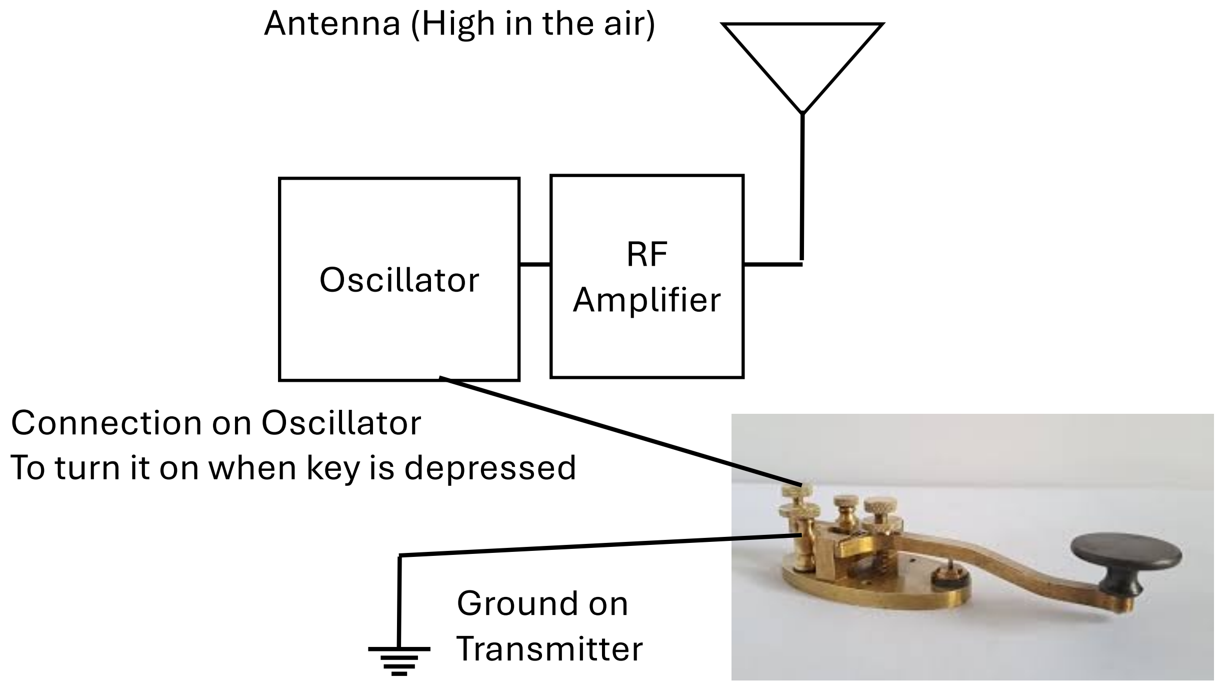
Class 2

Analog Radio Transmitter and Receivers

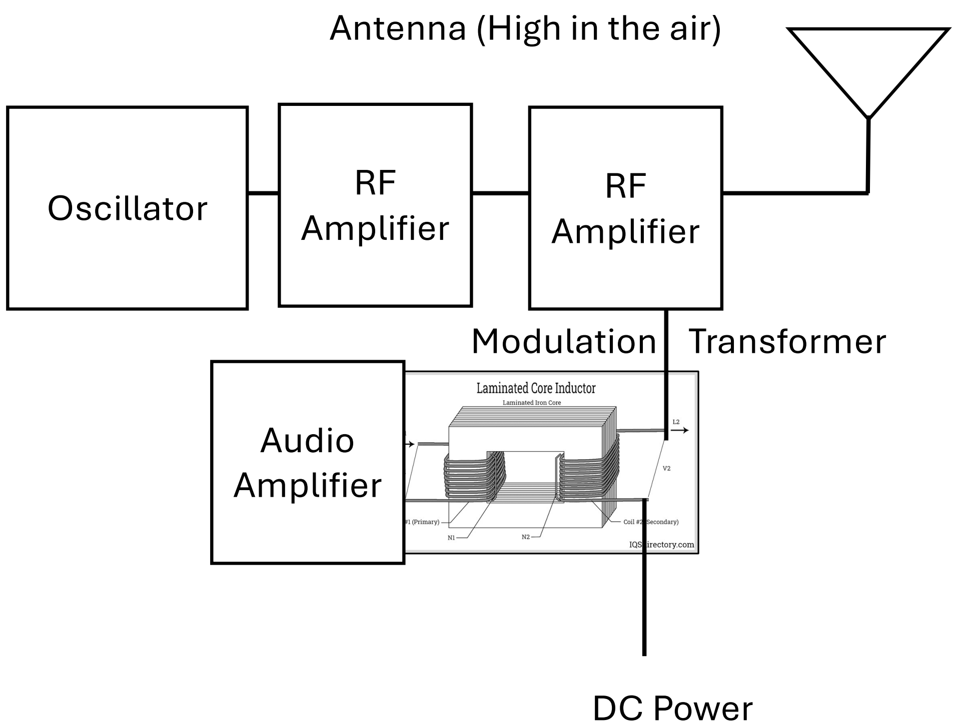
Radio Circuits

- From the 1910s to mid 1990s, all radio systems used the same design techniques
- First, everything was done with vacuum tubes
- Then, transistors
- Then, integrated Circuits
- Later, Large Scale Integrated Circuits (complete designs on one IC)
- Then, in the 1990s, computers became fast enough that designs started to be developed in software
- Now almost all radio systems are implemented in Software and called Software Designed Radios (SDRs)
- For this class we will discuss the designs of the 20th century
- We will not be discussing SDRs

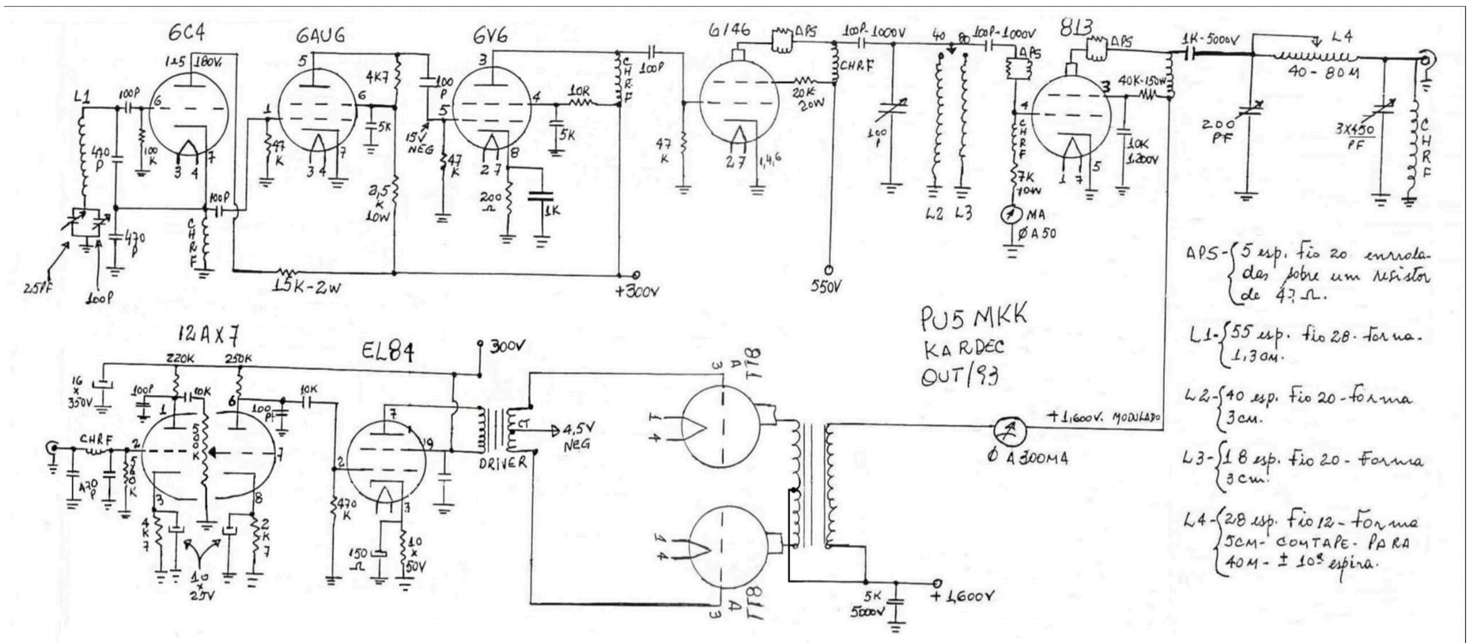
Continuous Wave (CW) Transmitter



Amplitude Modulation (AM) Transmitter

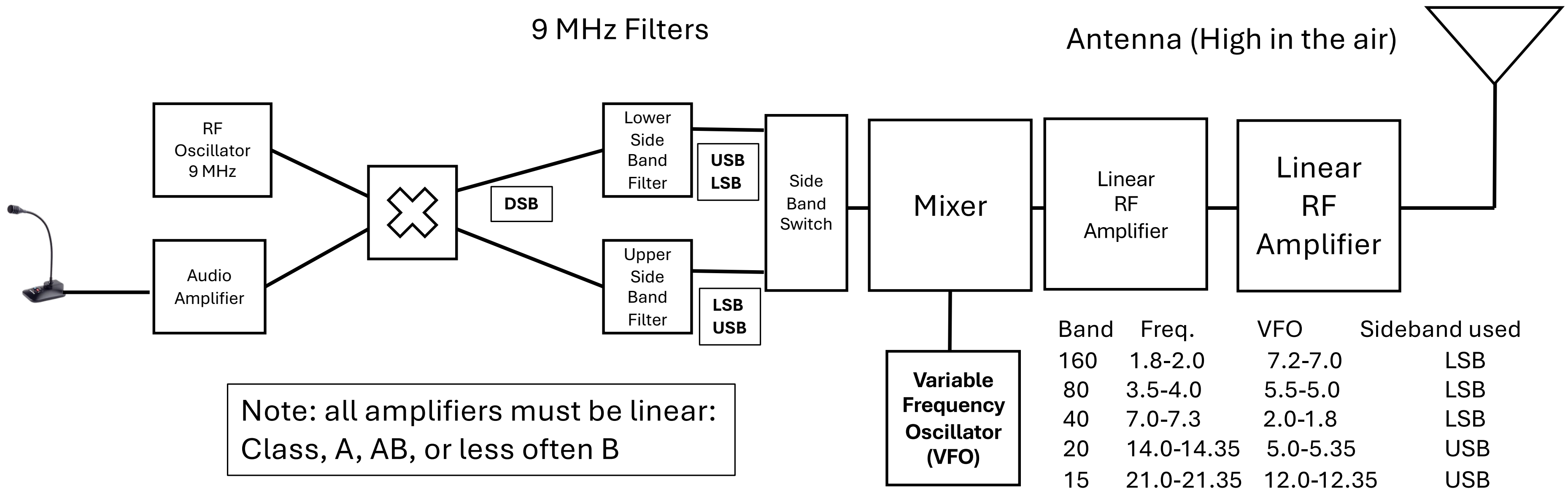


500 Watt Vacuum Tube AM Transmitter



Power needed:
1600 volts DC at approximately 0.5 Amps, 300 volts DC at approximately 100 mA and 550 volts DC at approximately 100 mA,
10 volts AC 10 amps, 6.3 volts AC at about 10 amps, -4.5 volts at about 0 amps

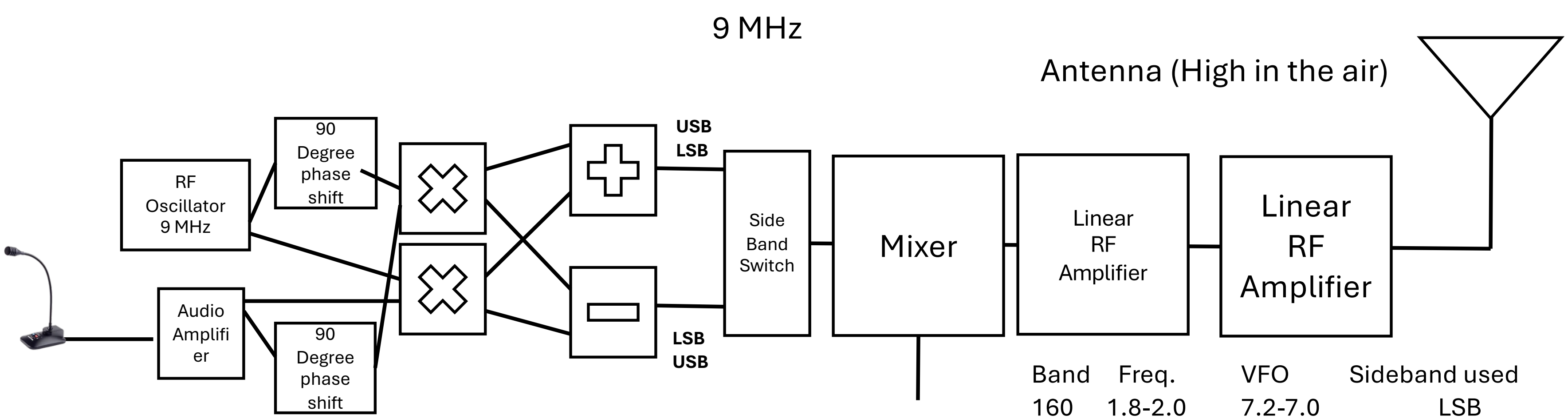
Single Side Band Transmitter (SSB) - Filter



Note: all amplifiers must be linear:
Class, A, AB, or less often B

Band	Freq.	VFO	Sideband used
160	1.8-2.0	7.2-7.0	LSB
80	3.5-4.0	5.5-5.0	LSB
40	7.0-7.3	2.0-1.8	LSB
20	14.0-14.35	5.0-5.35	USB
15	21.0-21.35	12.0-12.35	USB
10	28.0-29.7	19-20.7	USB

Single Side Band Transmitter (SSB) - Phasing



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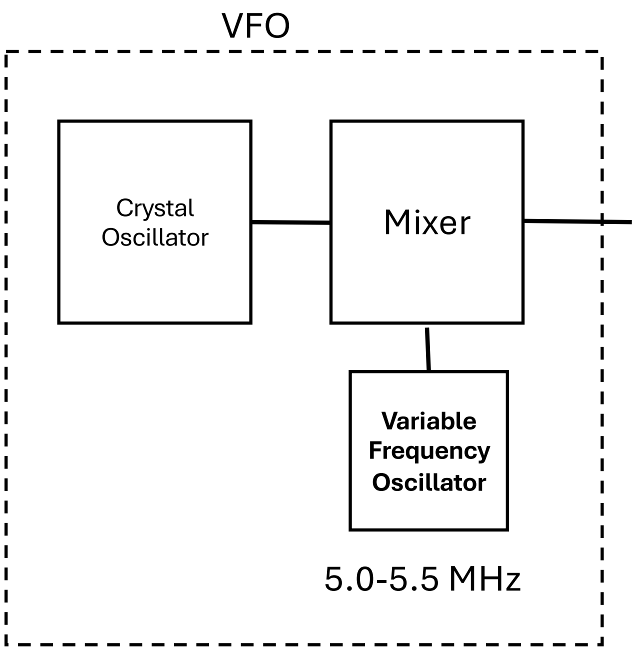
Band	Freq.	VFO	Sideband used
160	1.8-2.0	7.2-7.0	LSB
80	3.5-4.0	5.5-5.0	LSB
40	7.0-7.3	2.0-1.8	LSB
20	14.0-14.35	5.0-5.35	USB
15	21.0-21.35	12.0-12.35	USB
10	28.0-29.7	19-20.7	USB

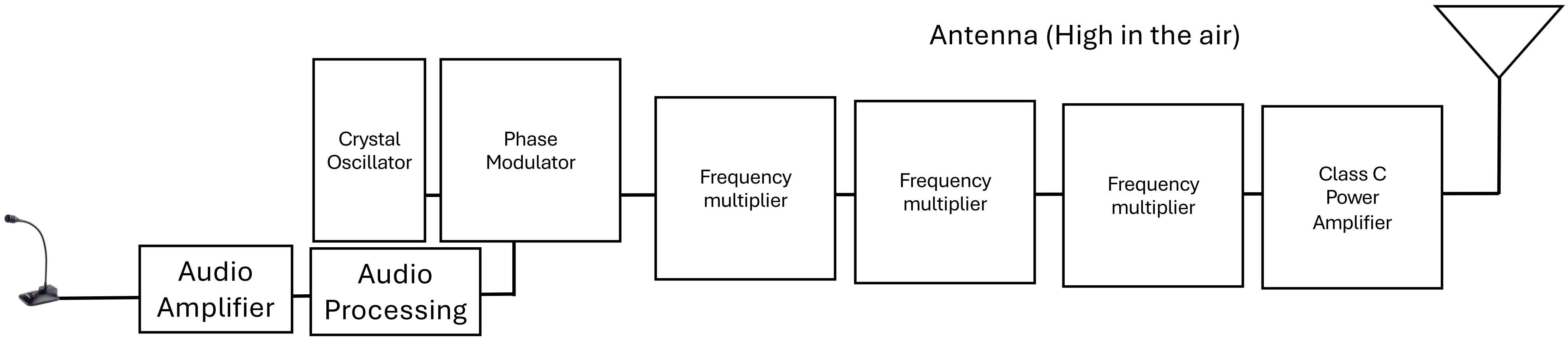
How the VFO is constructed



Band	Freq.	Internal Oscillator	Crystal	VFO	Sideband used
160	1.8-2.0	5.5-5.3	1.7	7.2-7.0	LSB
80	3.5-4.0	5.5-5.0	none	5.5-5.0	LSB
40	7.0-7.3	5.5-5.3	3.5	2.0-1.8	LSB
20	14.0-14.35	5.0-5.35	none	5.0-5.35	USB
15	21.0-21.35	5.0-5.35	7.0	12.0-12.35	USB
10	28.0-29.5	5.0-5.5	14.0	19.0-19.5	USB
10	28.5-29.0	5.0-5.5	14.5	19.5-20.0	USB
10	29.0-29.5	5.0-5.5	15.0	20.0-20.5	USB
10	29.5-29.7	5.0-5.2	15.5	20.5-20.7	USB

Frequency Modulation (FM) transmitter Pre 1980s

NOTE: FM is created by making an PM transmitter and doing audio processing



For 2 meters:	8.169166 MHz	x3 24.5075 MHz	x3 73.5225 MHz	x2 147.045 MHz
For 6 meters:	8.6033 MHz	x3 25.81 MHz	not used not used	x2 51.62 MHz

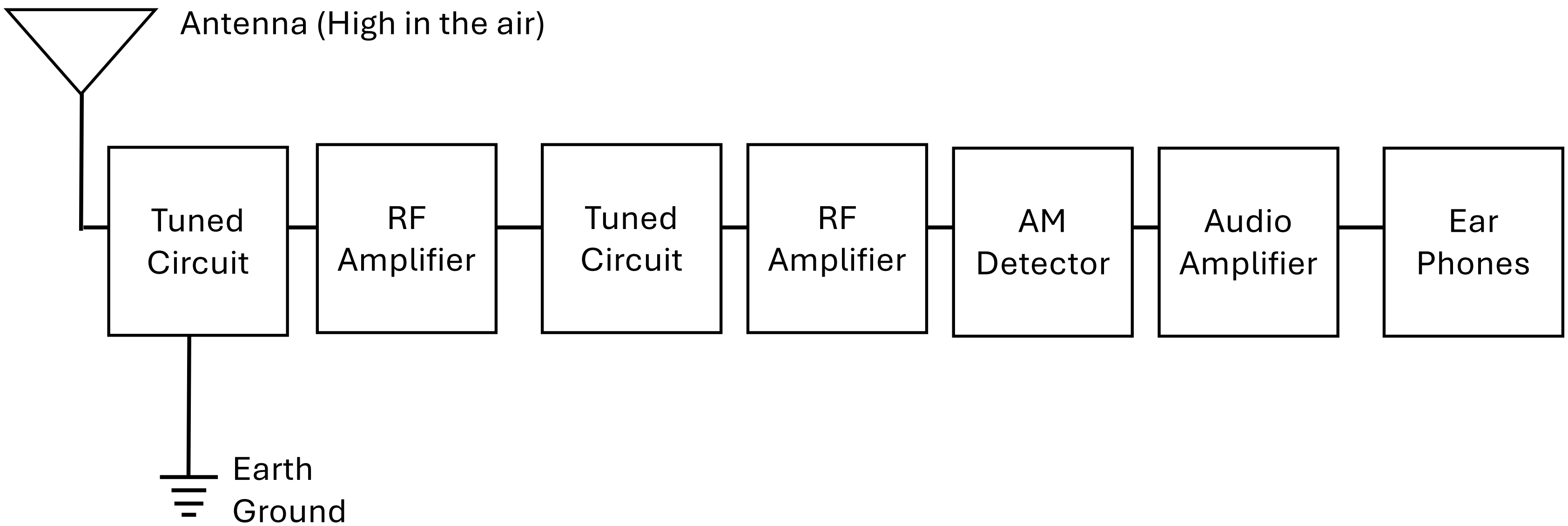
Modern FM Transmitters

- Designs since the mid 1980s have eliminated the use of frequency specific crystals and
- Channel Crystals replaced by frequency synthesizers that use a computer to generate all need frequencies

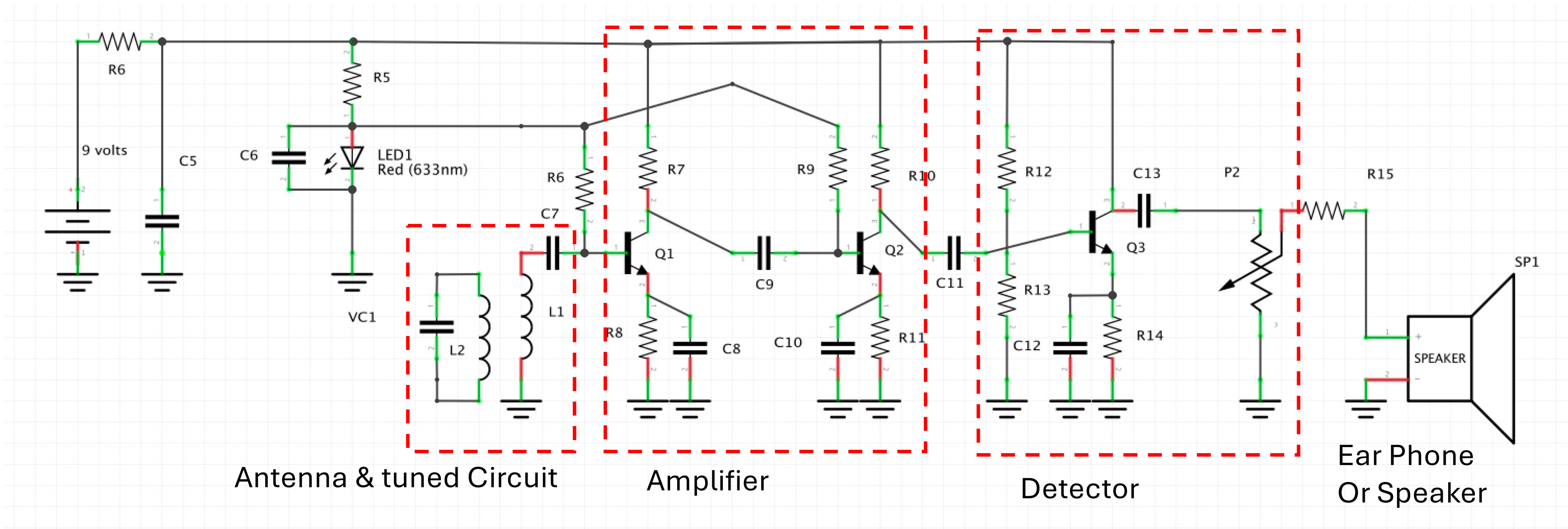
Tuned Radio Frequency (TRF) Receiver

- In a TRF receiver, there are multiple stages of amplification at the radio frequency of the transmitter
- The more stages of amplification, the more sensitive the receiver
- Unfortunately, multiple stages often have stray inductance and capacitance that results in the output of the receiver being fed back into the input, thus resulting in oscillations

TRF Block Diagram



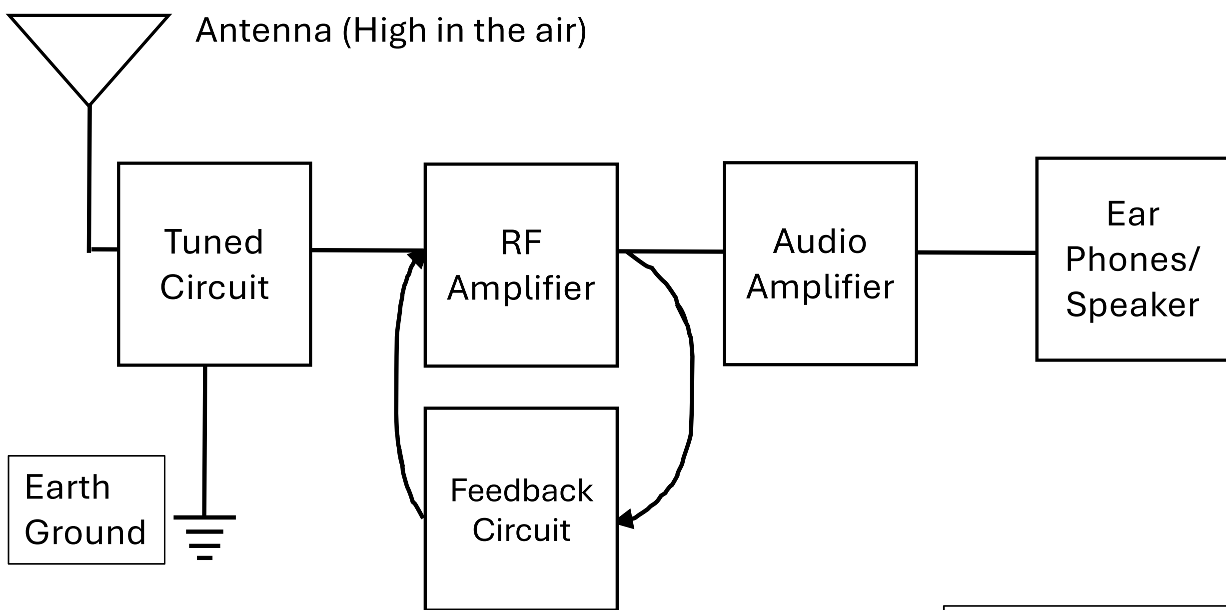
Example: Simple TRF Receiver



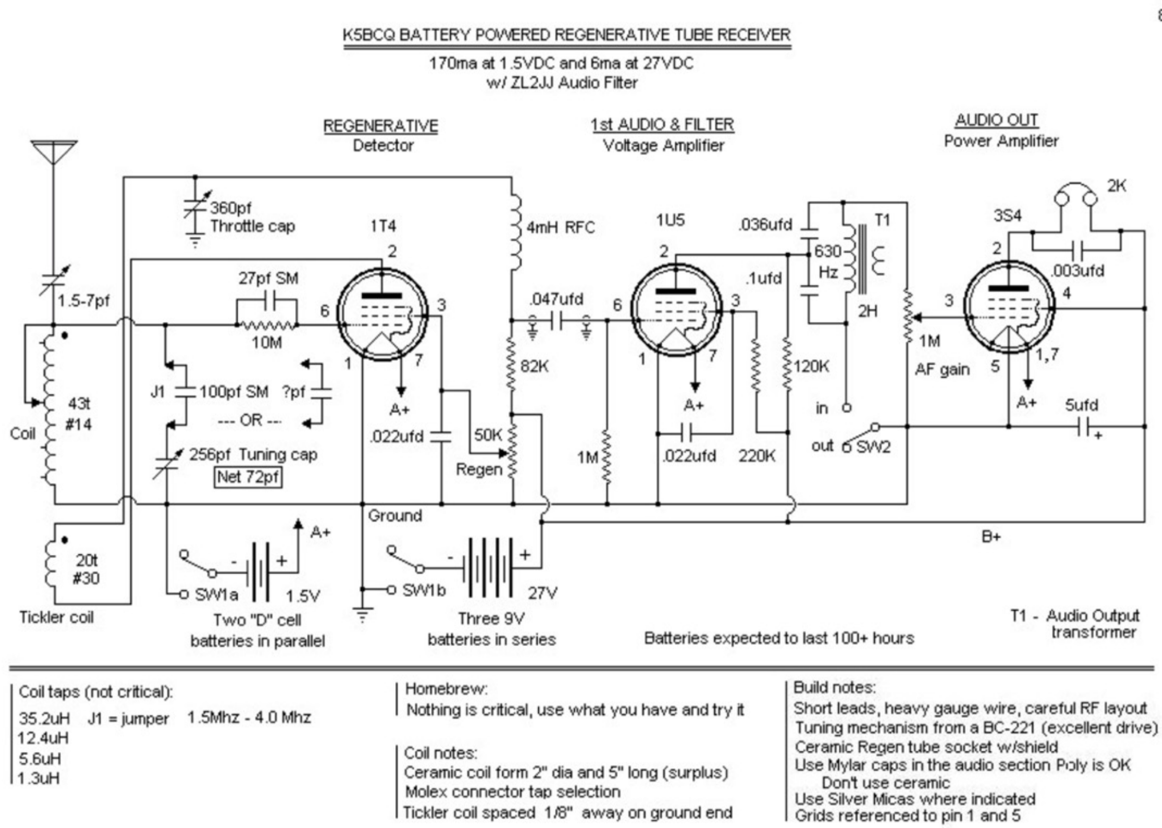
Regenerative Receiver

- The original patent for the regenerative receiver was filed by Edwin Armstrong in 1914
- He demonstrated it at the Marconi site (across the road from CDL)
- It uses an RF amplifier that feeds some of the output back into the input
- The amount of feedback is adjusted by a regeneration control and is adjust to make the amplifier gain be just before it starts oscillating
- A regenerative receiver can be made very sensitive to receiver very weak signals
- The regeneration stage typically also detects the AM signal
- Putting it into oscillation can make it receiver CW signals

Block Diagram of Regenerative Receiver

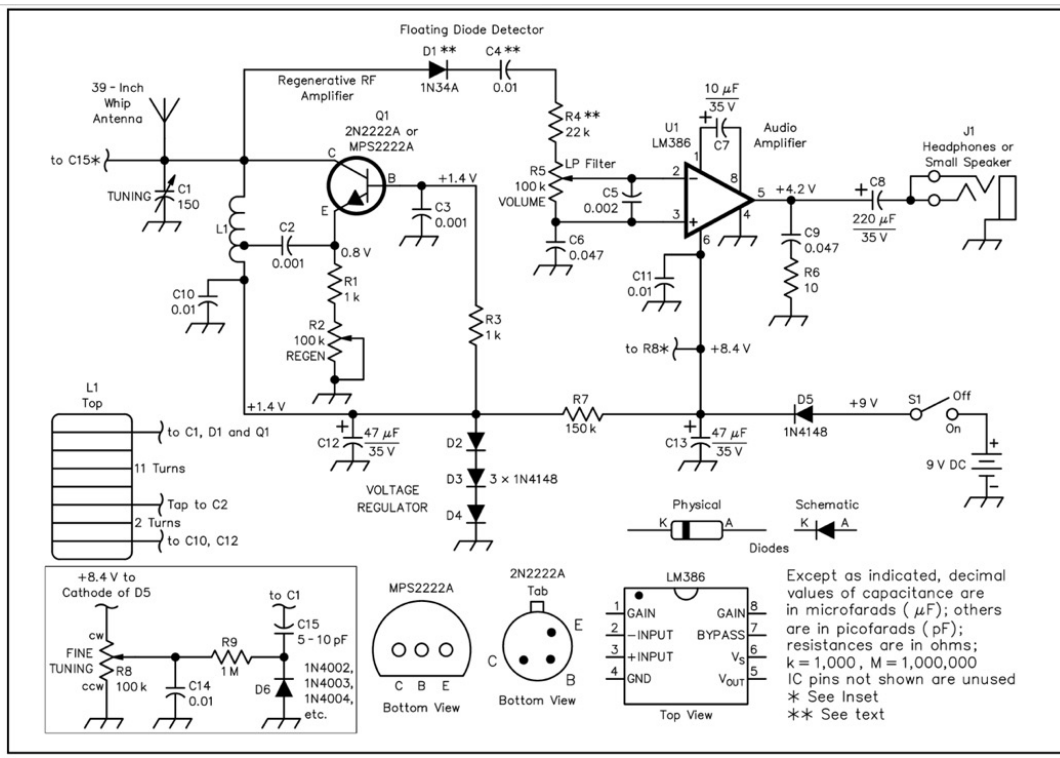


Example Regenerative Receiver with Tubes



Example Regenerative Receiver with Transistors and Integrated circuits

For more information:
Click on the link and read article
https://www.arrl.org/files/file/Technology/tis/info/pdf/0009061.pdf



Simple Regen Receiver From QST

Super-Regenerative Receiver

- In a Super Regenerative Receiver, the circuit is made to in and out of oscillation at a rate around 50,000-100,000 times per second
- Thus, no regeneration control is needed
- The receiver is very sensitive
- However, nearby (in frequency or location) transmitters can overload the receiver and prevent receiving the desired signal

Example Super-Regenerative Receiver

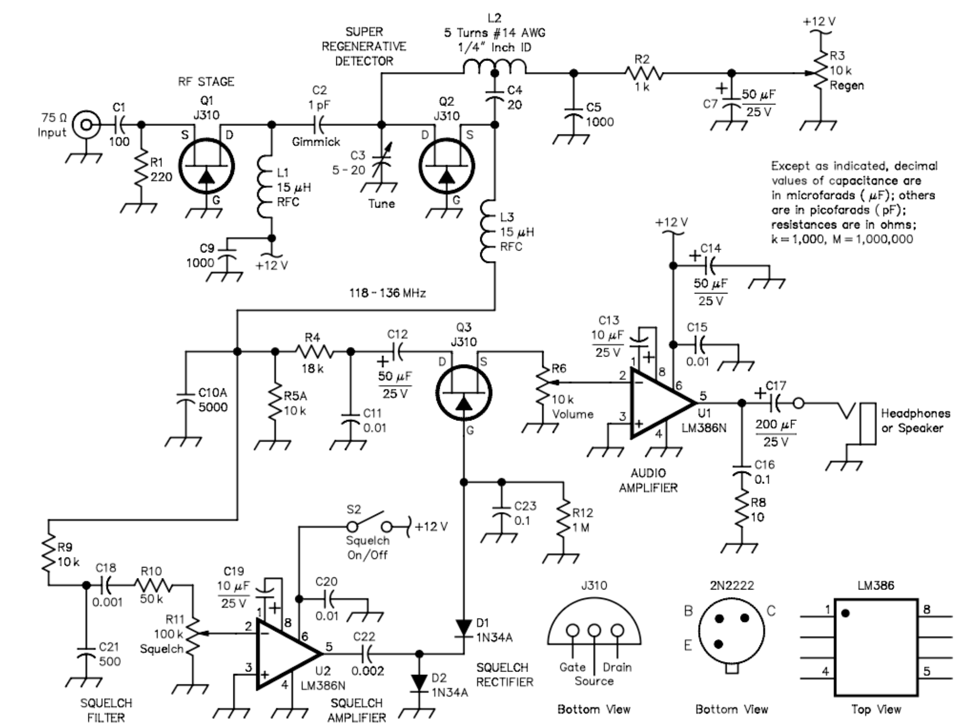


Fig 12—A super-regen VHF aircraft-band (118-136 MHz) receiver with squelch.

QEX **Sept/Oct 2000 27**

For more information click on link and read the article new_super_regen_for_vhf_uhf_2000_09qex018.pdf

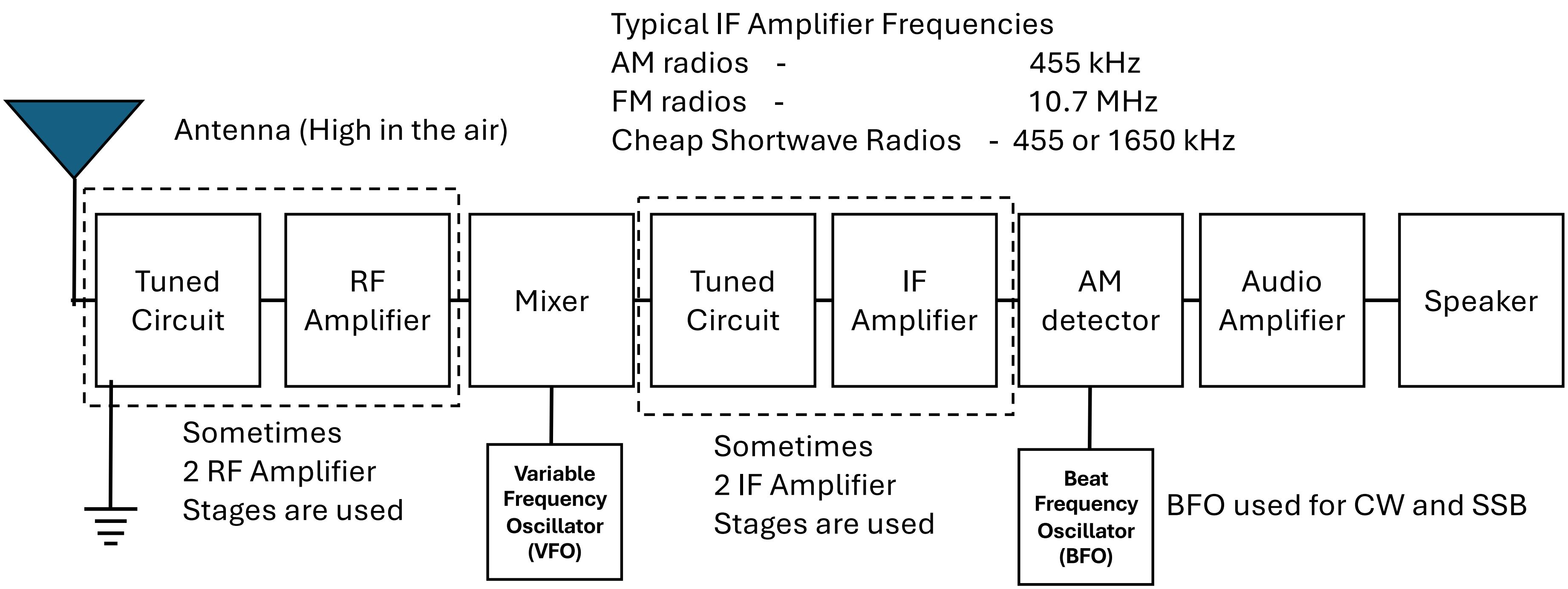
Disadvantages of Regenerative Receiver

- It takes skill to adjust the receiver
- The control needs to be adjusted often from:
  - The antenna swaying in the wind
  - Changes in frequency of the receiver
- When a super regenerative or regenerative receiver goes into oscillation it radiates a signal like a transmitter
  - This can interfere with other receivers nearby
  - The Nazi’s used this to direction find underground stations when the operators mis-adjusted their receivers and left them on

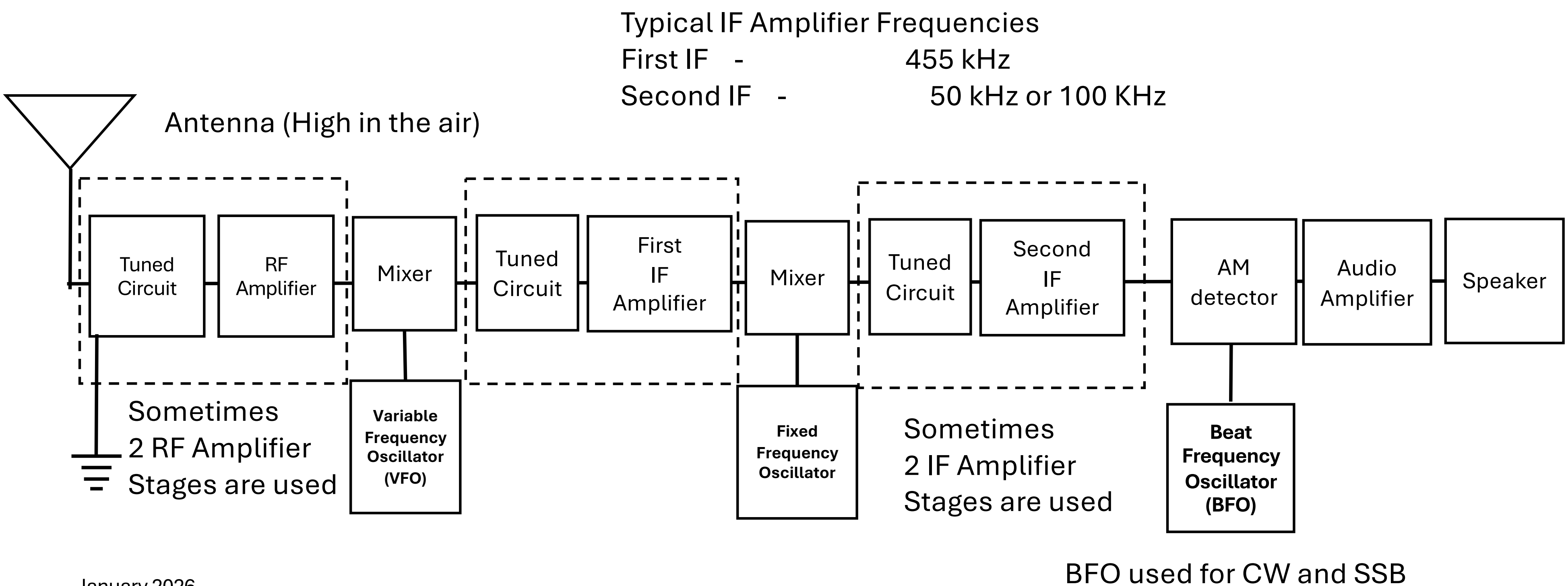
Superheterodyne Receiver

- Lucien Lévy: Patented the fundamental circuit scheme for the superheterodyne receiver in 1917
- Edwin H. Armstrong: Developed a more practical version of the superheterodyne method and was granted U.S. patent 1,342,885 in 1920 for his work
- In a Superheterodyne receiver, the received frequency is changed to a (typically) lower frequency where:
  - Gain and
  - Selectivity is easier to design into the circuits
- But, unless superhet receivers are correctly designed, they can pick interference from other frequencies than the desired frequency

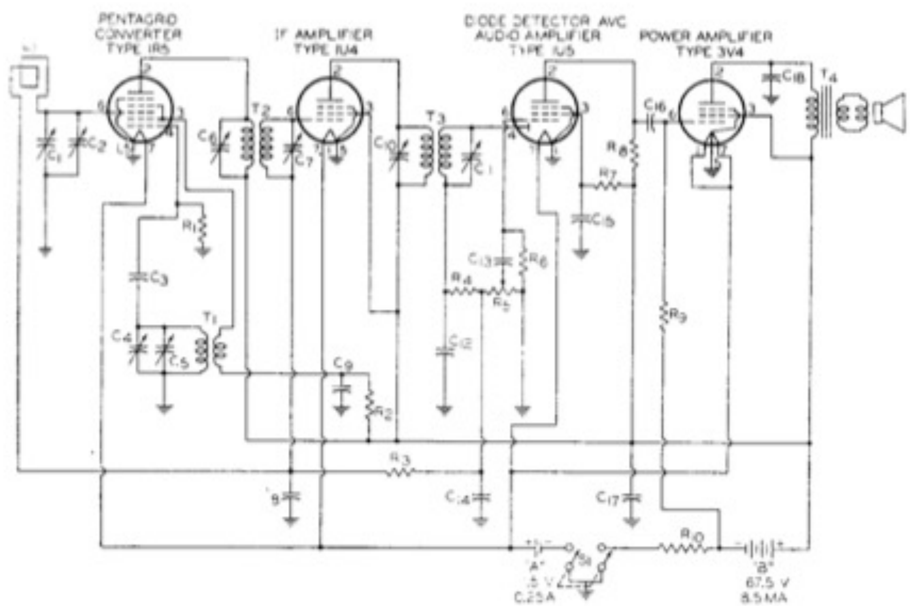
Block Diagram of Superheterodyne Receiver



Block Diagram of Double Conversion Superheterodyne Receiver



PORTABLE BATTERY-OPERATED SUPERHETERODYNE RECEIVER



C_1 C_4 = Ganged tuning capacitors: C_1, 10-274 μμf; C_4, 7.5-122.5 μμf
C_2 C_5 = Trimmer capacitors, 2-15 μμf
C_3 = 56 μμf, ceramic
C_6 C_7 C_{10} C_{11} = Trimmer capacitors for if transformers
C_8 = 0.05 μf, paper, 50 v.
C_9 C_{15} = 0.02 μf, paper, 100 v.
C_{12} = 82 μμf, ceramic
C_{13} C_{18} = 0.002 μf, paper, 150 v.
C_{14} = 33 μμf, ceramic
C_{17} = 10 μf, electrolytic, 100 v.
C_{16} = 0.0022 μf, paper, 600 v.
L_1 = Loop antenna, 540-1600 Kc
R_1 = 100000 ohms, 0.25 watt
R_2 = 15000 ohms, 0.25 watt
R_3 = 3.3 megohms, 0.25 watt
R_4 = 68000 ohms, 0.25 watt
R_5 = Volume control, potentiometer, 2 megohms
R_6 = 10 megohms, 0.25 watt
R_7 = 4.7 megohms, 0.25 watt
R_8 R_9 = 1 megohm, 0.25 watt
R_{10} = 390 ohms, 0.25 watt
S_1 = Switch, double-pole, single-throw
T_1 = Oscillator coil for use with tuning capacitor of 7.5-122.5 μμf, and 455 Kc if transformer
T_2 T_3 = Intermediate-frequency transformers, 455 Kc
T_4 = Output transformer for matching impedance of voice coil to 10000-ohm tube load

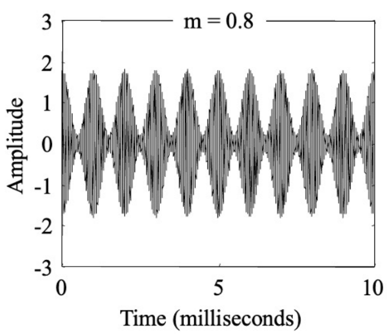
Superhet Receiver from RCA Receiving Tube Manual

January 2026

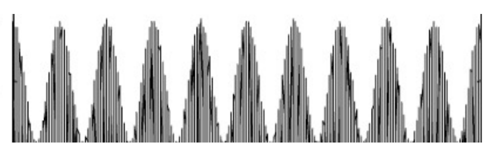
For free RCA manuals see https://www.worldradiohistory.com/BOOKSHELF-ARH/Technology/RCA-Books/
And click on the link for the receiving tube manual you want to read
for example RCA-Receiving-Tube-Manual-1960-RC-20.pdf

Demodulation of AM

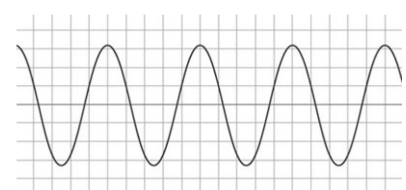
- The simplest way to detect AM is to rectify the received signal
- Then filter out the RF leaving just the audio signal



Diode Rectifier

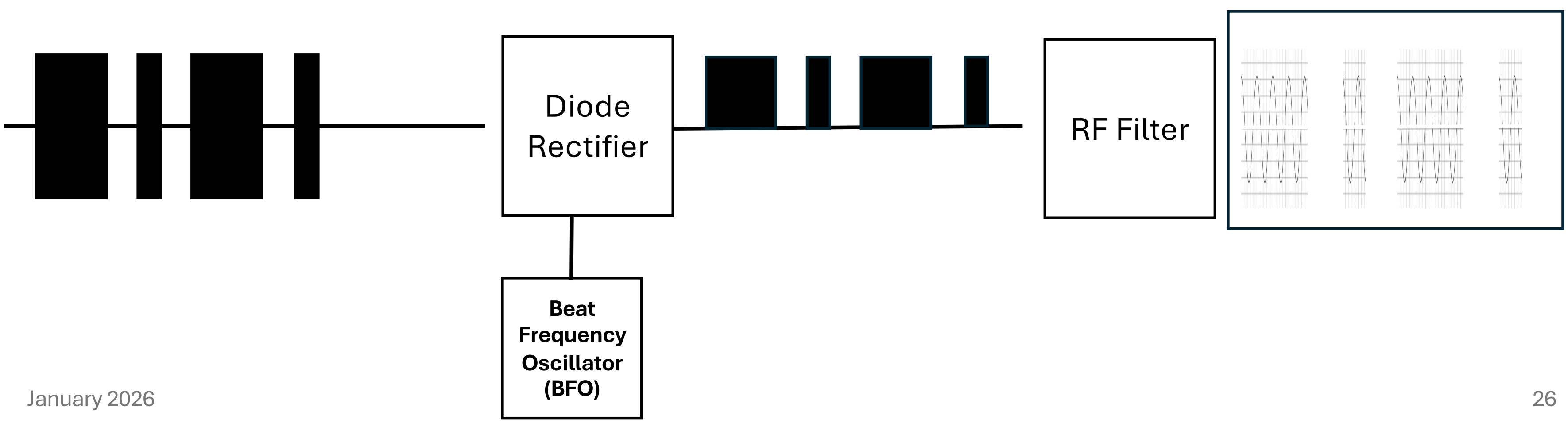


RF Filter



Demodulation of CW

- The simplest way to demodulate CD is to use an AM detector and add an RF or IF signal 400 Hz to 1.5 kHz from the received signal
- The detector mixes the two signals together and generates a tone when the CW signal is present

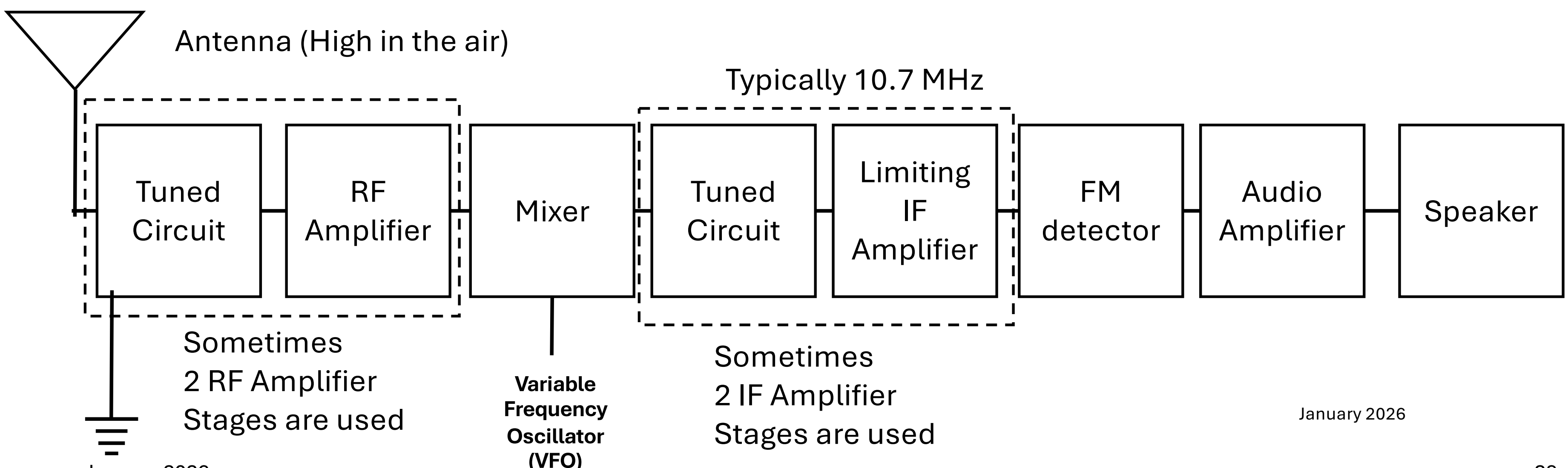


Demodulation of Single Side Band (SSB)

- Demodulation of SSB is similar to that of CW
- But the BFO signal needs to be within less than 100 Hz of the missing carrier signal
- Early SSB receivers tended to drift off frequency and the received signal had distortion that made is sound like "Donald Duck"
- This limited adoption of SSB in the 50s and 60s
- Modern SSB receivers use a mixer instead of an AM detector
- They also can be tuned and stay tuned to within a few Hz of the mixing carrier
- Some receivers have GPS built-in or accept timing information from a GPS receiver to make the tuning very precise (less than 1 Hz of error)
- The speech sounds natural

Demodulation of FM and PM

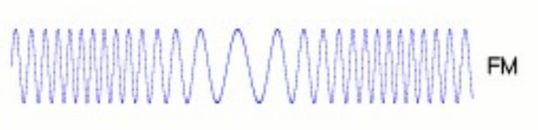
- Demodulation of FM in a receiver needs to additional circuits compared to an AM receiver
- An IF amplifier that limits the maximum signal and thus clips it to a constant level
- An FM detector that uses a special coil called a discriminator coil and two diodes



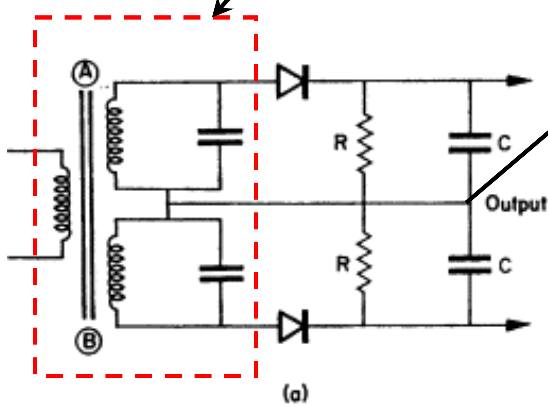
January 2026

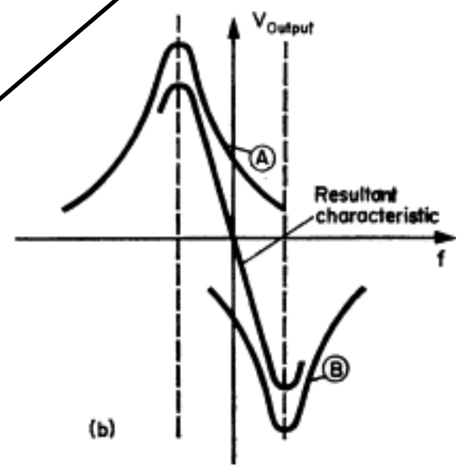
Discriminator Operation

The output changes with the changes in frequency



Specially designed coil





Adjustment of the coil can be difficult at times to get proper distortion free operation

References

- Recommended Textbooks
- ARRL: *The ARRL Handbook for Radio Communications*
- Make: *Radio*

- *Old but still good reference:*
- Rappaport, *Wireless Communications: Principles and Practice*
- Goldsmith, *Wireless Communications*
- Molisch, *Wireless Communications*
- Garg and Wilkes, *Wireless and Personal Communications Systems*

- Useful Online Resources
- FCC Spectrum Allocation Charts
- 3GPP Specifications (for LTE/5G)
- IEEE 802.11 Standards overview
- ITU Radio Regulations
- Simulation Tools
- MATLAB/Simulink Wireless Toolbox
- Python libraries: scipy, matplotlib, commpy
- Free online spectrum analyzers & demos