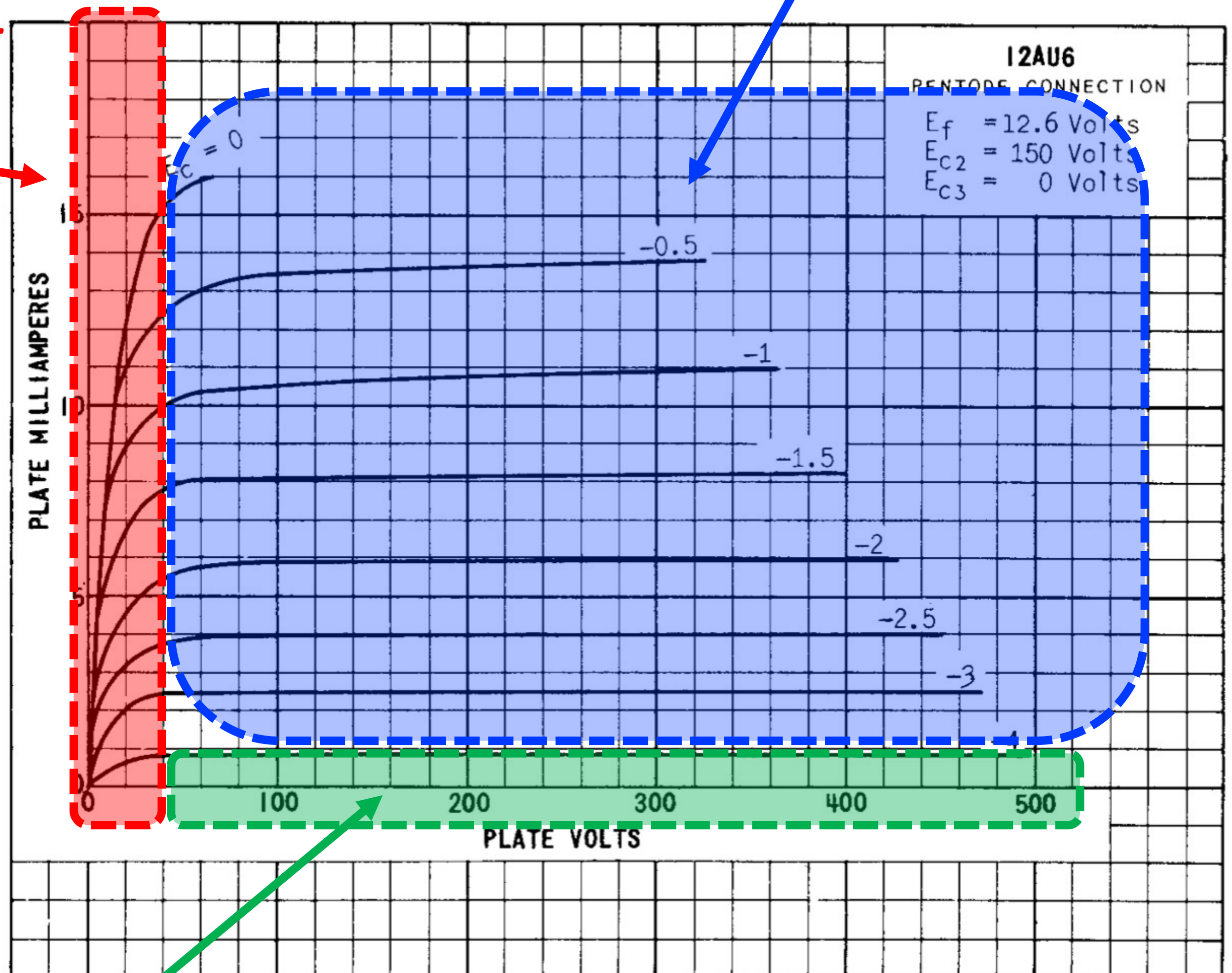




Pentode Curves

Current varies with voltage quite cleanly
Good for regular amplifiers

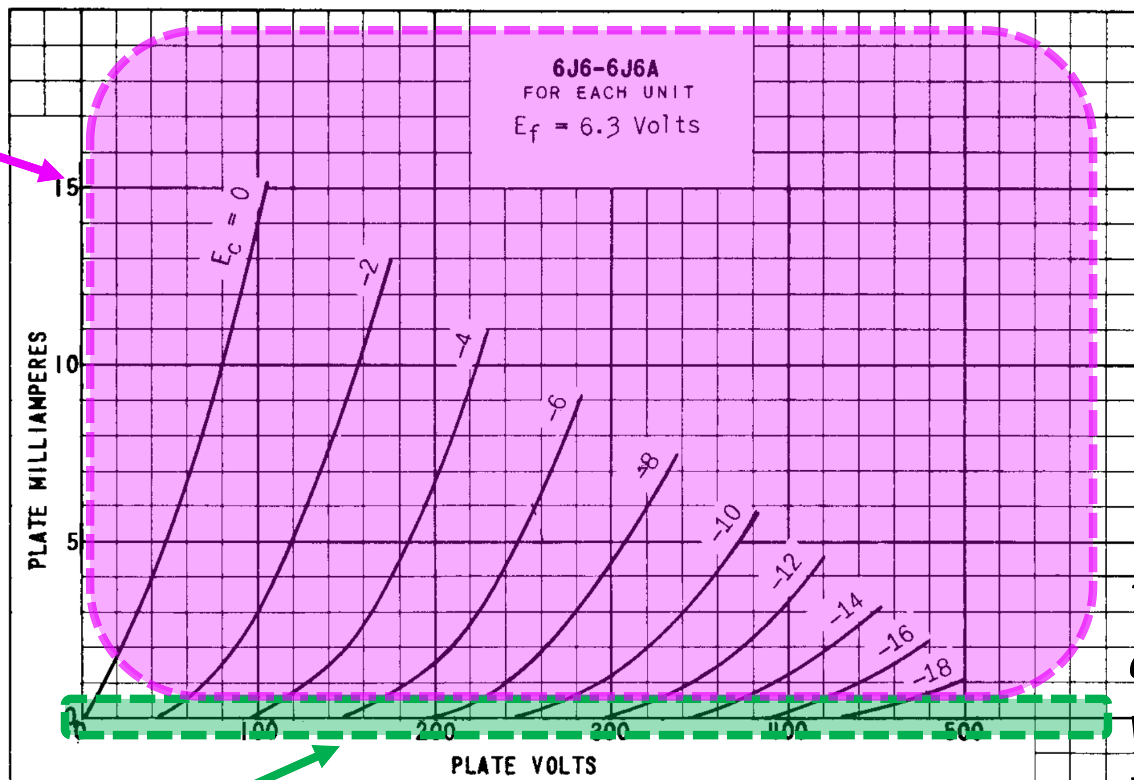
Very steep I/V relations…
like a low-Ohm resistor…
or a wire…
Or a closed Switch!



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

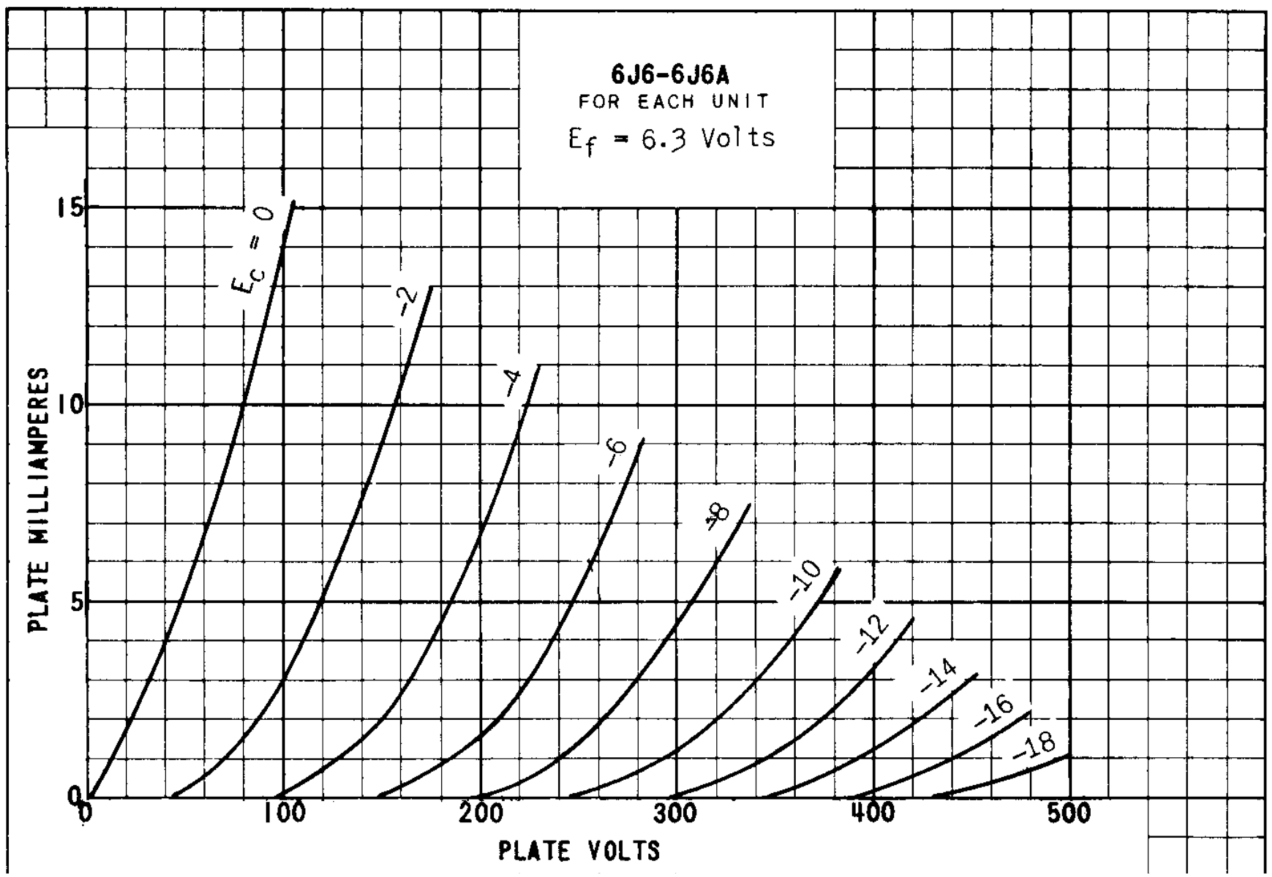
Beyond that we get these sort of diagonal lines which gradually evolve from infinite ohms to less and less ohms.
Fine for regular linear amplifiers maybe. Not really a switch, though



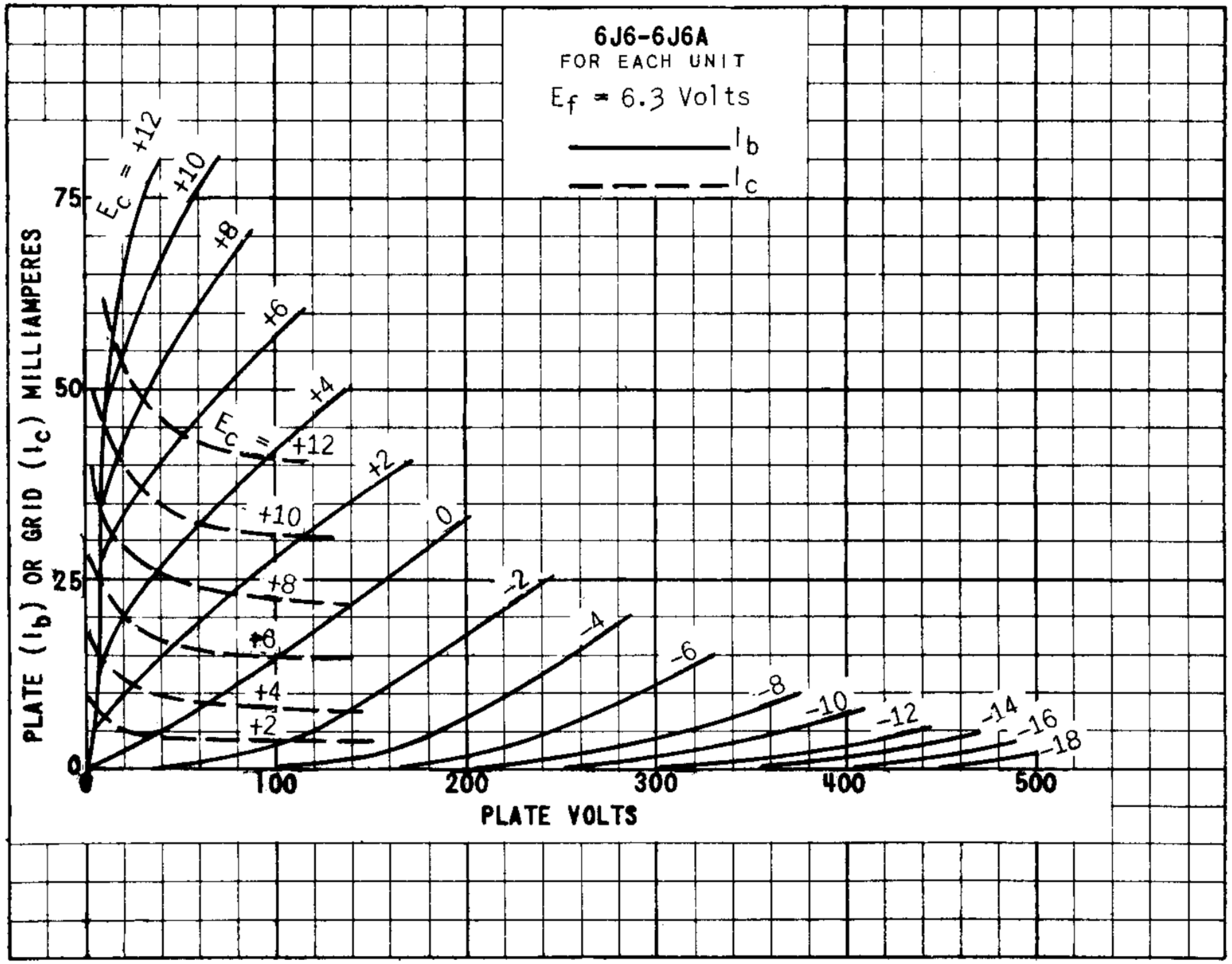
*Triodes **do** have a cutoff range where if grid voltage below threshold, no current flows*

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

In addition to the <0 grid voltages…

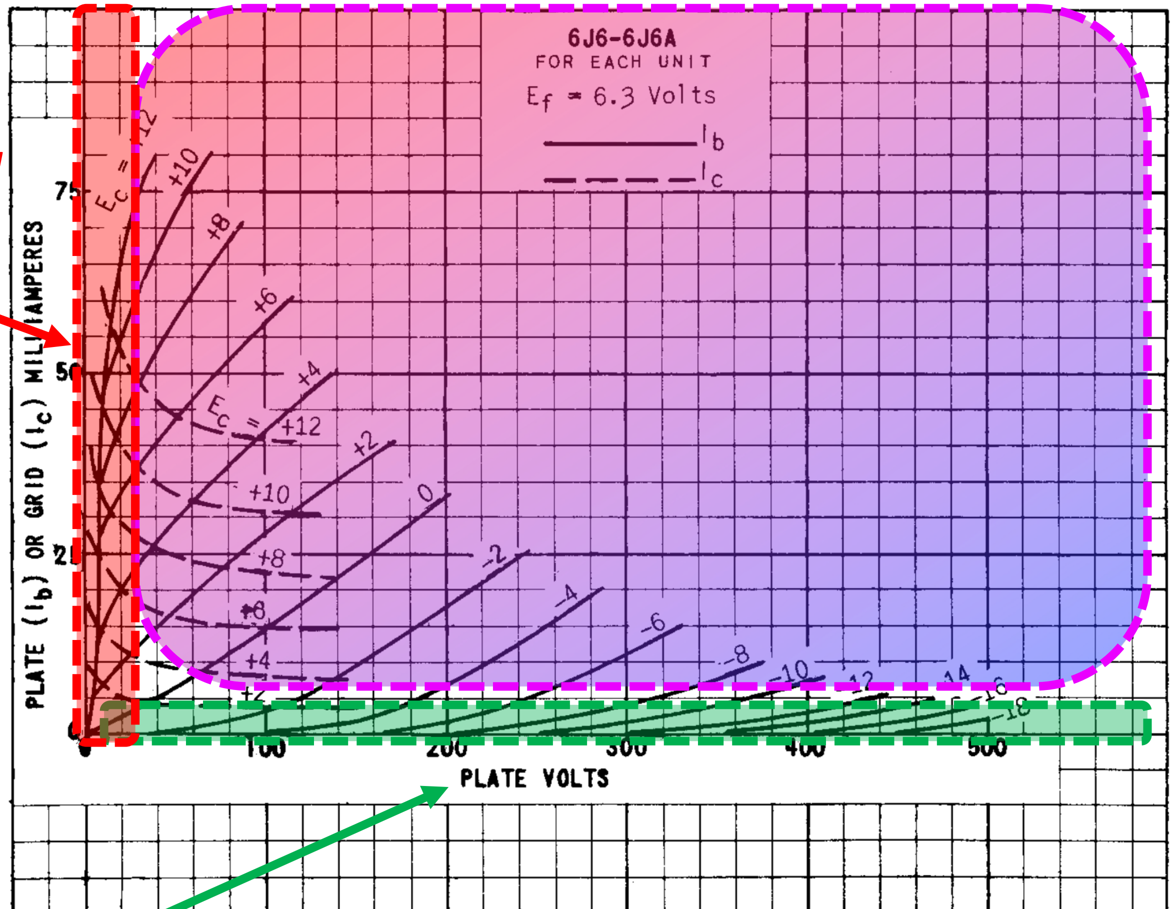


Some triodes could work at grid voltages >0



With positive Grid Voltages, Triodes can actually give ok behavior!

Can get near vertical lines here….so basically a nice closed switch



Triodes have a cutoff range where if grid voltage below threshold, not current flows

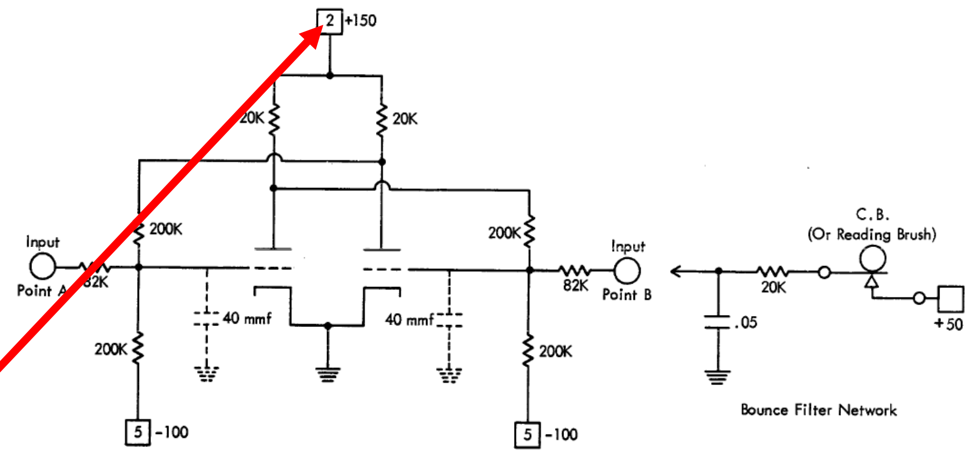
Almost no I for any V like a high-Ohm resistor… or an open… Or a open Switch!

Unfortunately…

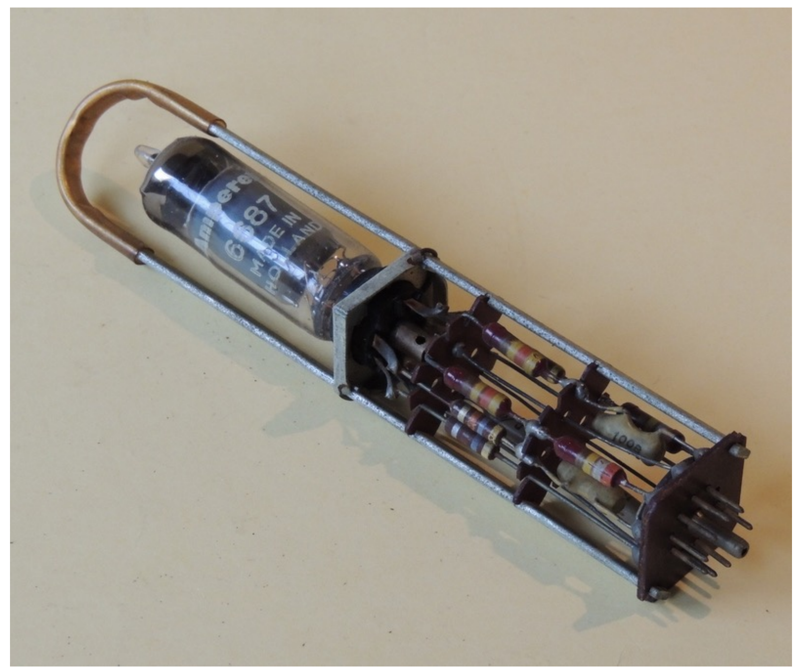
- At positive grid voltages the input impedance of triodes drops drastically
- The grid can now take milliAmps of current (normally grid current is ~0)
- Not possible in our low-voltage circuits since this loads them down.
- So it is basically impossible to get decent switch-like-behavior out of a triode at low voltages (the 6J6 tubes, for example need to be running with about 60V to even start to approach this)

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

The “soft-clipping”

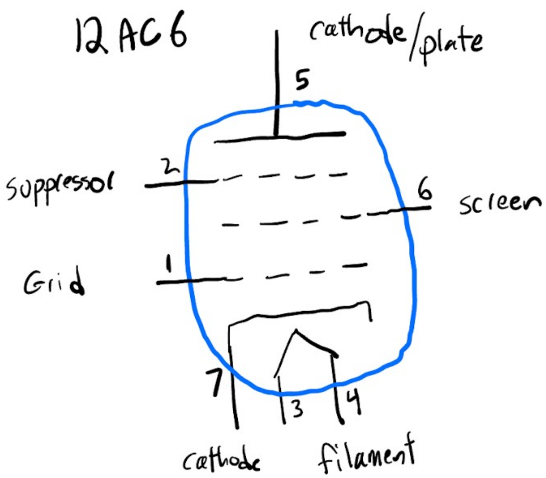
- The fact that triodes **don’t** transition very abruptly is one reason why people really like assign “good” sound effects to triodes.
- They tend to not “clip” as hard because they very gradually turn on and off at the extremes of their operating range whereas pentodes (And later transistors) have very clearly defined ON/OFF regions

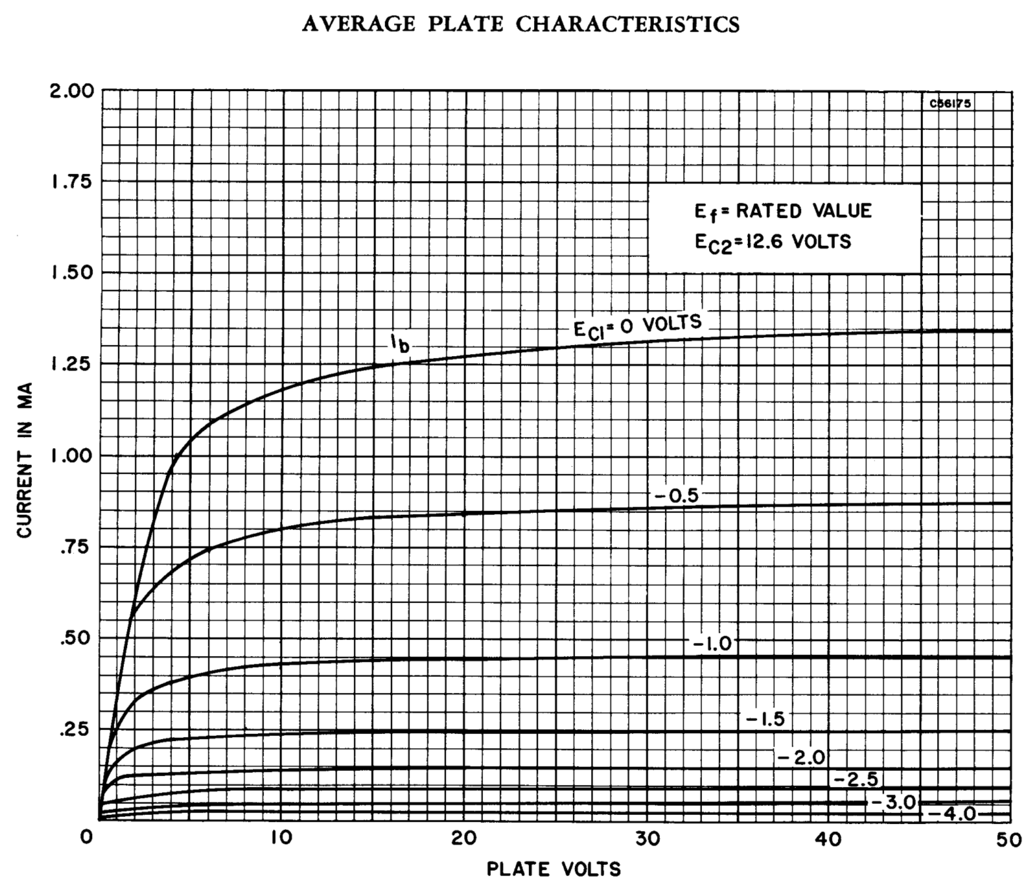
Conclusion

- 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

12AC6 12V Pentode Tube

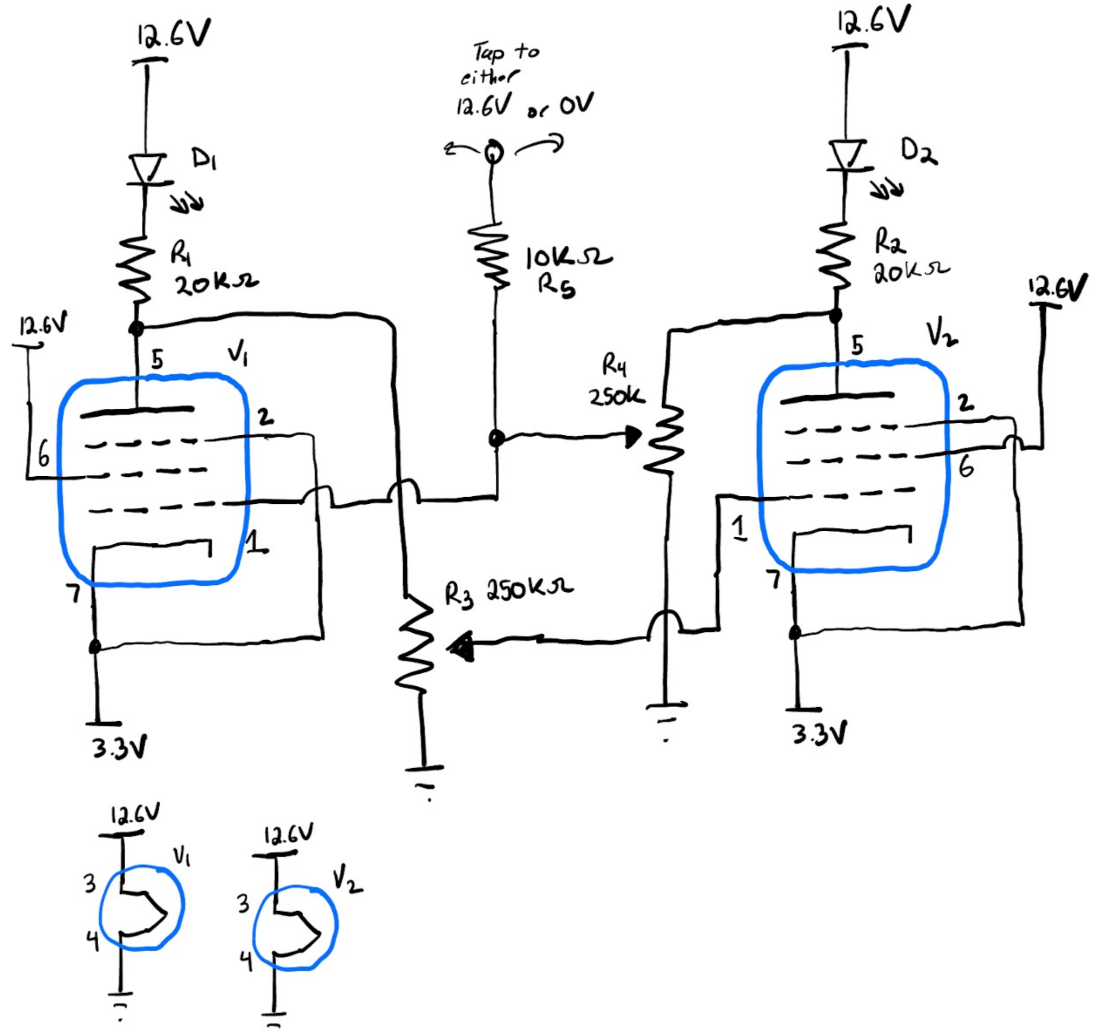
- We’ll use this in the end of lab 03 to make an actual flip flop
- It acts pentodic at low voltages!





Instead we'll Build the Flipflop with Pentodes

- Use



So 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

So interesting…

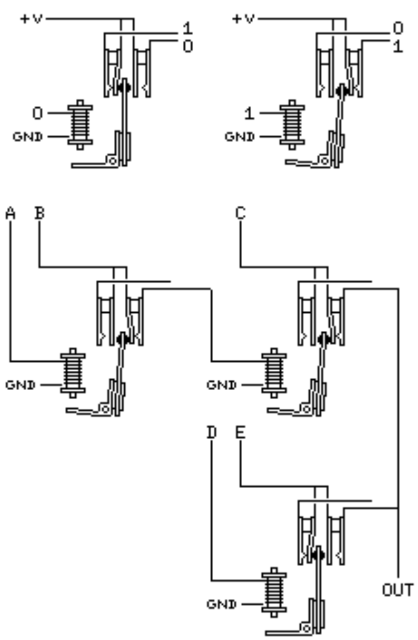
- Of course the first computers weren't until the 1940s so we're jumping ahead a bit, but all throughout the 1920s and 1930s, tube circuits like this were used to gradually build up Computer Theory. (next week…)
- Even a very insightful line in Claude Shannon's Masters Thesis where it finally got linked together formally (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* $\log_2 2^N = N$.

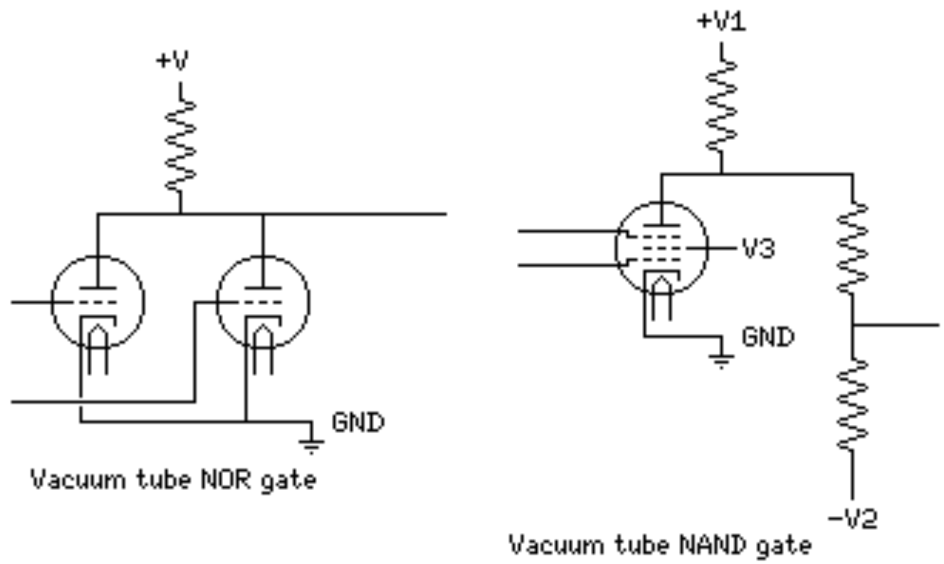
  -Claude Shannon, 1948

Combine those FlipFlops with the ability perform Boolean logic operations

- Using either relays or vacuum tubes make some logic:



Relay Logic Gates



Vacuum Tube Logic Gates

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

If you can make NAND (or NOR)

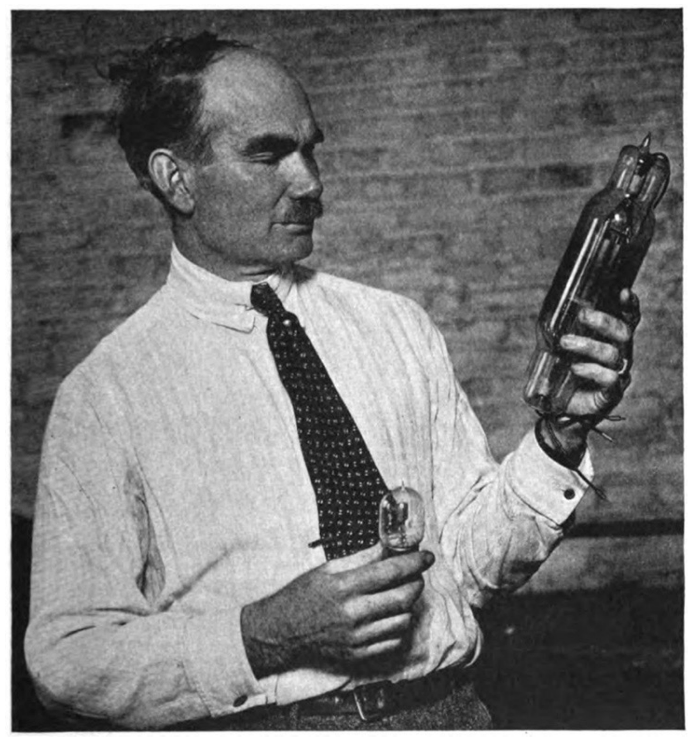
- **<u>Any</u>** Boolean logic expression can be reduced to either the following shape:
  - $Y = \overline{A|B|C| \ldots}$ *(which is a NOR)*
  - *OR*
  - $Y = \overline{A\&B\&C\& \ldots}$ *(which is a NAND)*
- With the ability to remember bits and the ability to perform logic operations of any type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

But Let's Return to Armstrong and his circuits

- So

But Let's Return to Armstrong and his circuits (~1914/5)…

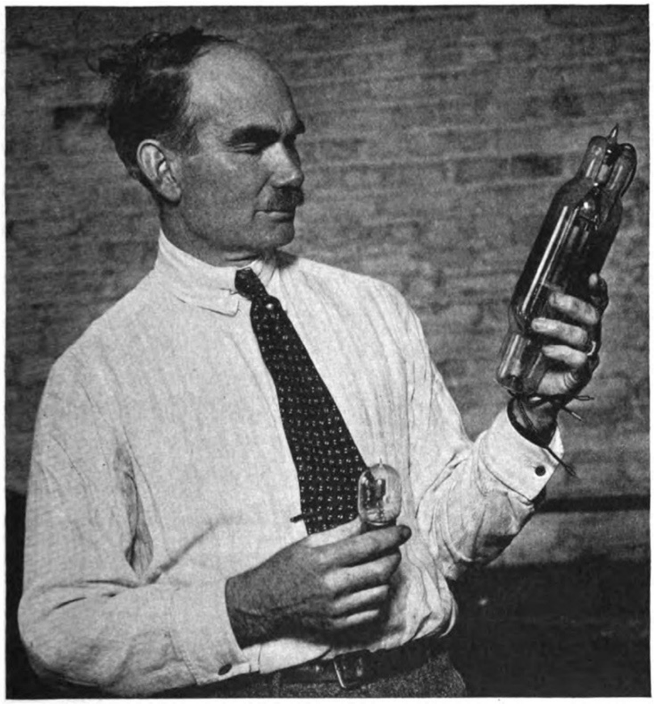
- Remember Lee de Forest?
- First person to put a third wire into a thermionic tube
- He had like a dozen companies that failed and always seemed to become bffs with shysters and conmen/conwomen
- Sued lots of people
- Declared himself to be "father of radio" later in life
- But it is largely established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



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

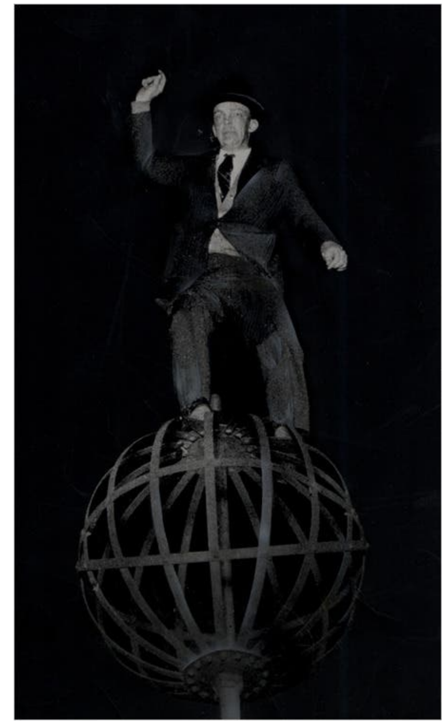
Well de Forest Sued Armstrong

- He claimed he had invented regeneration based on some unclear doodlings from 1912, and he and Armstrong started fighting a very long drawn out legal battle that lasted ten years…well into the 1920s
- Went all the way to the Supreme Court and in 1924 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

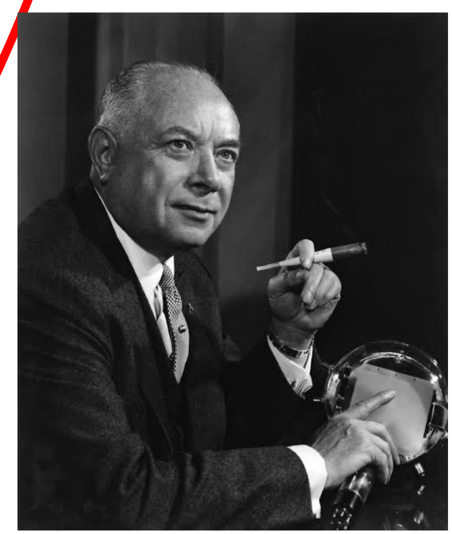


- Armstrong kept experimenting and developed a regenerative design that used a local oscillation to selectively filter and "quench" undesired feedback oscillations.
- As a result you could drive your receiver further into feedback and not "transmit"…gains of over 1 million were possible but circuit was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

Armstrong Kept Doing Stuff

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

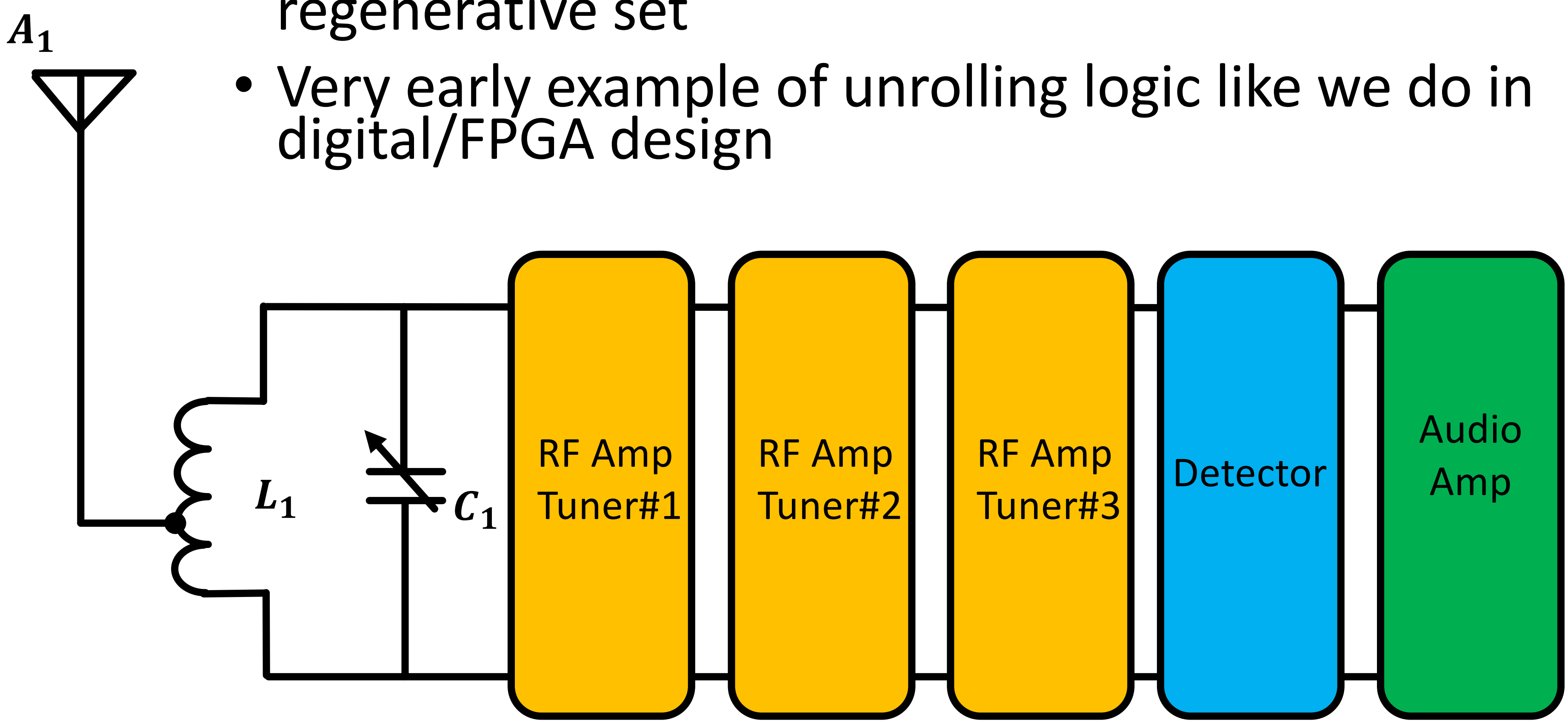
Radio Corporation of America



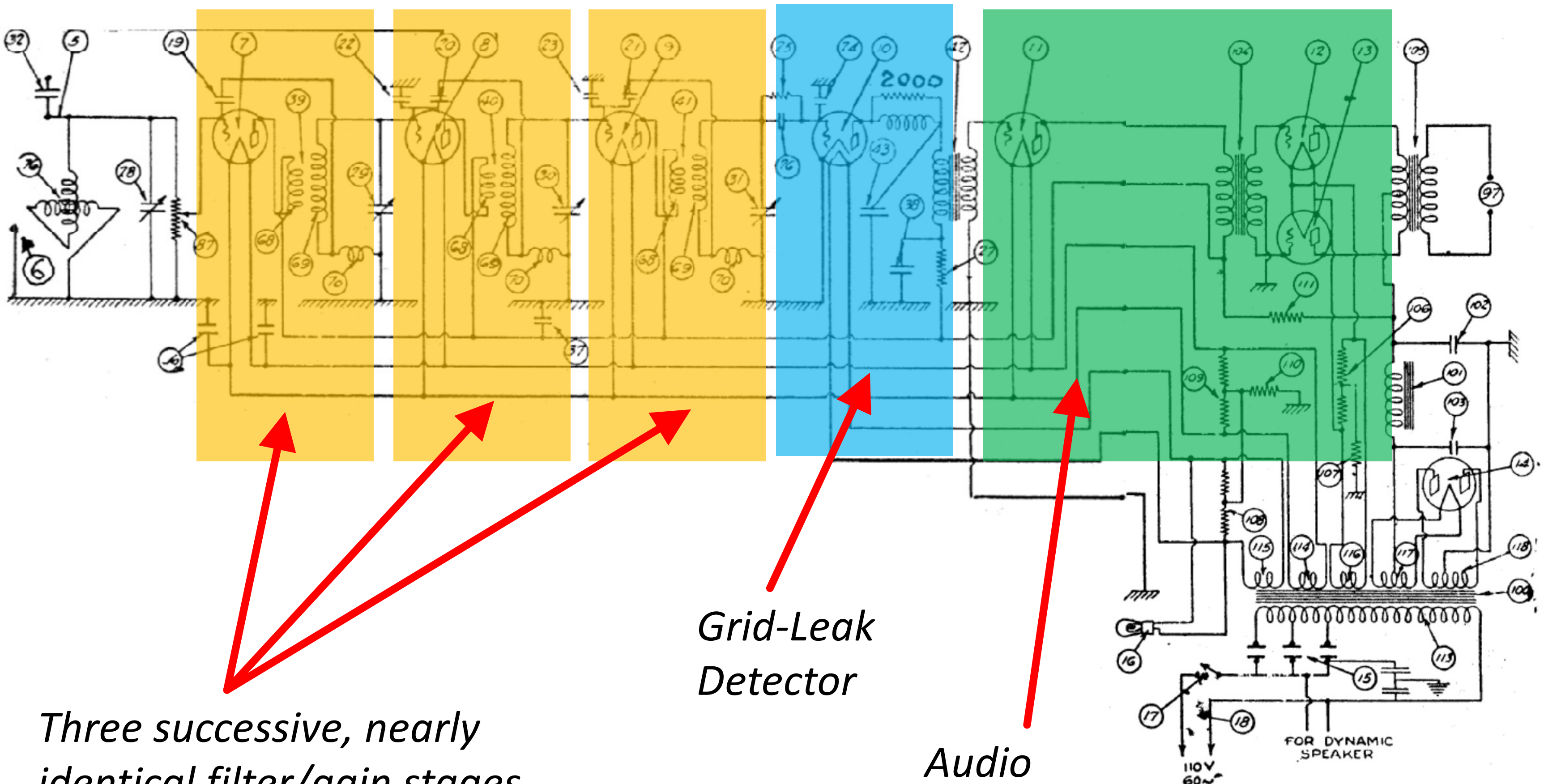
David Sarnoff, Leader of RCA

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



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

Grid-Leak Detector

Audio Amps

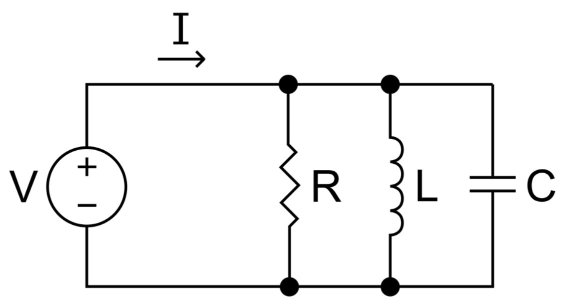
More Tubes ==/!= Better?

- 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 dangerou
- 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

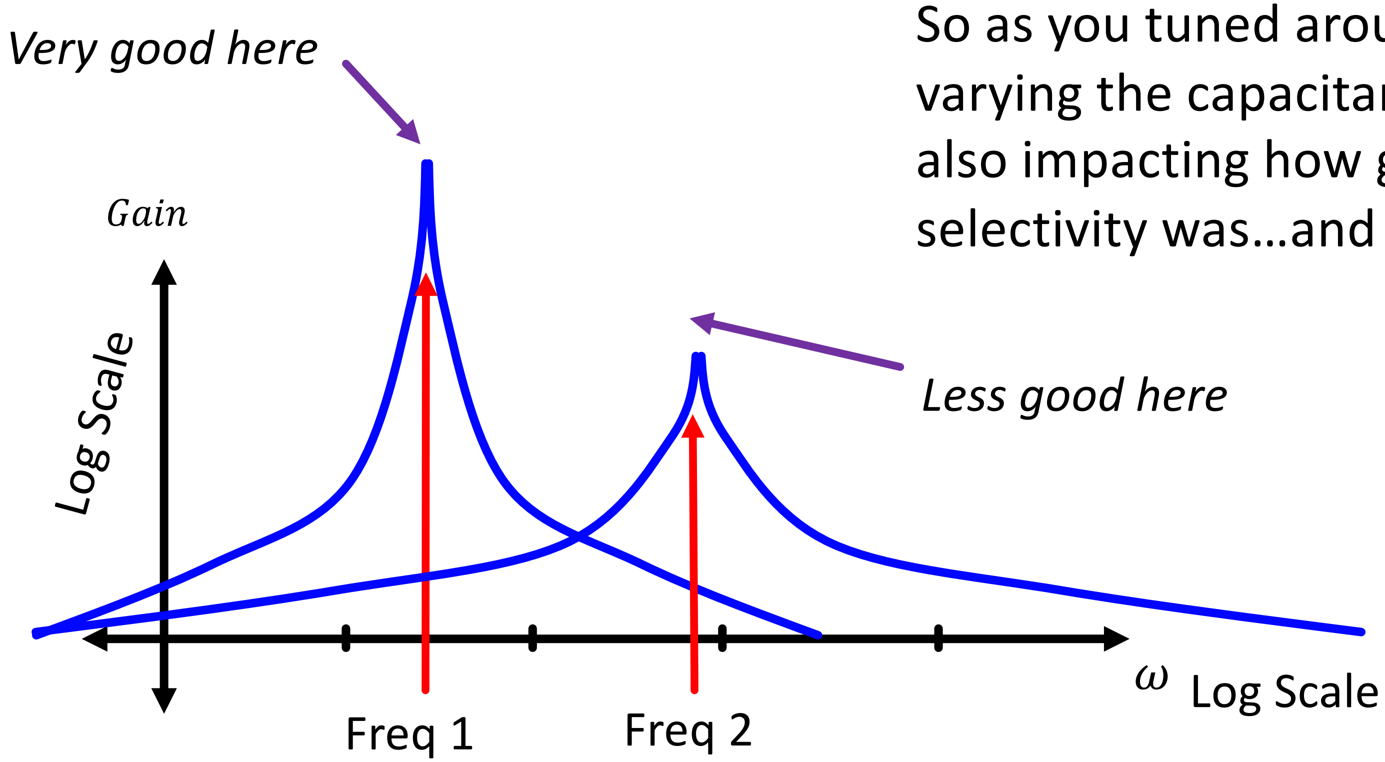
Having a Variable Tuner



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: $Q = R\sqrt{\frac{C}{L}}$

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 stupid that sounds? It sounds like communism or something….everyone will get paid the same amount of money regardless of the amount of money they earn.

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:

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

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

This one is at lower frequency. Keep it.

- 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:

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

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

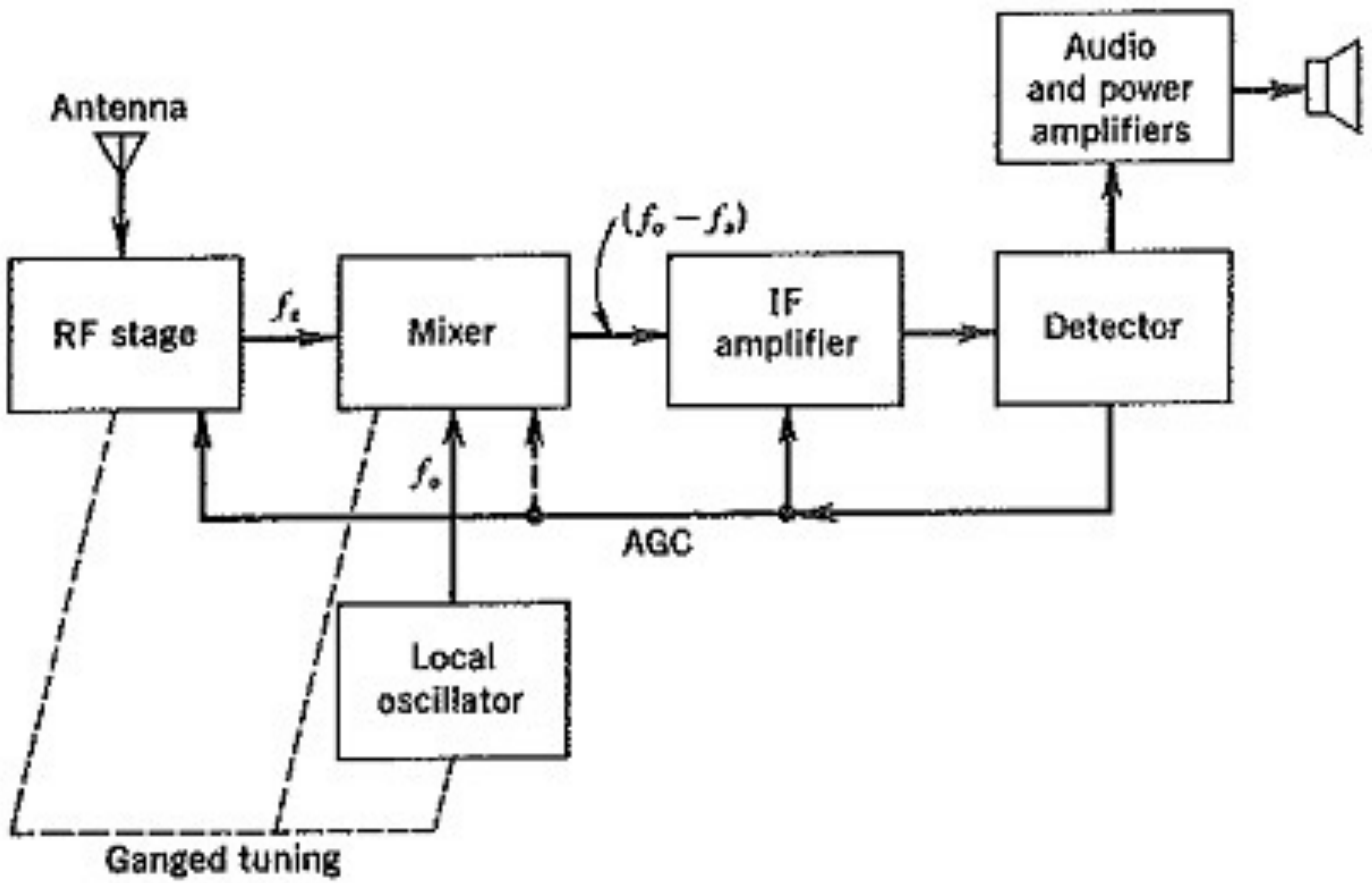


FIGURE 6-2 The superheterodyne receiver.

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

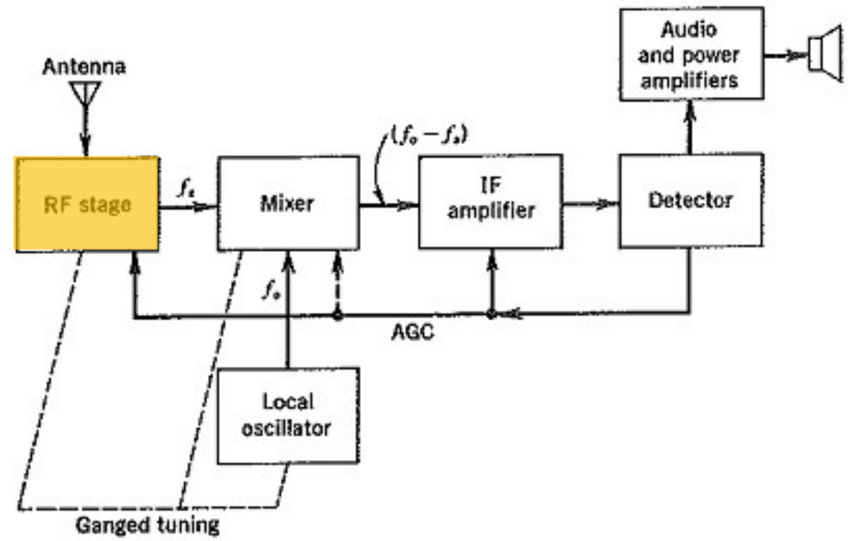


FIGURE 6-2 **The superheterodyne receiver.**

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

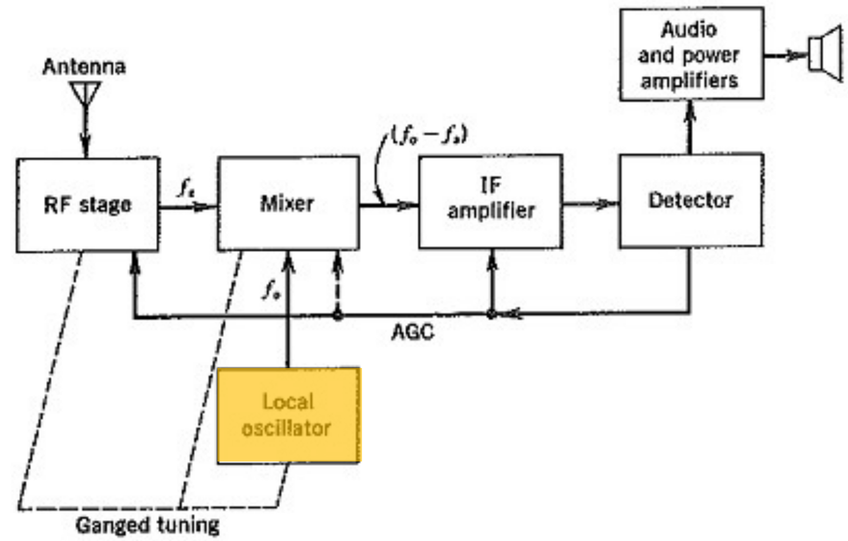


FIGURE 6-2 The superheterodyne receiver.

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

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

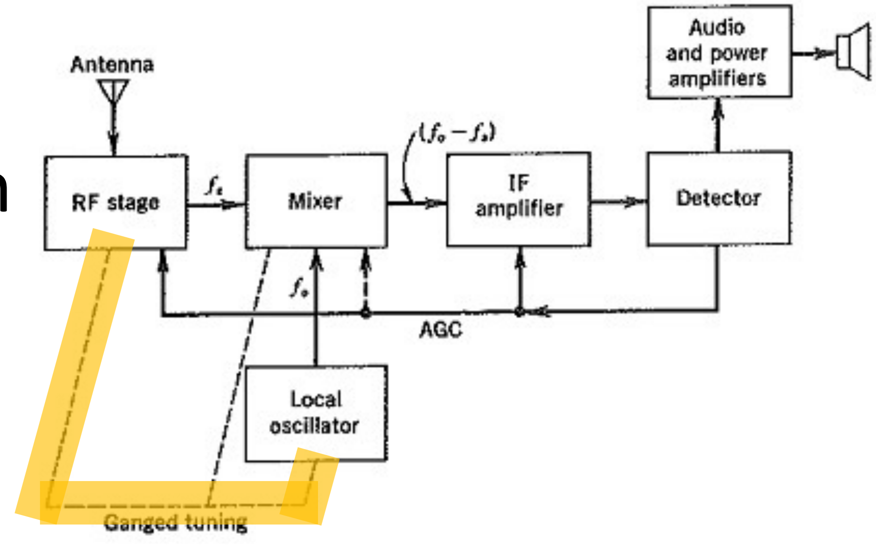
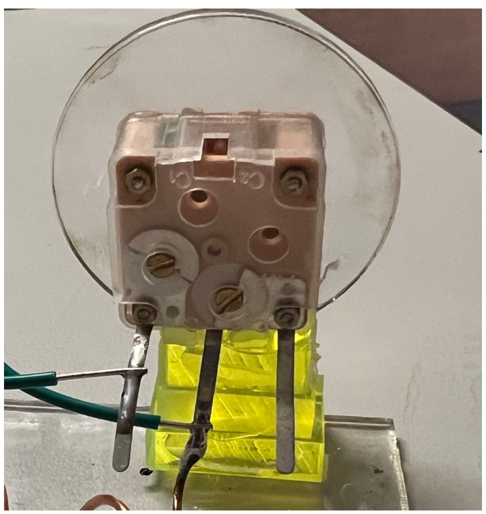
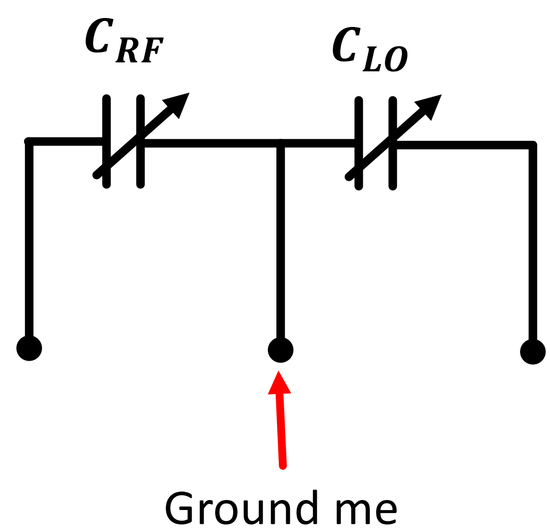


FIGURE 6-2 The superheterodyne receiver.



Schematic of
lab 1 tuning cap



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

The 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 IF should always be the same
- IF stands for “Intermediate Frequency”

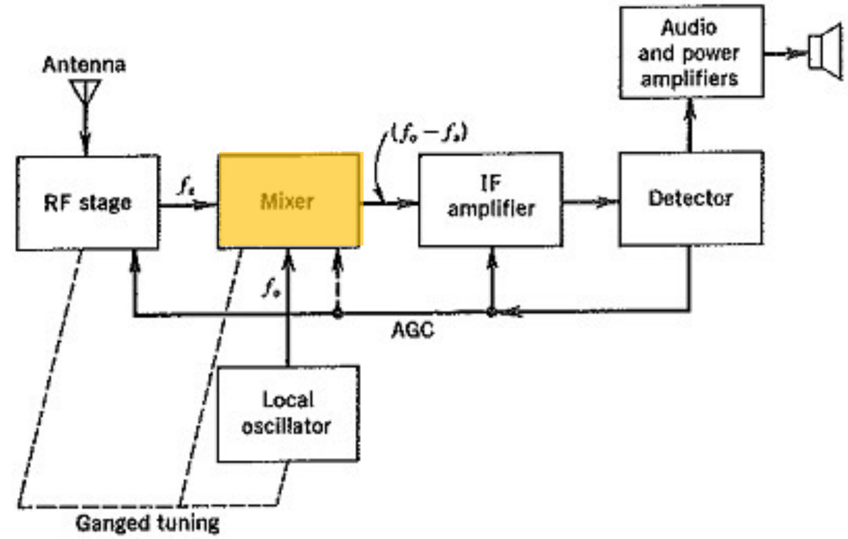


FIGURE 6-2 The superheterodyne receiver.

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

How Do We Multiply?

- Stupid 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 that come out and block with some filters!
- Profit
- Moving on…

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

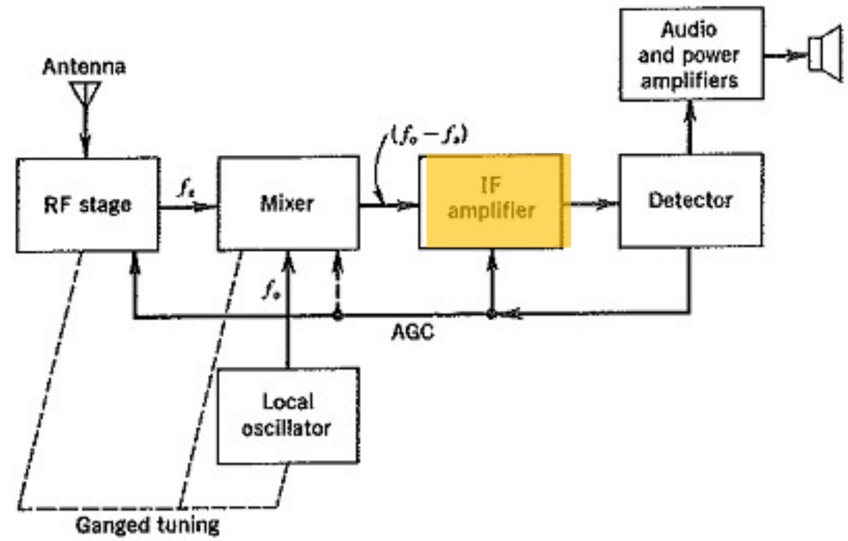


FIGURE 6-2 The superheterodyne receiver.

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

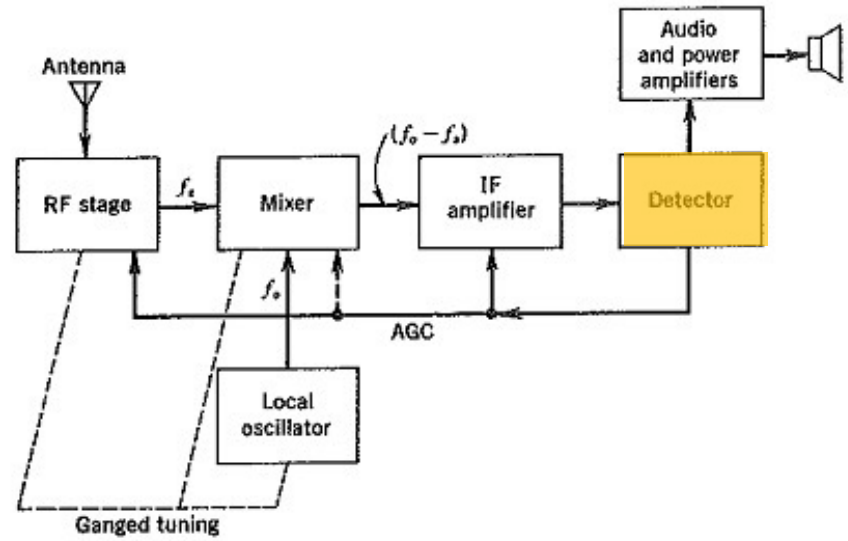


FIGURE 6-2 The superheterodyne receiver.

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

The Audio Amplifier

- Just make the audio louder (scale in power)
- All good!

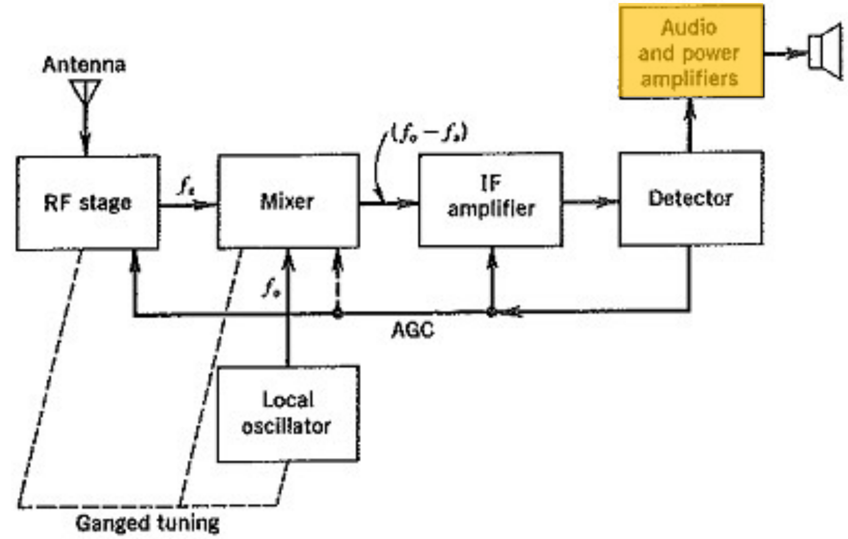


FIGURE 6-2 The superheterodyne receiver.

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.

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 and set up false patents to block/take over FM
- 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 them all.

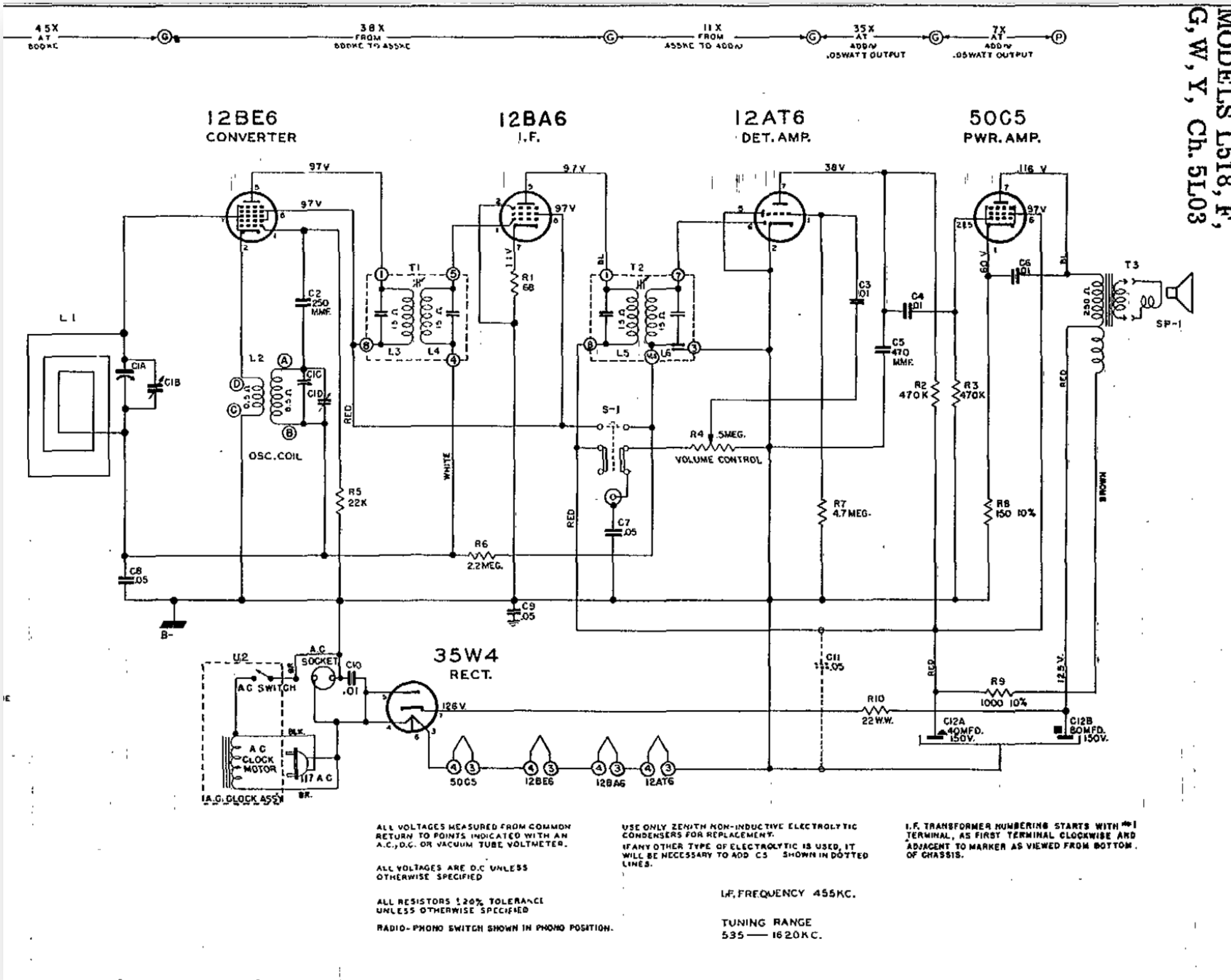
Commodity Radios

- Superheterodyning enabled cheap, good radios.
- Radios proliferated.
- Radio was *the internet* of the 1920s-early 1950s before being supplanted by TV.

1953 Zenith L518

- 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

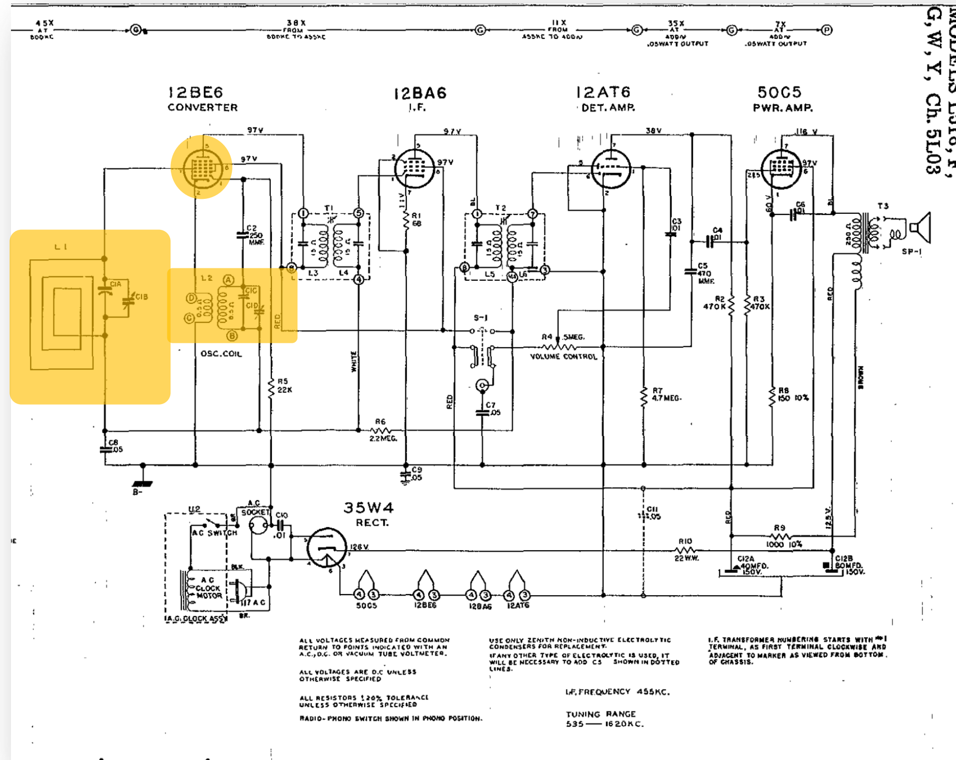
L518



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
A.C. CLOCK MOTOR
A.C. SWITCH
A.C. SOCKET
A.C. CLOCK ASSY
SP-1
B-
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.

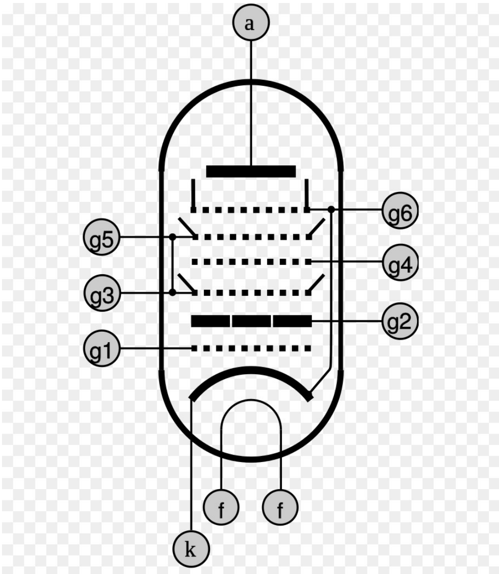
RF/Mixer/LO

- 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?



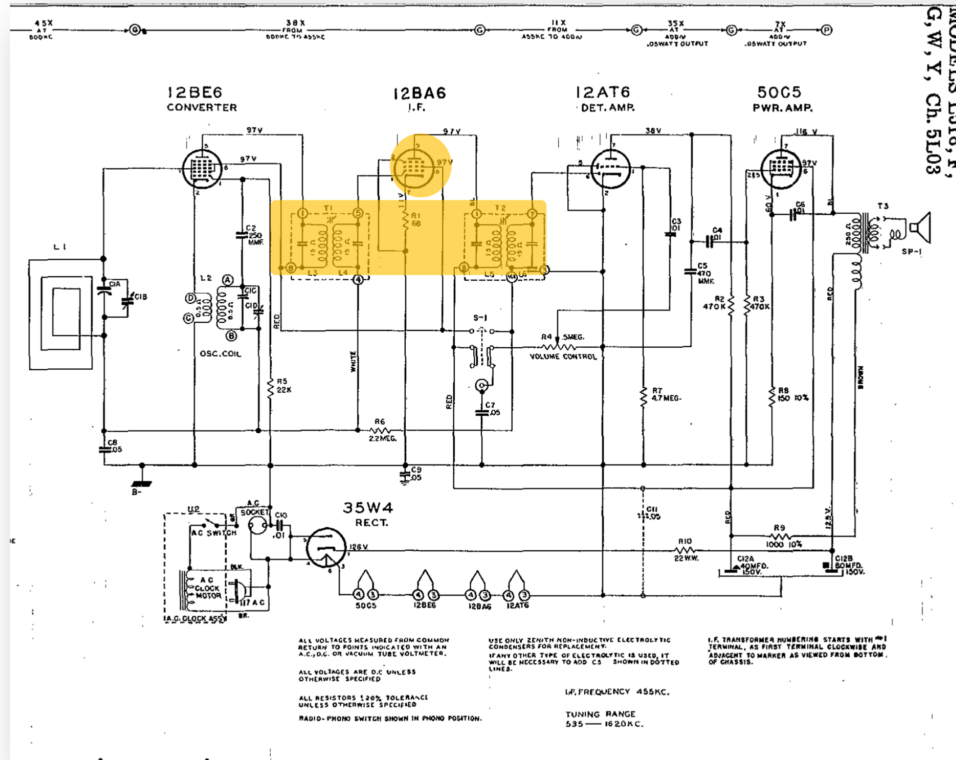
The Pentagrid Converter

- 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



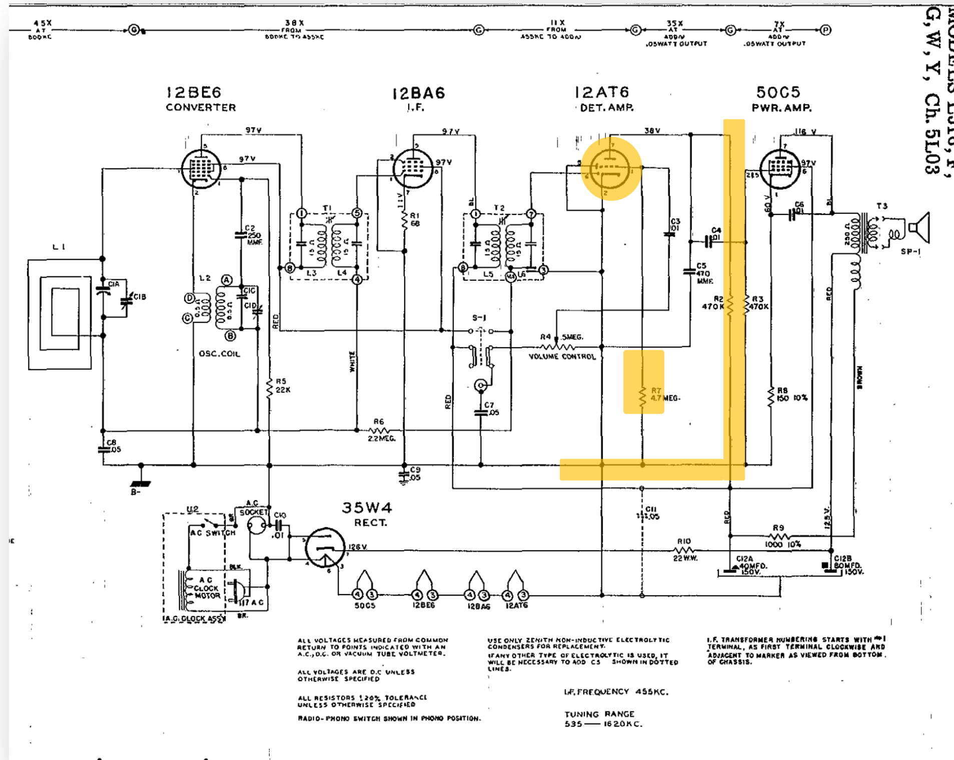
IF Amp

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



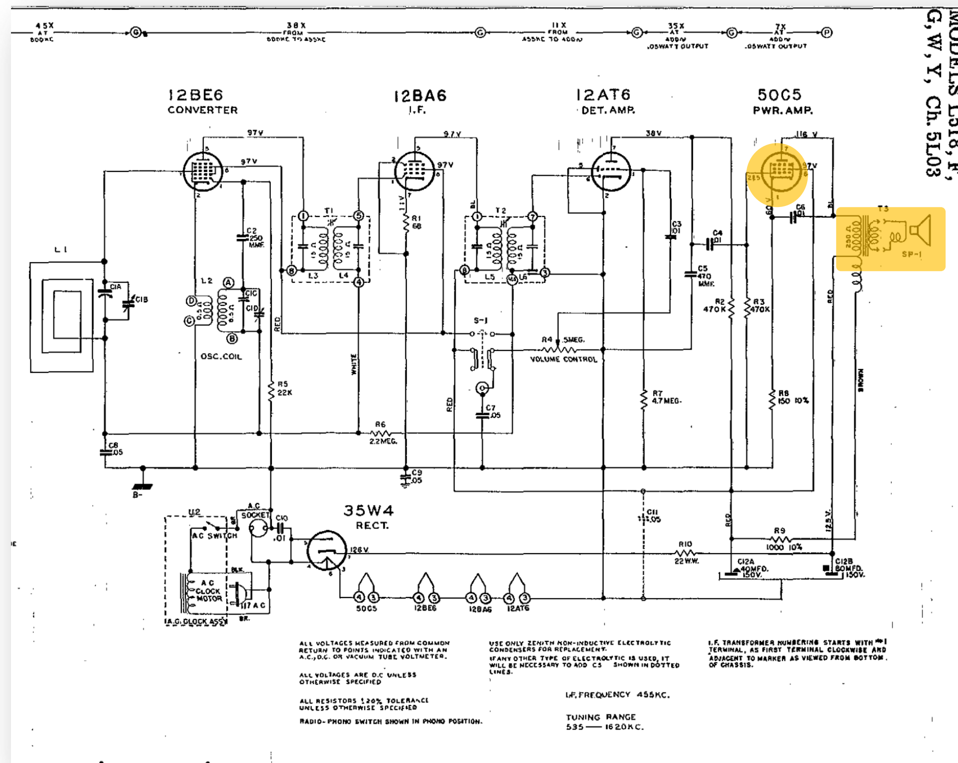
Detector

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



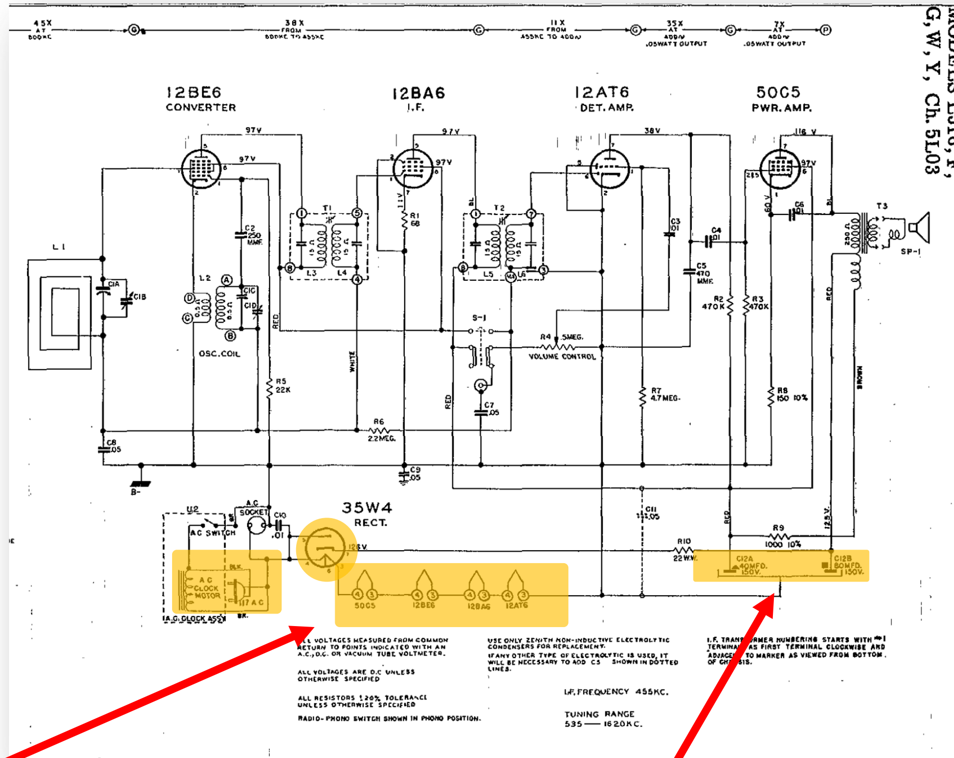
Audio Amp

- 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

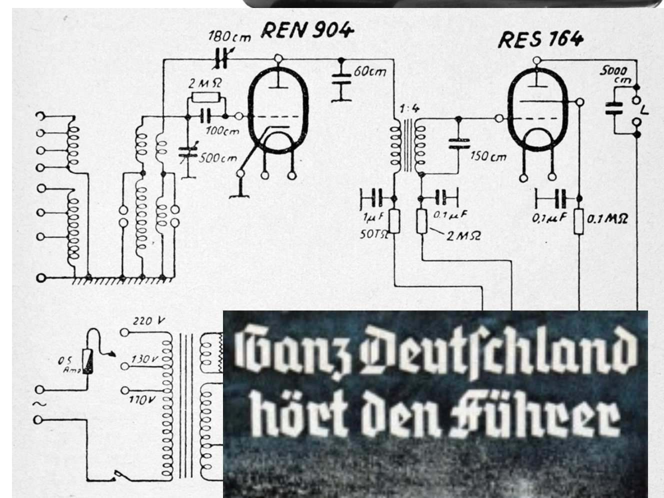
Radio/Broadcast Audio Everywhere

- By 1930's, cheap, robust sets changed the world. Its impact could not have been understated
- Radio shows were listened to by millions
- Real-time news
- Events became lived
- Society became synchronized at all levels
- People got to hear leaders

Fireside Chats by FDR

The People's Radio: Nazi Germany

- Hitler and Goebbels charged engineers with designing 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...

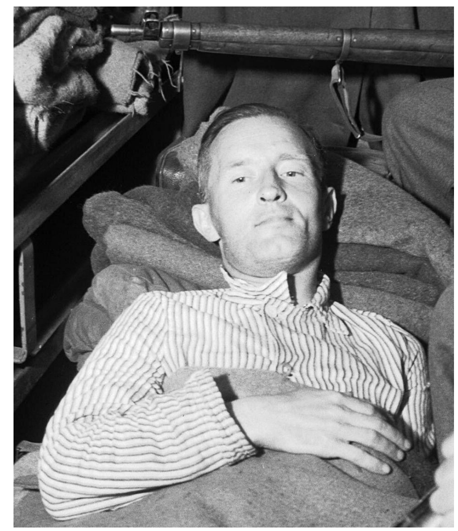
-Albert Speer
Nuremburg Trials 1946

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

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

Radio Lourdes

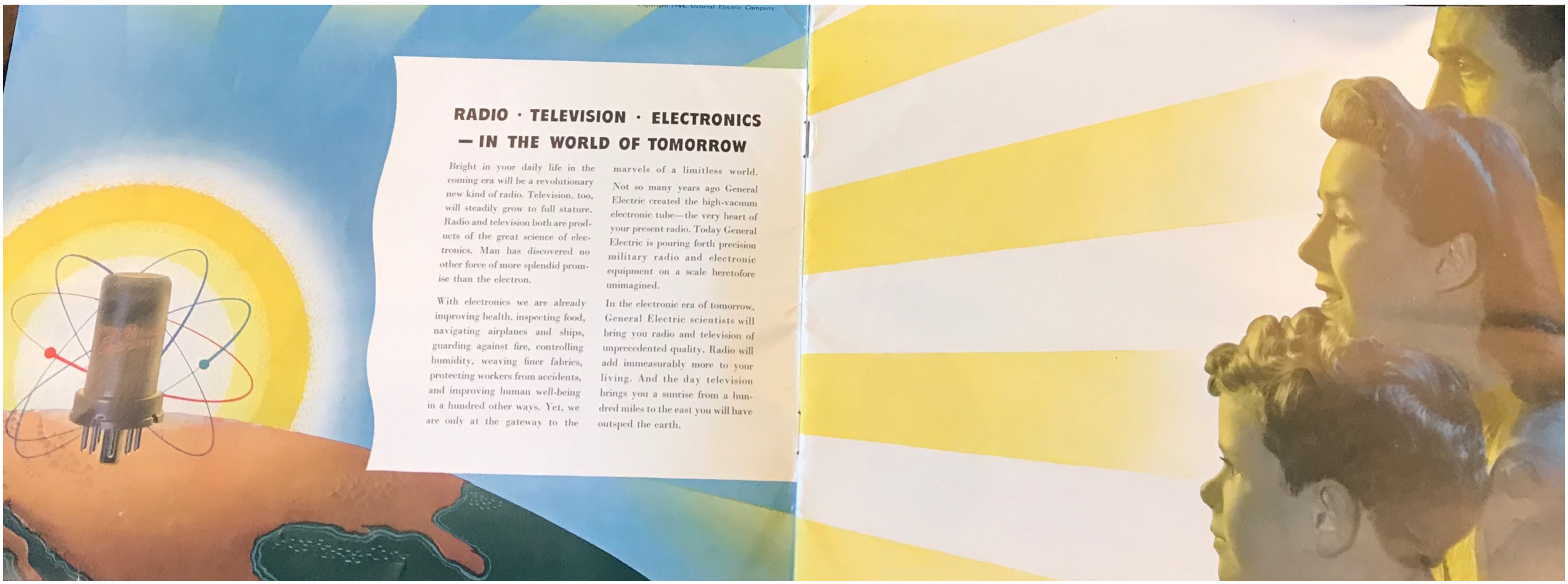
- During the Occupation of France by Nazi Germany, England right across the channel would broadcast messages meant to coordinate the Resistance and other things.
- Battle of propaganda:
  - Germany broadcast to England
  - England to Germany/France
  - US to Japan
  - Japan to US



Lord Haw Haw

Obsession, Hope?

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



1944 GE advertisement…they couldn't sell sets but they sent out teasers

First of a Common Pattern

- EECS Developments/creations outpaced our ability to anticipate how we as a society would react
  - Lighting
  - TV
  - Computers
  - Cellphones
  - Tiktok
  - ChatGPT
  - Etc…

- All thanks to what this thing started
- A lot to take in.

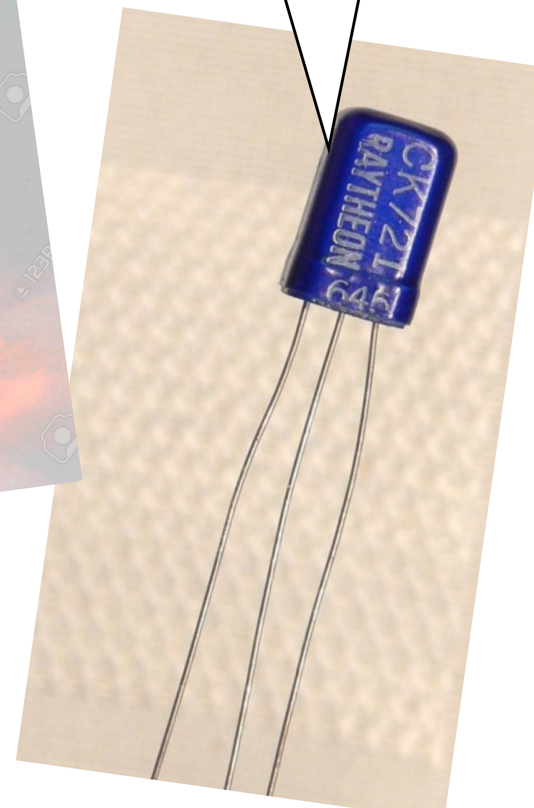
But the Days of Tubes were Numbered

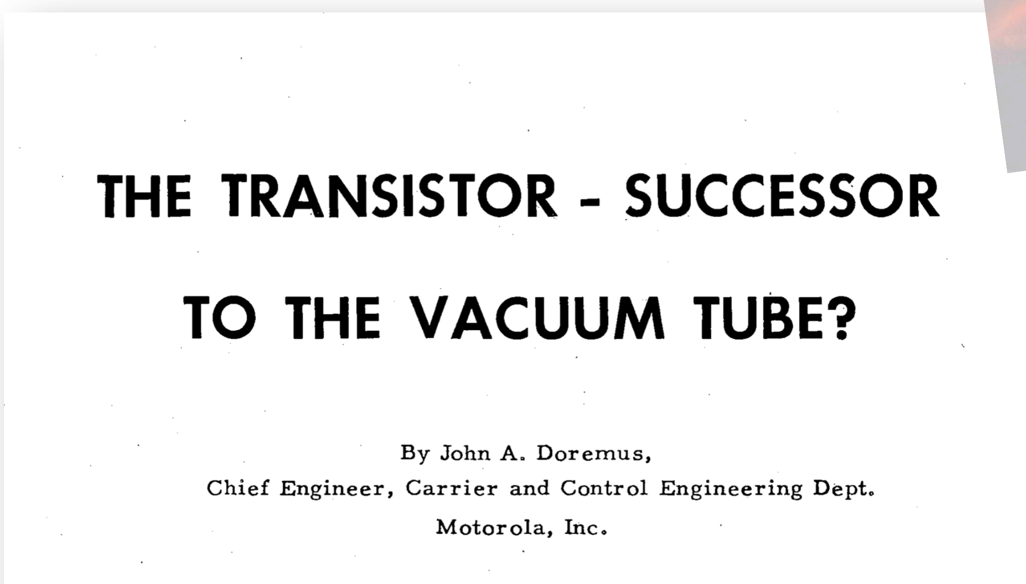
- A lot of pressure to make electronics smaller
- Later variants of vacuum tubes did get smaller:
  - Subminiature tubes
  - Compactrons
  - Nuvistors

Next Time

- Solid-state triodes appear

Step aside, boomer





THE TRANSISTOR - SUCCESSOR TO THE VACUUM TUBE?

By John A. Doremus,
Chief Engineer, Carrier and Control Engineering Dept.
Motorola, Inc.