Radio Receivers

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VO1NO

Role of the Receiver

- The **Antenna** must **capture** the **radio wave.**
- The **desired frequency** must be **selected** from all the EM waves captured by the antenna.
- The **selected signal** is usually very weak and **must be amplified.**
- The **information** carried by the radio wave, usually an audio signal, **must be recovered – Demodulation.**
- The **audio signal** must be **amplified.**
- The amplified **audio signal** must then be **converted** into **sound waves** using a speaker or headphones.

The 3 S's of Receivers

- **Sensitivity**
- **Selectivity**
- **Stability**

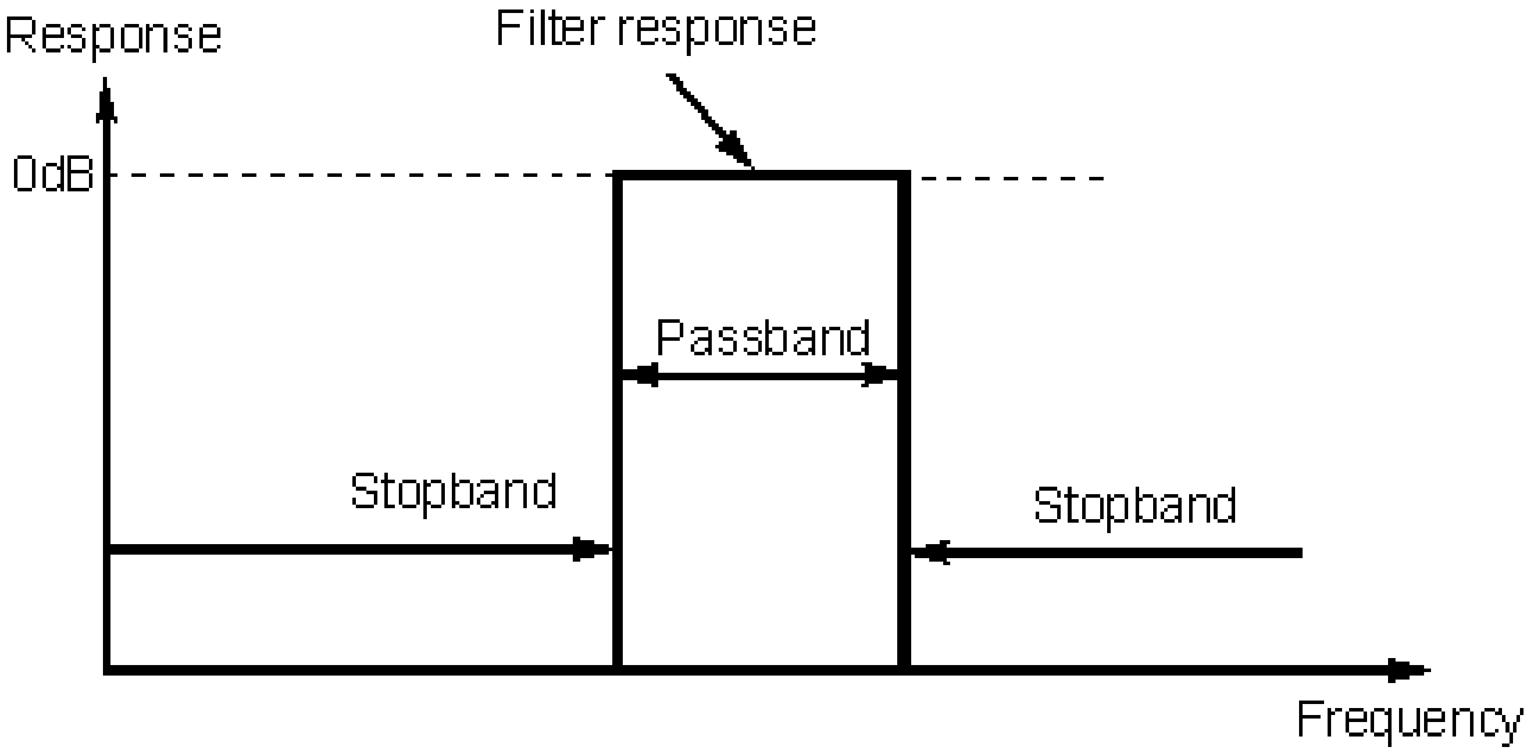
Sensitivity

- Refers to the **minimum signal level** that the receiver can **detect.**
- Measured in **Microvolts** or **fractions of Microvolts**.
- The **greater the sensitivity** (ie: the smaller the number of microvolts) the **weaker a signal** it can **receive.**
- Very weak signals can be received – **sensitivity is not an issue** with modern receivers.
- *Between 1.7 and 24.5 MHz on SSB, the Kenwood TS-870 has a sensitivity of 0.2 microvolts or less*

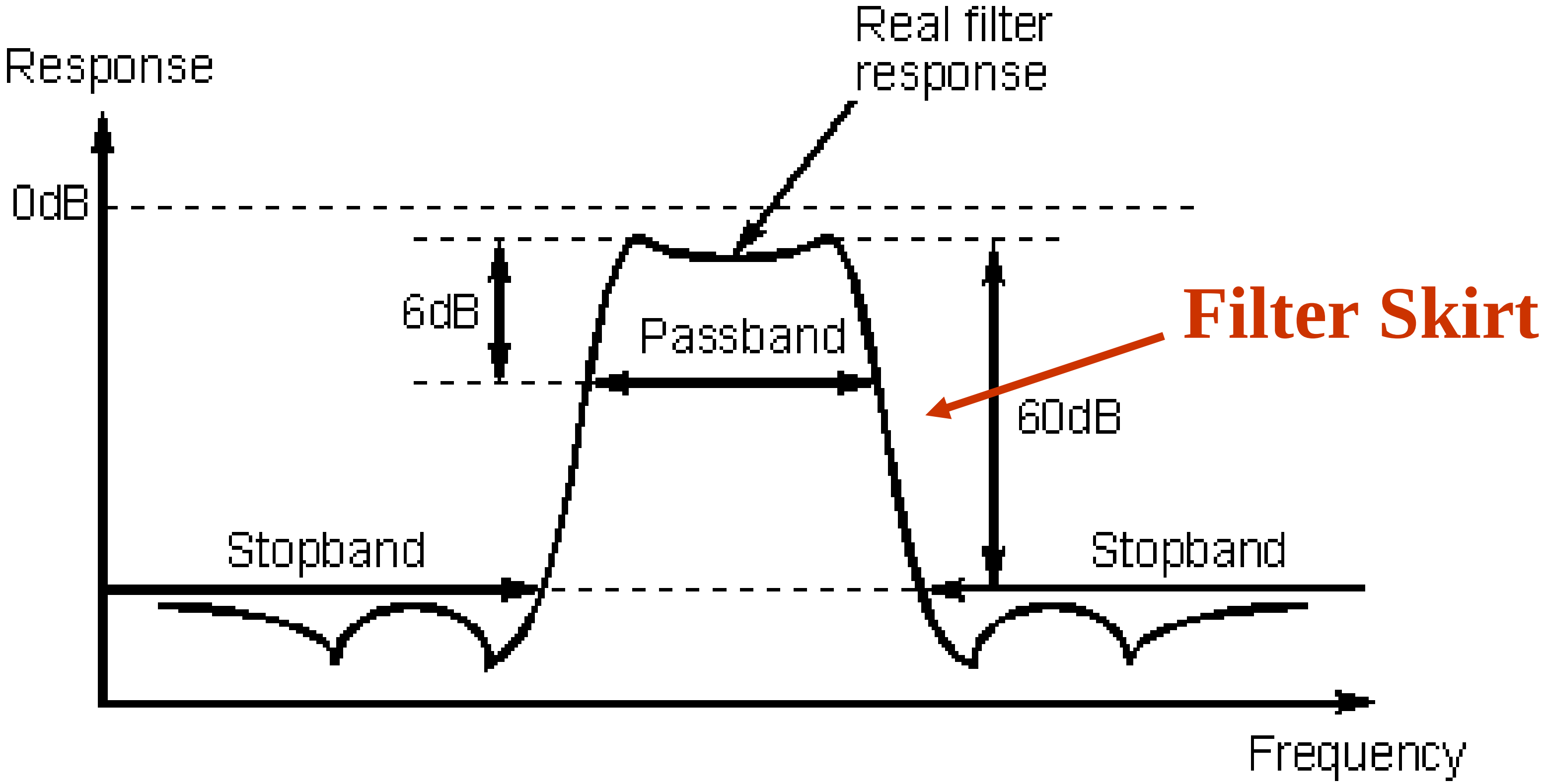
Selectivity

- Refers to the **receiver's ability** to **separate** two **closely spaced signals.**
- The **more selective** a receiver, the **narrower** the **bandwidth and/or the steeper the filter skirt.**
- **Specified** as the **bandwidth** at **6 dB** attenuation, and at **60 dB** attenuation (ie: the –6 dB and –60 db points).
- Filter Skirt steepness is perhaps **THE key characteristic** that separates the boys from the men in HF receiver design!
- *Example: On SSB the Kenwood TS-870 has a selectivity of 2.3 kHz at – 6 dB and 3.3 kHz at – 60 dB. This is a very selective receiver.*

Ideal Receiver Selectivity



Actual Receiver Selectivity



Stability

- The **receiver's ability** to **remain on a frequency** for a period of time.
- **Unintended change** in frequency is **called drift.**
- Specified as **number of Hz drift** over a **period of time** after warmup, or as **ppm (part per million)** for more modern radios.
- **Not an issue for modern receivers**, but is a consideration for older designs, especially those using vacuum tubes.

Cross Modulation

- **Cross Modulation** occurs when a **strong signal** is **too powerful for the receiver's front end** (first RF Amplifier) to pass through without **distortion.**
- It results in the **wanted signal being Amplitude Modulated by the strong unwanted signal** ie: the unwanted signal can be heard on top of the wanted signal.

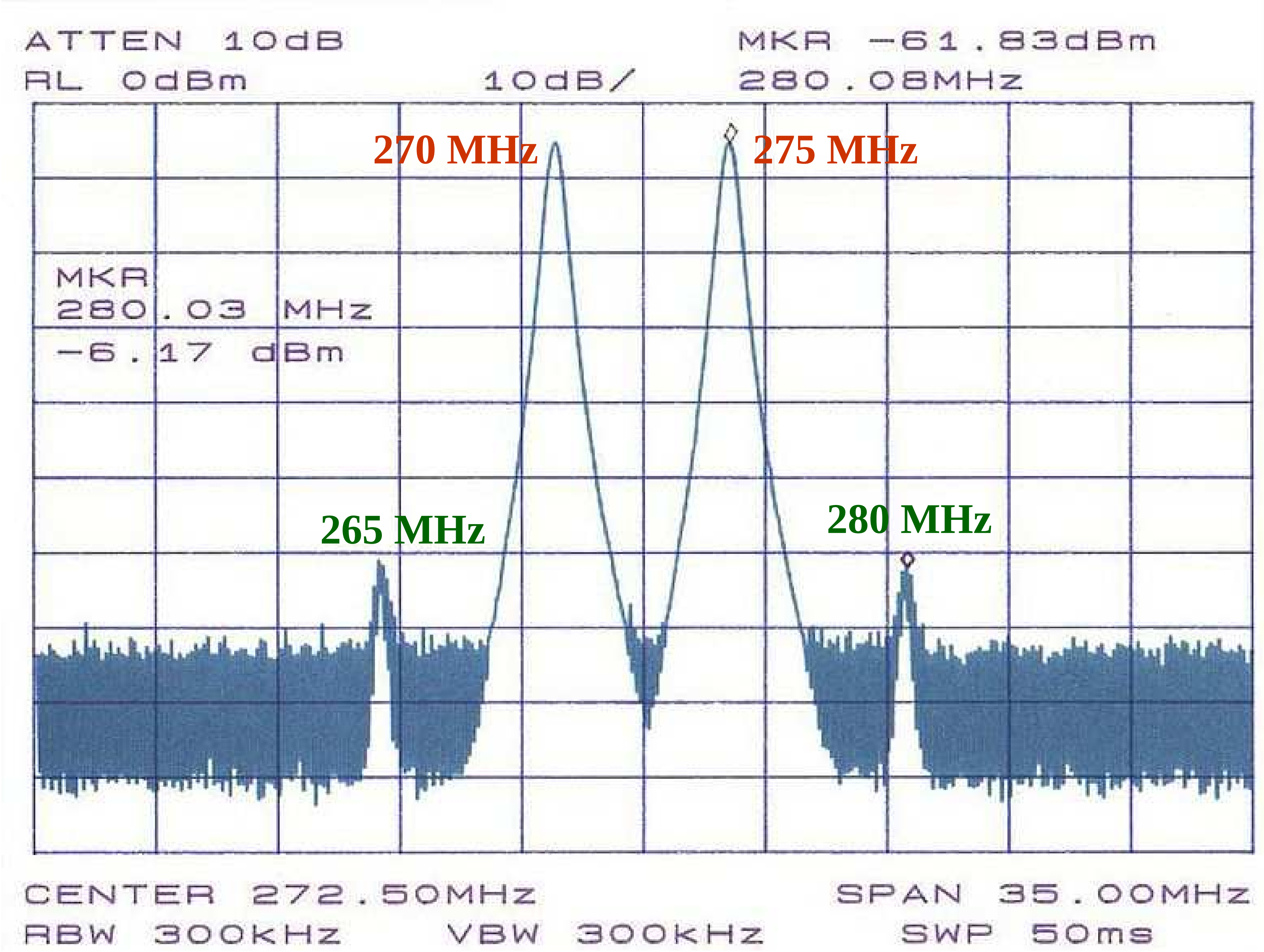
Curing Cross Modulation

- To prevent cross modulation, many receivers have an **Attenuator** that inserts a resistive pad (circuit) between the antenna and the receiver.
- This **weakens the strong signal** enough that it **no longer causes problems.**
- If the **interfering signal** is **out of the band altogether,** then an appropriate **filter** between the antenna and the receiver may also help.
- **FM receivers** are **immune to Cross Modulation** as they are **unaffected** by **amplitude variations** on received signals.

Attenuator – Kenwood TS-950SDX

Intermodulation

- **“Intermod”** is sometimes incorrectly called Cross Modulation, but is a different phenomena.
- It is the result of **two or more signals** of different frequencies **being mixed together**, forming **additional signals at frequencies** that are **not, in general, at harmonic frequencies** (integer multiples) of either.
- The **mixing** usually takes place **inside the receiver,** but can even take place at rusty fence joints!
- **Very prevalent problem** on **2M and 70cm** FM when driving through **downtown!**



ATTEN 10dB
RL 0dBm
10dB/
MKR -61.83dBm
280.08MHz
MKR
280.03 MHz
-6.17 dBm
270 MHz
275 MHz
265 MHz
280 MHz
CENTER 272.50MHz
SPAN 35.00MHz
RBW 300kHz
VBW 300kHz
SWP 50ms

Images

- **Signals** on a **different frequency** than the one tuned to, but which are **received anyway.**
- Occurs because of the **frequency conversions** that are conducted **within the receiver.**
- **Image rejection** is specified in **dB.**
- *The image rejection specifications for the Kenwood TS-870 are 80 dB or greater.*

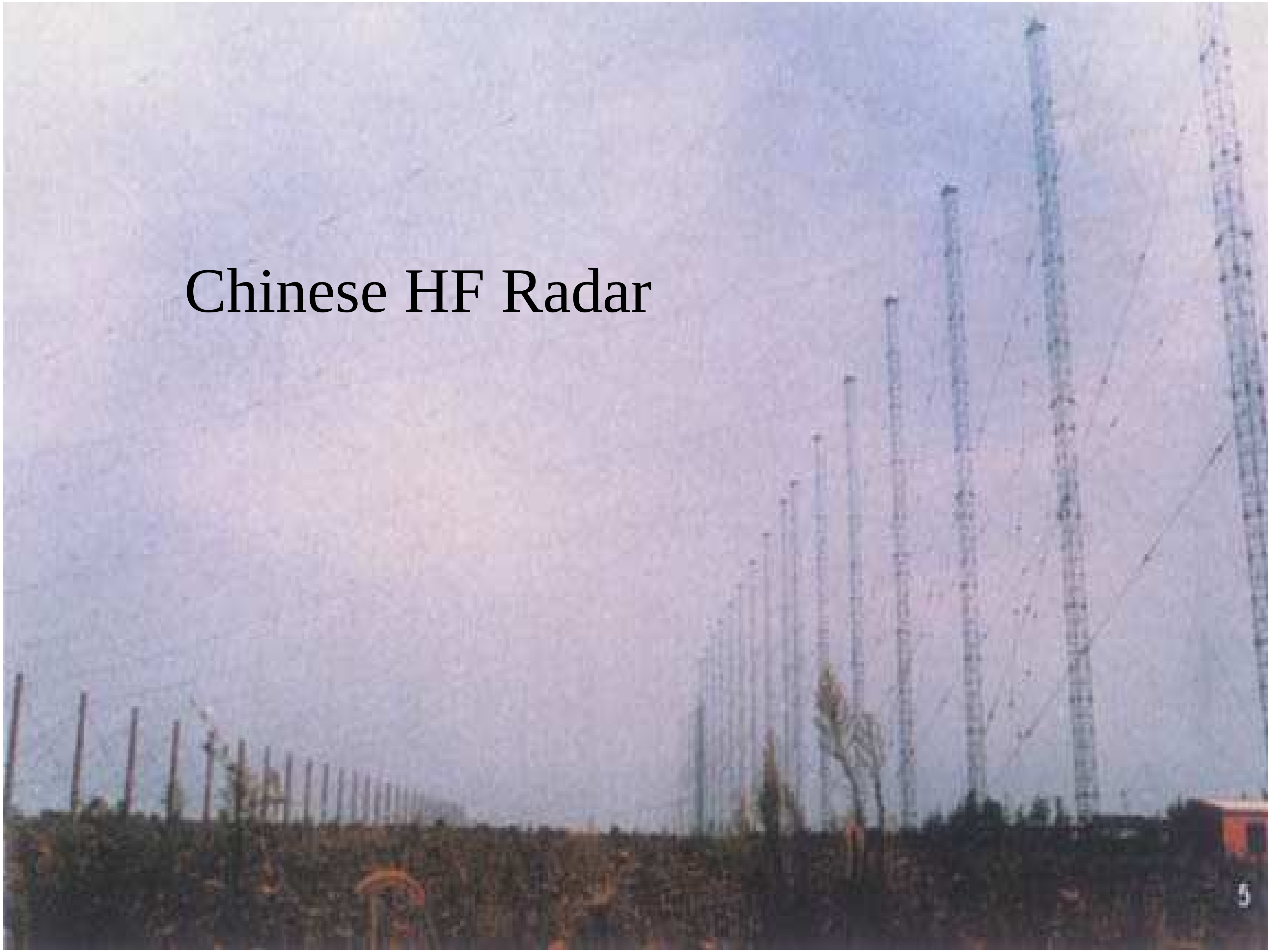
Natural Noise

- **Natural noise**, called **QRN**, is also called **Static.**
- It comes from **objects in the galaxy** that radiate RF energy, and from **natural phenomena** such as **lightning.**
- The presence of natural noise sets the **Noise Floor** for the band in question at that particular time, and appears as a steady hiss.
- **Lightning** appears as a **burst of static**, and can be dealt with to some degree by noise limiters.

Man-Made Noise

- Also called **QRM**, Man-Made Noise generally comes from **sparking equipment**, and also from **equipment that generates RF.**
- Some countries use **HF radars** that produce sharp pulses.
- The best solution to most man-made noise is to **eliminate it at the source**, as it is often close to home.
- Start at **home**, and then **search the neighborhood**, using a portable receiver to track down the noise.
- **Digital Signal Processing (DSP)** is of great assistance in reducing QRM.

Chinese HF Radar




SOLAR PAK

Receiver Limitations

- It does **no good** to make HF receivers **any more sensitive** – they are already sensitive enough to **hear the natural noise floor,** and cannot hear anything below that level anyway.
- Any **component that generates gain** also **generates internal noise** – it is unavoidable!
- So, while the noise floor on VHF and UHF is much lower than HF, the **quality of the active device** (transistor) in the **front end of the receiver** determines the **sensitivity of the system.**

Signals and Noise

- Another way to specify the **sensitivity** of a receiver is to express how many **microvolts of signal** are required to give a certain **Signal to Noise Ratio (SNR).**
- Some use the **Signal + Noise to Noise Ratio**, or **(S+N)/N.**
- These ratios are specified in dB.

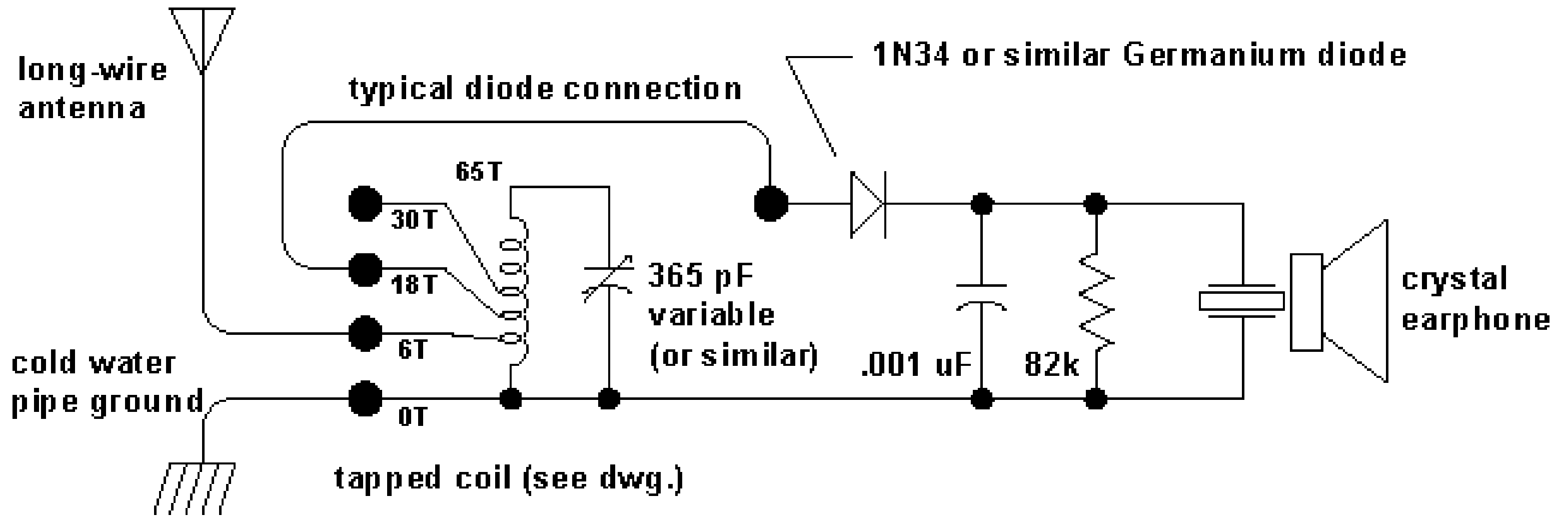
Can we Increase Selectivity?

- While it is **possible to add filters** (either discrete or virtual using DSP techniques) to increase selectivity, remember that **every mode** has a **defined bandwidth.**
- If the **selectivity is too wide, excess noise** will be received. If **too narrow** however, the **complete signal will not be received.**
- **CW filters of 250 Hz** are common, but going too narrow will result in **"ringing".**
- **Human voice** requires a range of **300 – 2700 Hz.** Using too narrow a filter will make the voice unintelligible.

Frequency Calibration

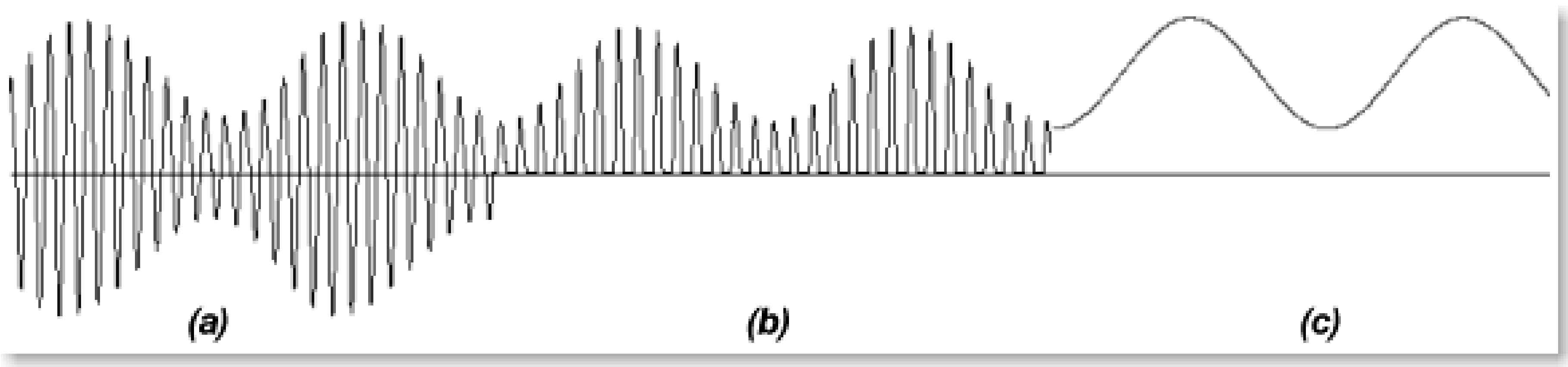
- **YOU** are **responsible** for ensuring that you **operate within the Amateur bands!**
- **Radio dials** can be **analog** or **digital.**
- **DO NOT assume** that they are always **correct!**
- Older radios use **Crystal Calibrators** to enable you to check the accuracy of the dial.
- Newer, synthesized, radios use a **master time base** in the microprocessor to derive frequency information. If that time base is off, so will the calibration.
- Use **WWV / WWVH** to calibrate your radio.

Simple Crystal Radio



Crystal radio with typical connections for a long wire antenna and good ground connections. The diode is connected for weak signals and moderate selectivity.

AM Demodulation



“Baby Grand” Crystal Receiver

Tuned Radio Frequency Receivers

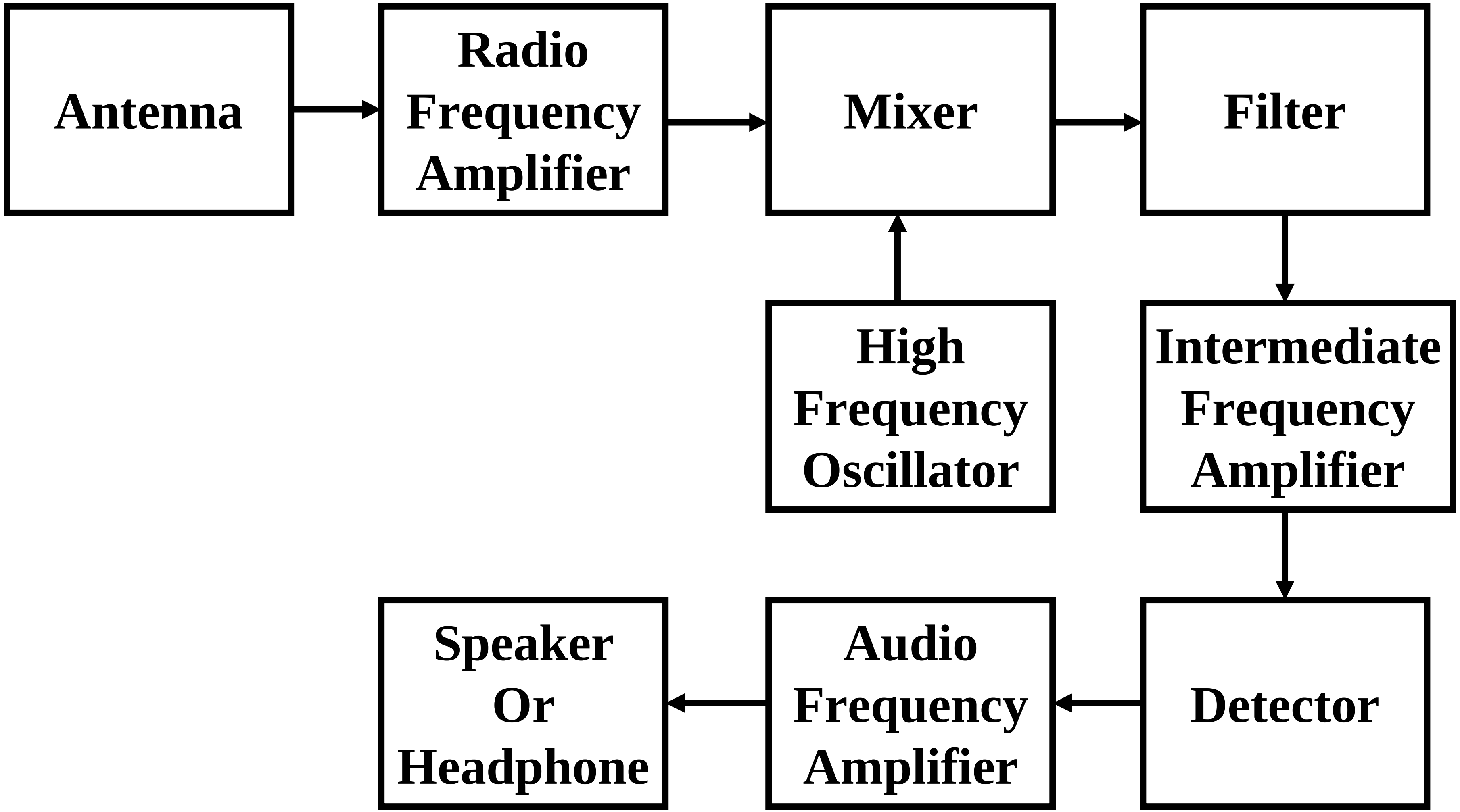
- A **Tuned Radio Frequency (TRF)** receiver has **several RF amplifier stages** followed by detector and audio amplifier stages.
- **Each RF amplifier** stage must be **tuned individually.**
- This is a very **cumbersome process!**
- For technical reasons, it is also **difficult** to achieve **sufficient selectivity** as the **frequency increases.**

American Beauty TRF Receiver

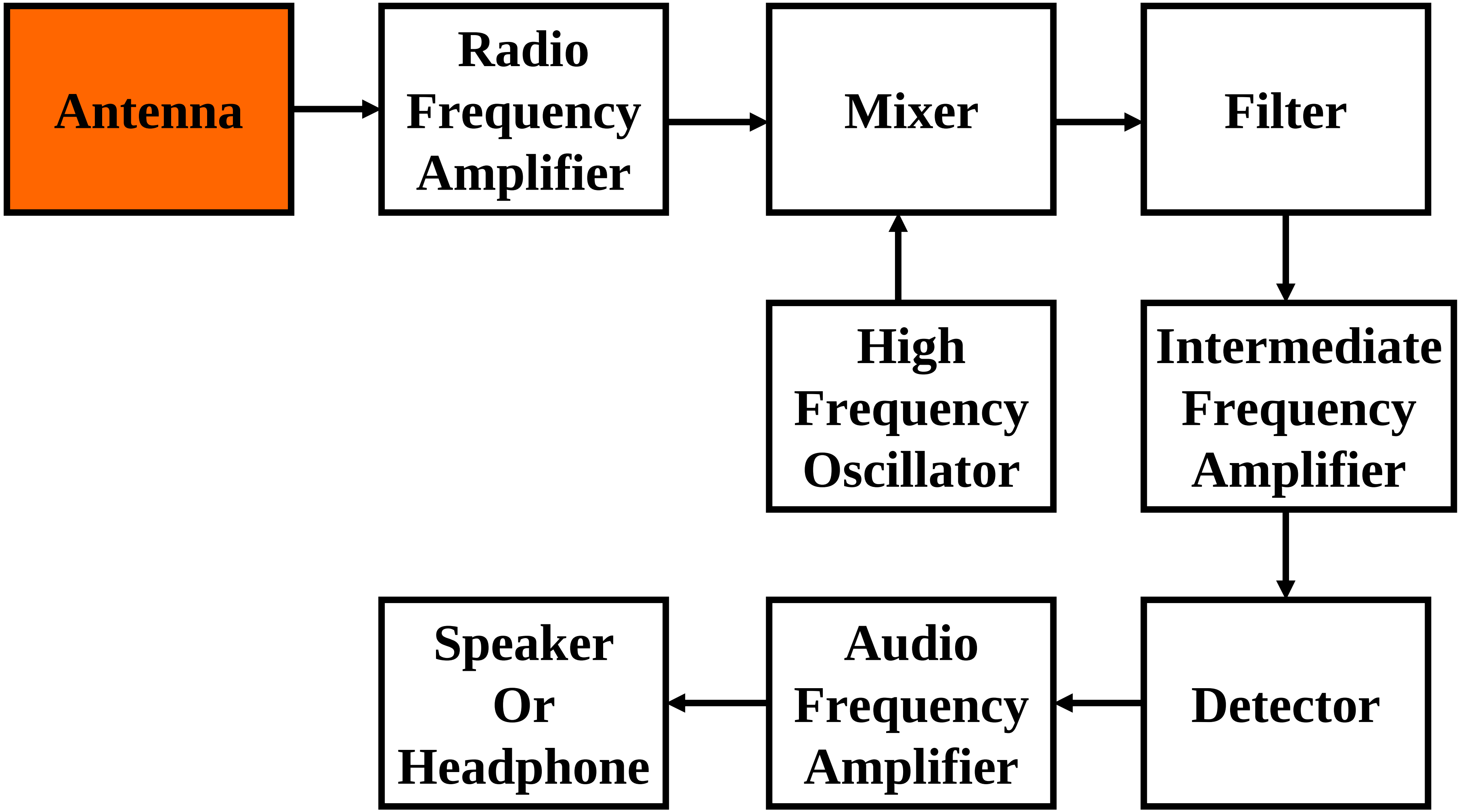
The Superheterodyne Receiver

- In 1918 **Major Edwin Armstrong** developed the **Superheterodyne receiver** to correct the problems of the TRF radio.
- It **mixes an incoming signal** with a **locally generated RF signal** to produce an **Intermediate Frequency (IF).**
- That IF is then **amplified, detected** and turned into **sound.**
- The Superhet is still the **most popular form of receiver,** accounting for 99% or more!

Superheterodyne Receiver



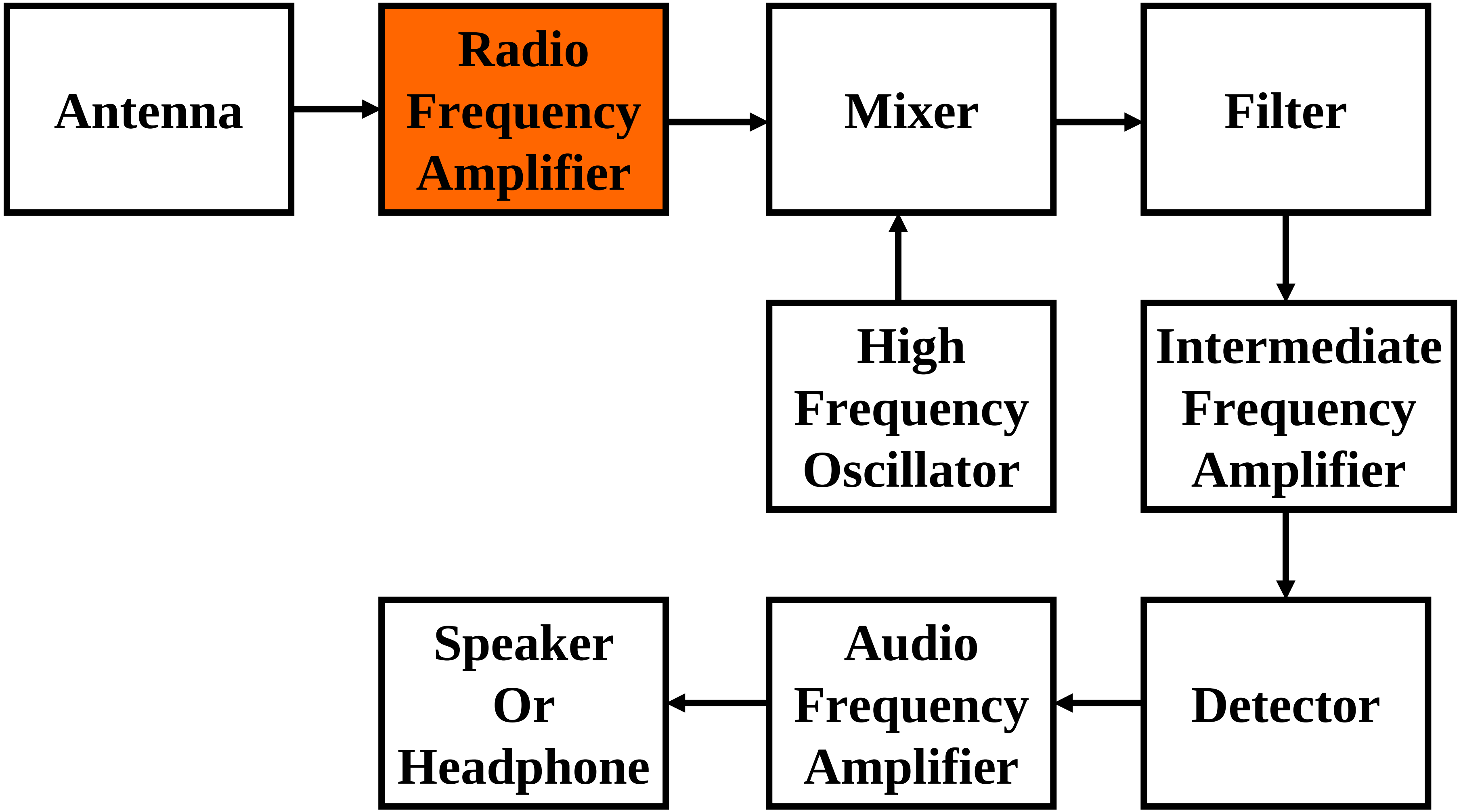
Superheterodyne Receiver



Antenna

- While technically the **antenna** picks up a **wide range of frequencies,** in practice some antennas are more **narrow-banded.**
- **Resonant antennas** eg: a half-wave dipole, are better able to pick up signals around their **design frequency.**
- **Non-resonant antennas** eg: Rhombics, can be used over a much **broader frequency range.**

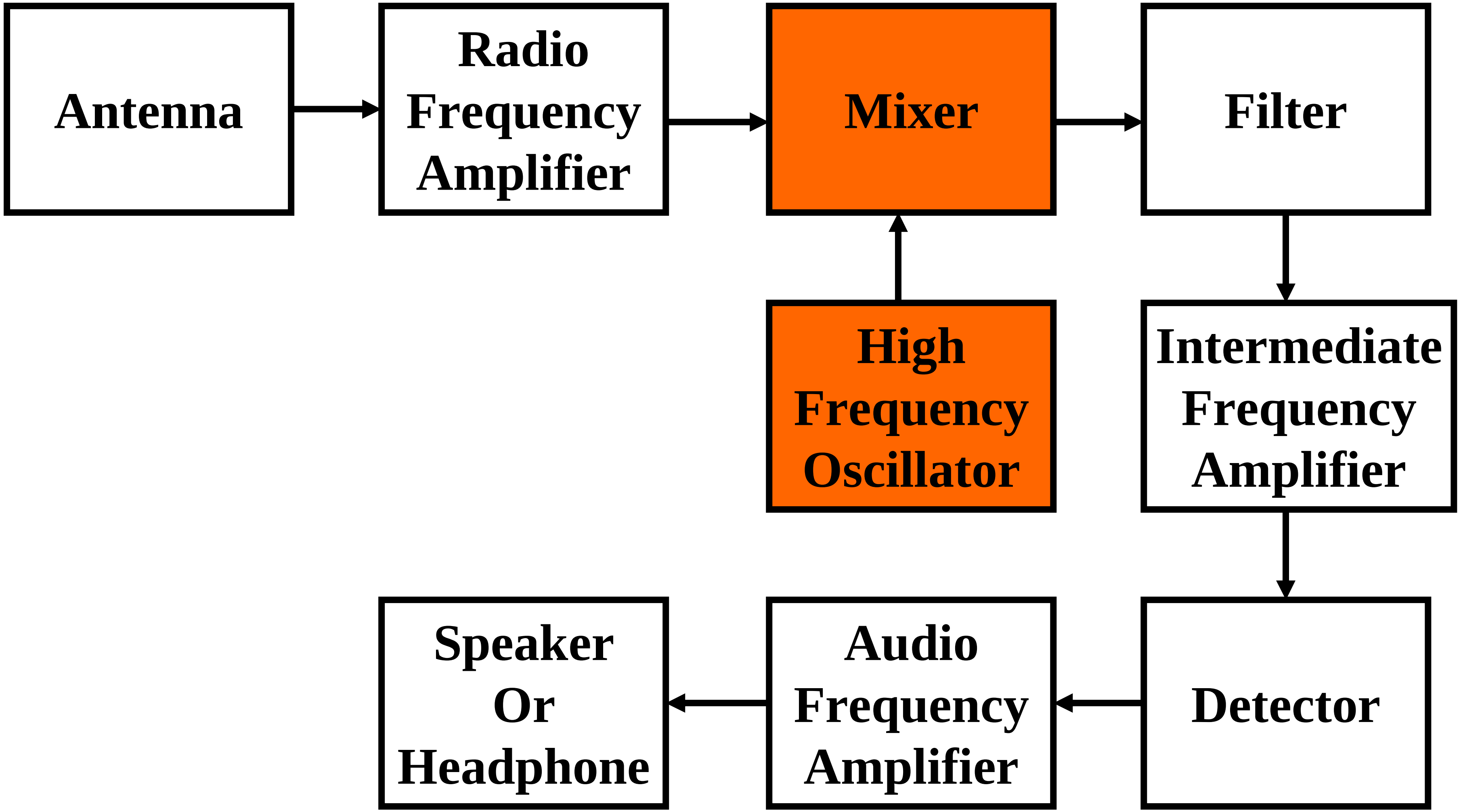
Superheterodyne Receiver



Radio Frequency Amplifier

- The **RF amplifier** takes the **weak signals** from the antenna and **amplifies them.**
- This is usually a **fairly broadband amp.** In better radios it consists of a **number of separate modules** that cover individual bands. These modules would be selected automatically as the radio is tuned.
- **Older radios** had a **manually tuned continuous preamplifier.**
- This stage does have **tuned circuits** to help **reject strong out-of-band signals** that could cause **Cross Modulation.**

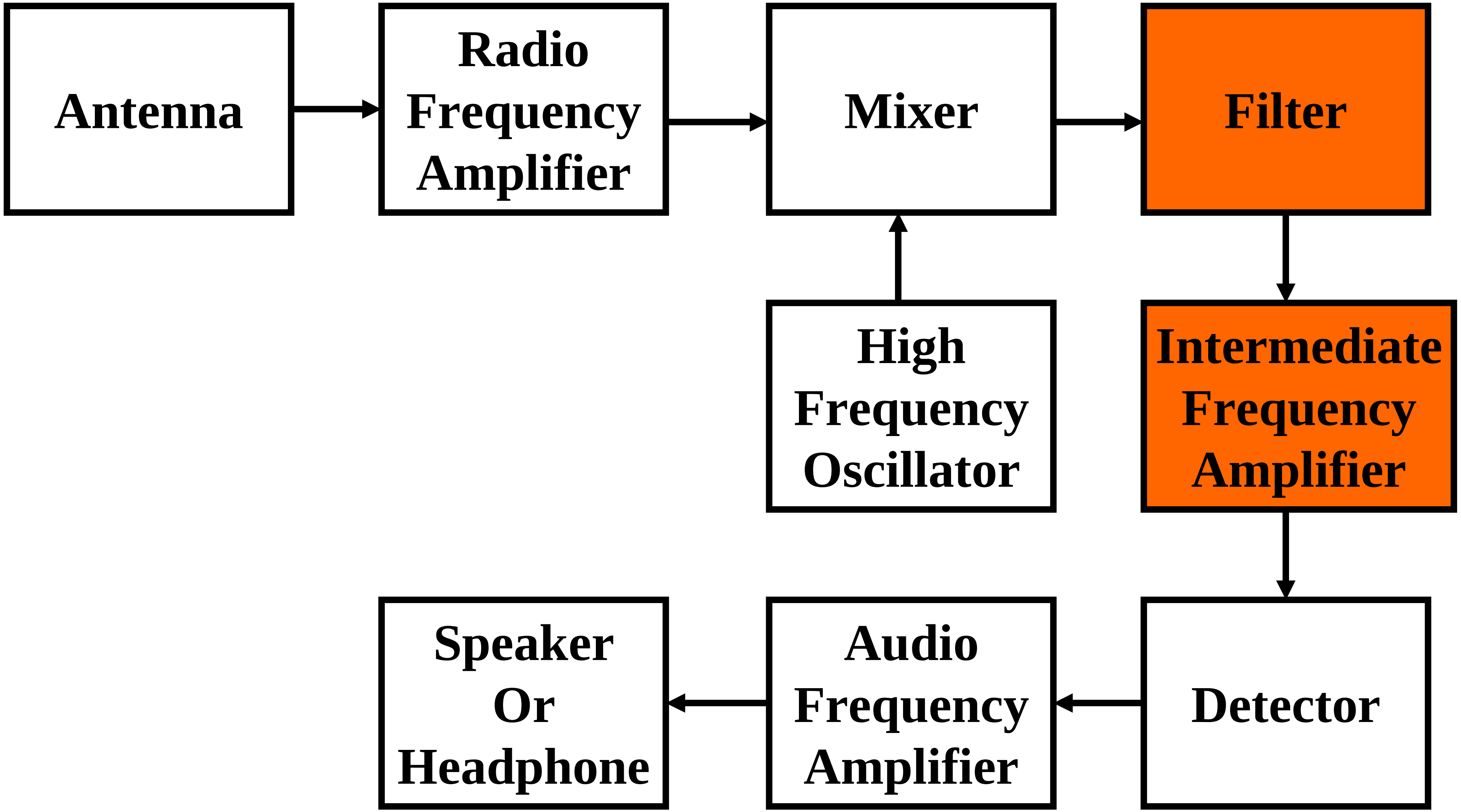
Superheterodyne Receiver



HF Oscillator and Mixer

- The **HF Oscillator,** more usually called the **Local Oscillator,** generates an **RF signal** that is **higher or lower** than the desired receive frequency by an amount called the **Intermediate Frequency.**
- It **mixes** with the signal from the **RF Amp** inside the **Mixer.**
- **Output** from the mixer is **the sum and difference** of the two signals.
- One of those two signals is the **Intermediate Frequency.** The choice is an engineering decision.

Superheterodyne Receiver



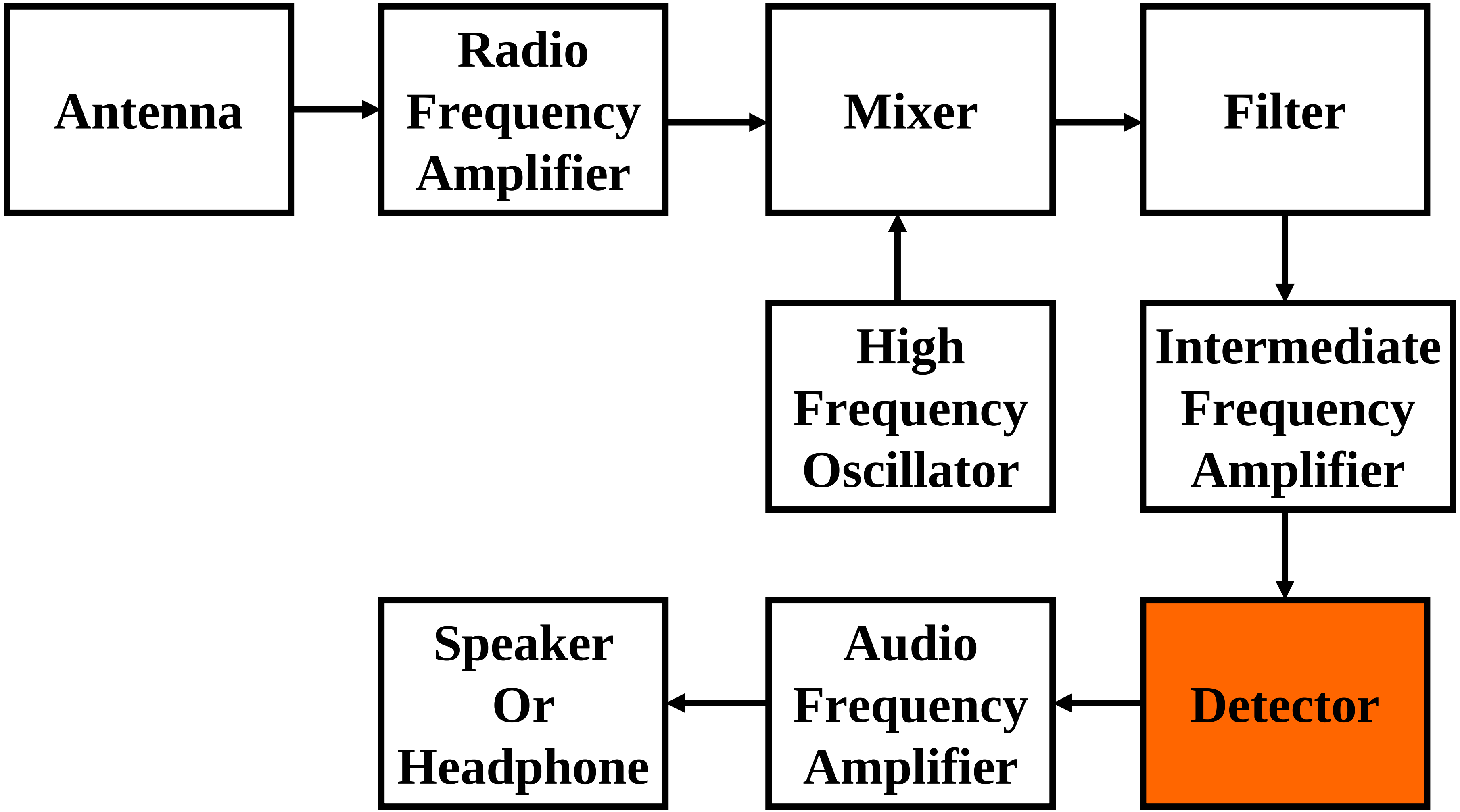
Filter and IF Amplifier

- The **Filter** can be **mechanical, crystal or ceramic.** Newer radios employ a **synthetic filter** using **Digital Signal Processing (DSP)** techniques.
- It **filters out** not just the non-IF signal, but is also the **primary location** where **selectivity** is obtained.
- The IF Amp **can** consist of **several stages.** It **amplifies the IF signal.** Because the IF has been pre-defined by the receiver's design, the **IF amp does not need to be tuned** after calibration by the manufacturer.

Receiver Filters

- **Receivers** often have **several filters** that can be switched in as **required by the mode.**
- Examples of the **filter widths** and the usual mode they would be used for are:
  - 250 Hz CW (for severe interference)
  - 500 Hz CW (for more relaxed conditions)
  - 2.4 kHz SSB
  - 6 kHz AM, possibly SSB if band is not busy

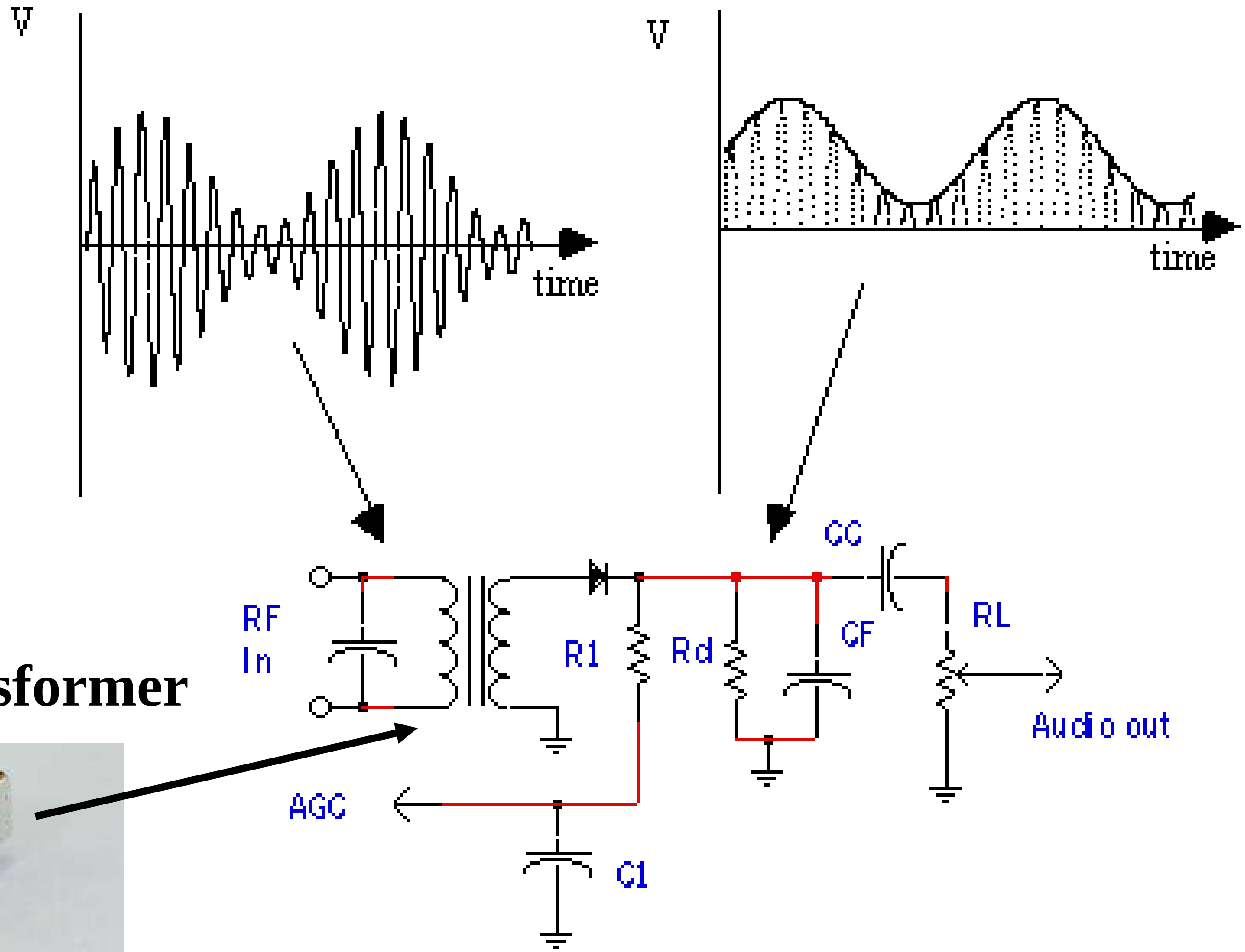
Superheterodyne Receiver



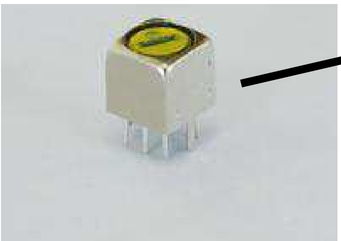
Detector Stage

- The **amplified IF signal** is sent to the **Detector**, where it is **rectified** and the **RF filtered out.**
- This leaves only a **weak audio signal** which is sent to the **AF amplifier** before going to the **speaker or headphones.**

AM Demodulation

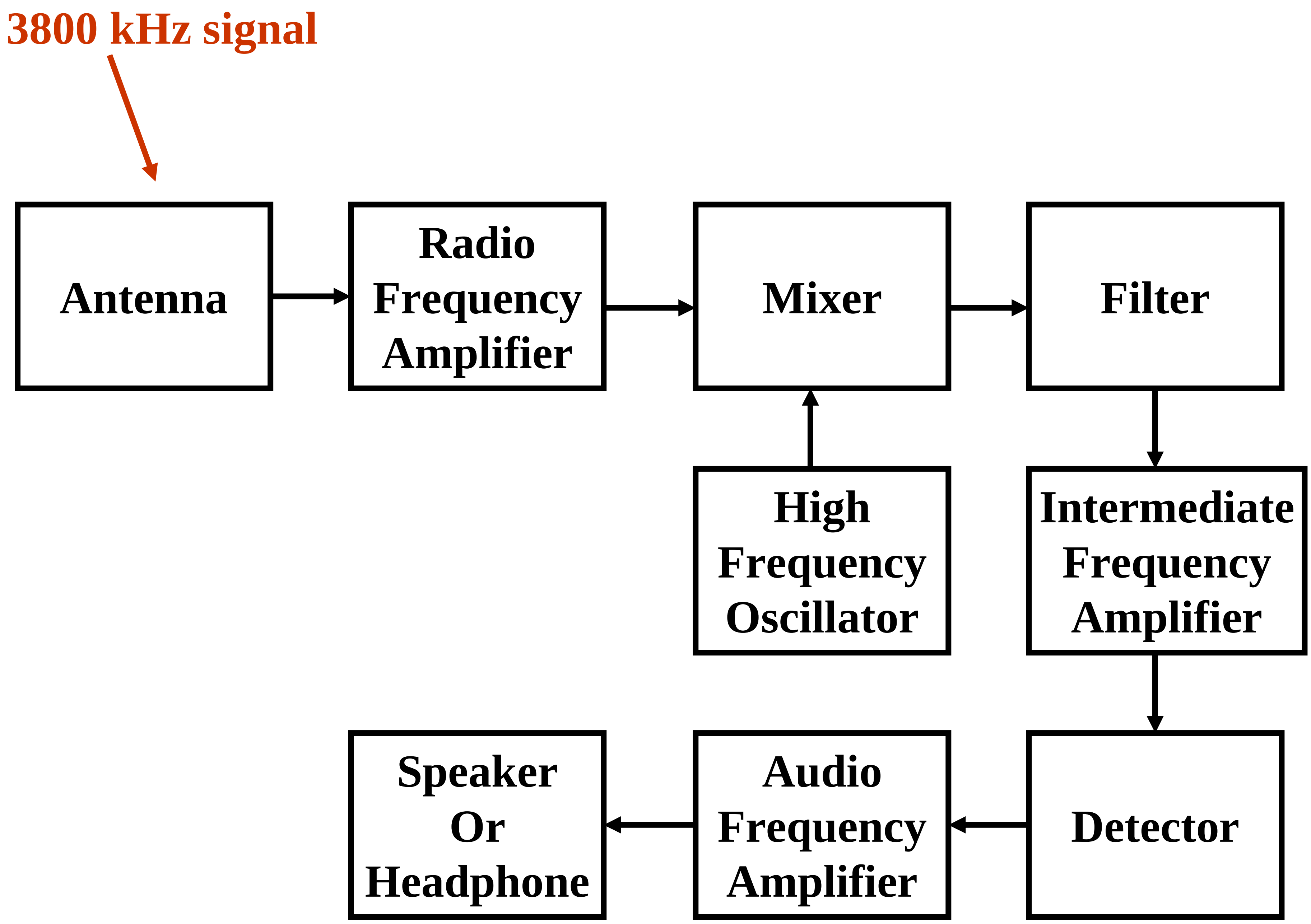


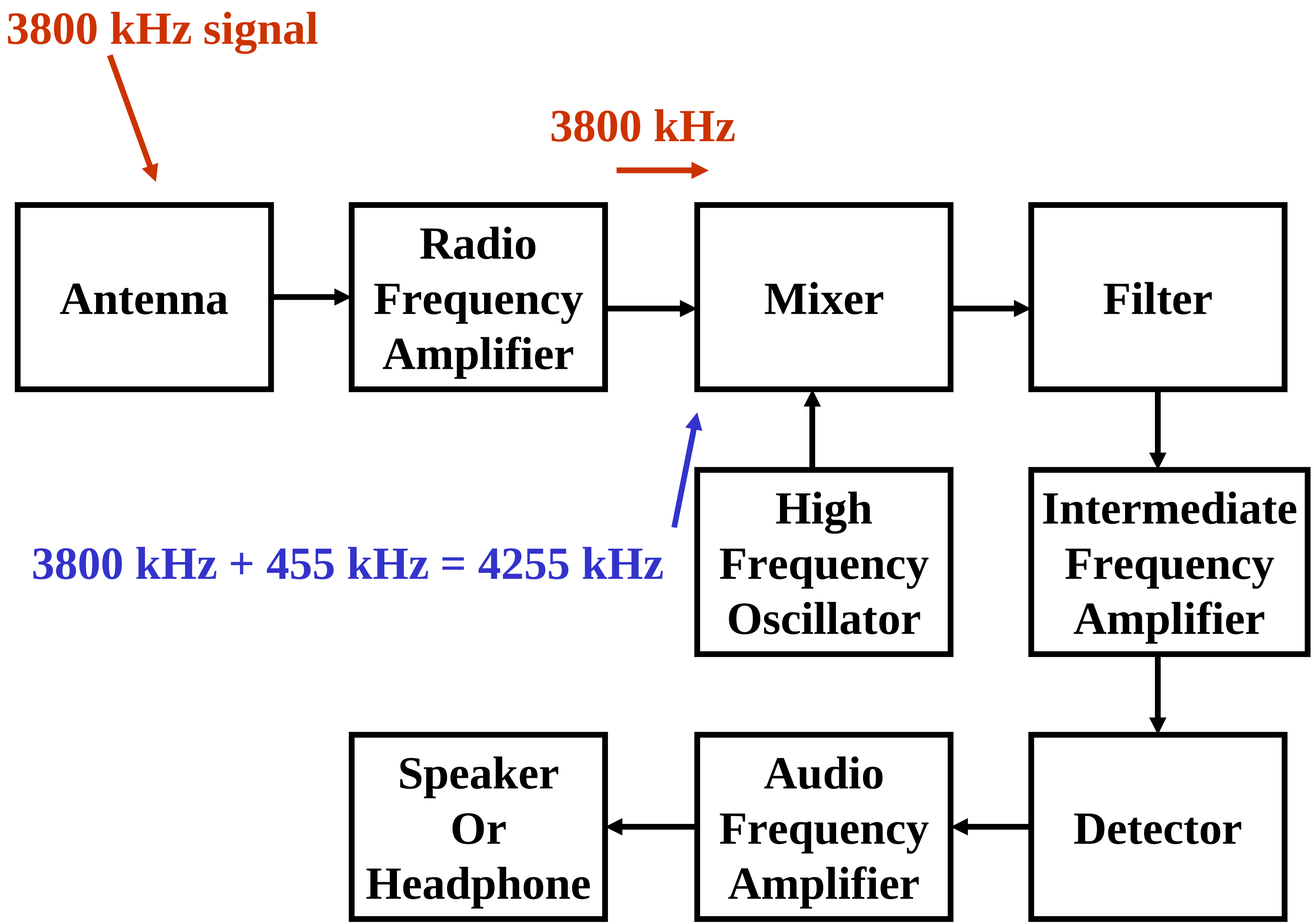
IF Transformer



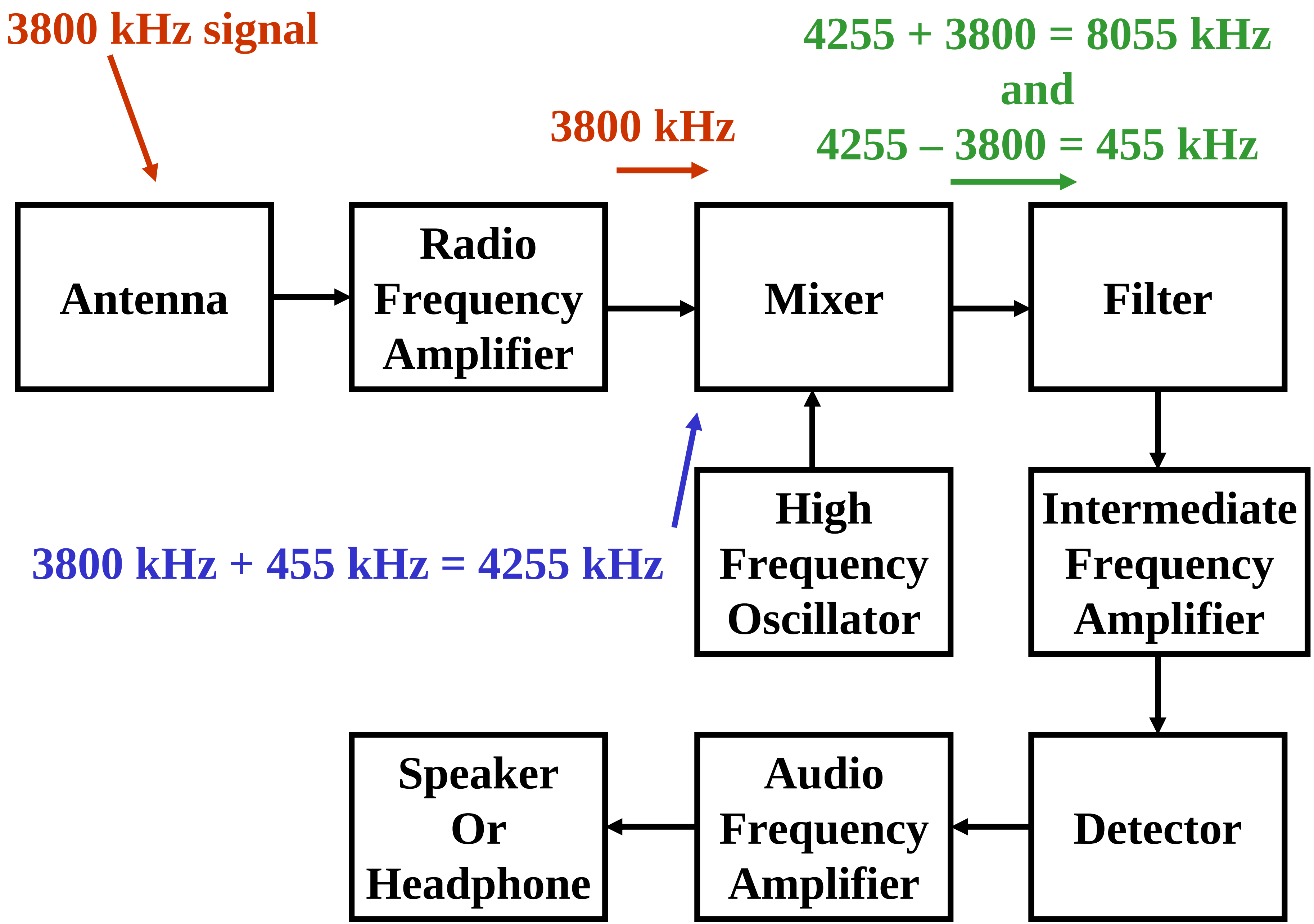
Superhet Example

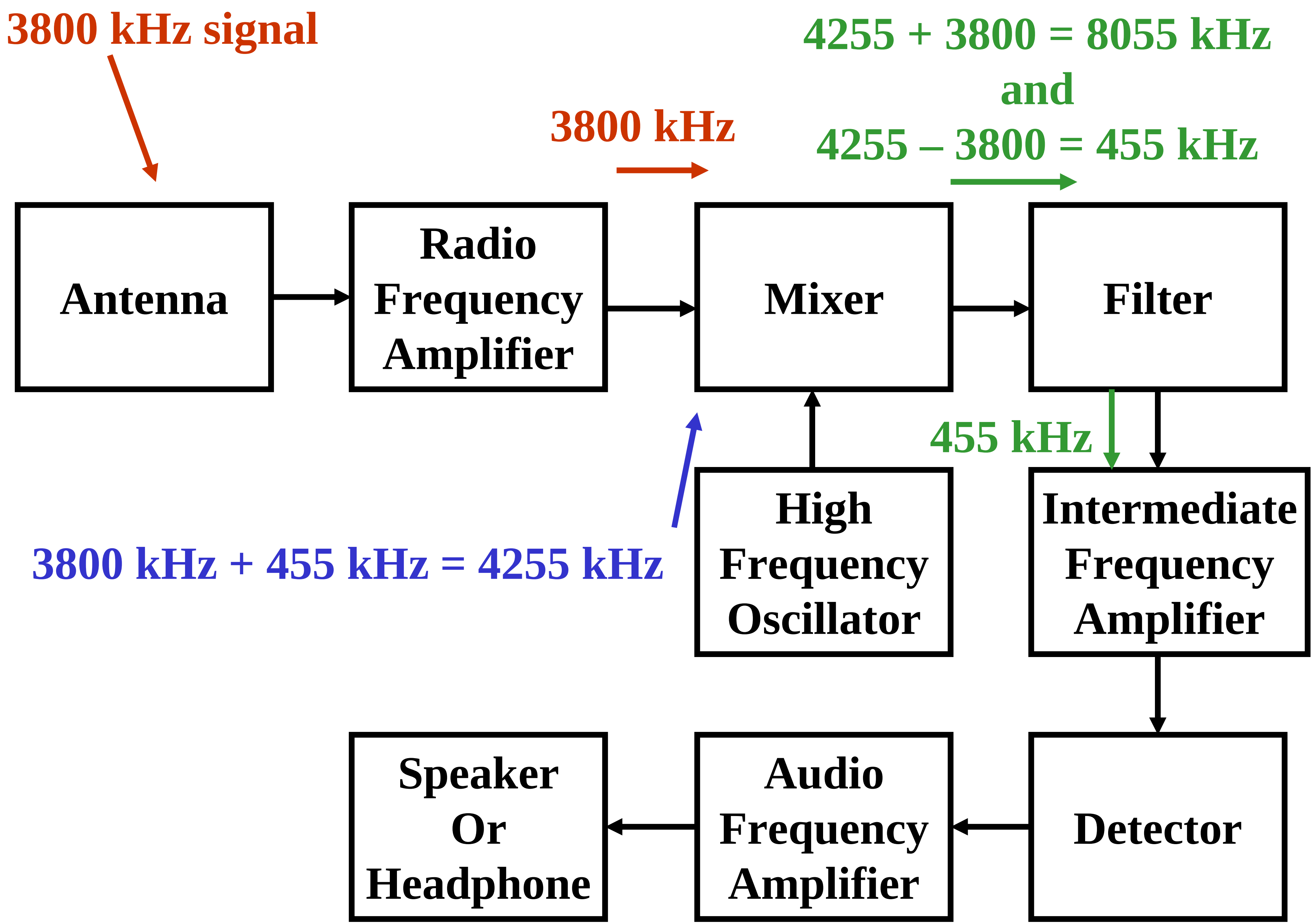
- In order to better illustrate how a Superhet receiver works, let's look at an example of how the **frequency conversion process** operates.
- We want to receive a signal on **3.8 MHz (3800 kHz)**
- Assume our receiver has an **IF of 455 kHz.**


3800 kHz signal
Antenna
Radio Frequency Amplifier
Mixer
Filter
High Frequency Oscillator
Intermediate Frequency Amplifier
Speaker Or Headphone
Audio Frequency Amplifier
Detector

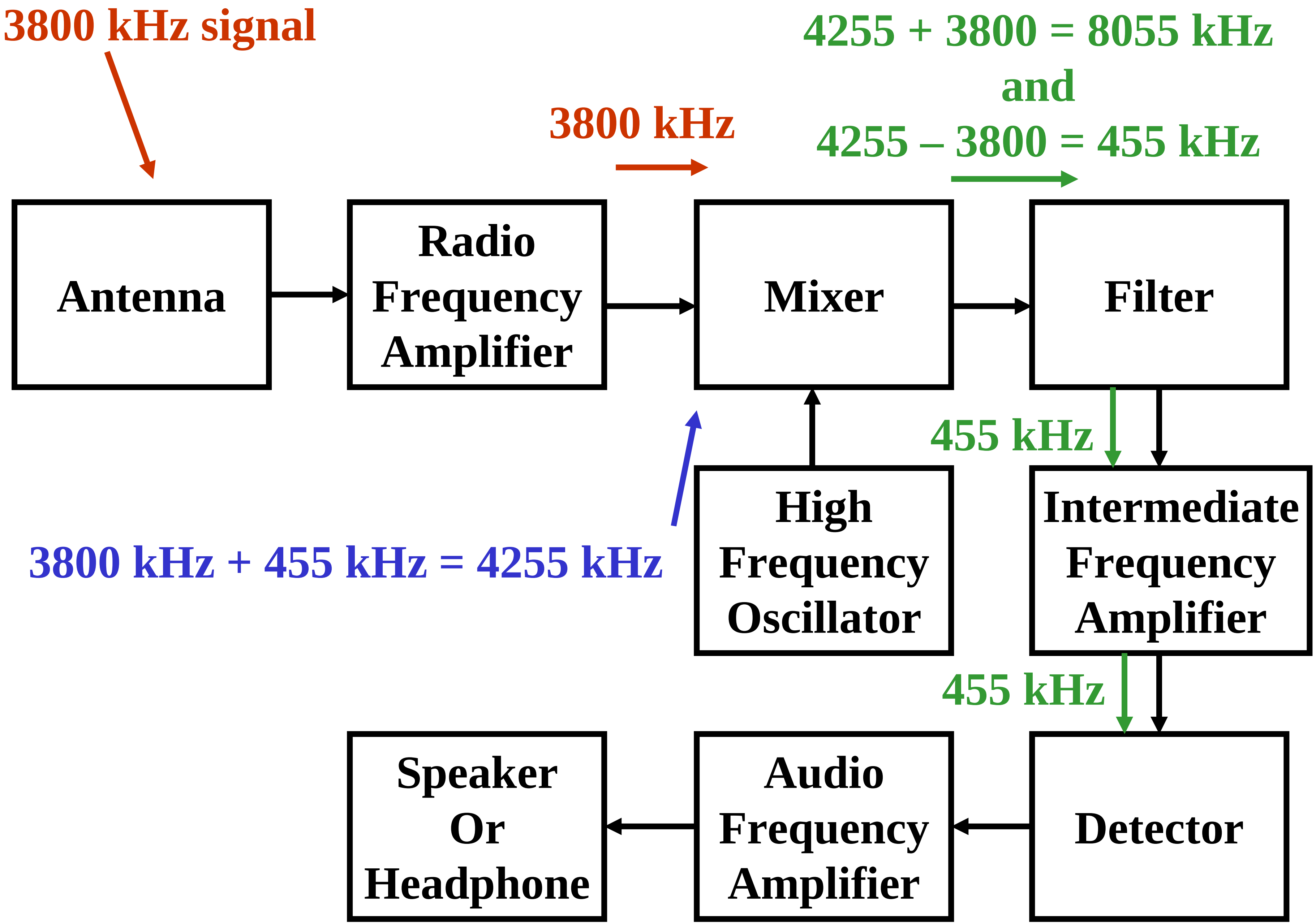


3800 kHz signal
3800 kHz
Antenna
Radio Frequency Amplifier
Mixer
Filter
High Frequency Oscillator
Intermediate Frequency Amplifier
3800 kHz + 455 kHz = 4255 kHz
Speaker Or Headphone
Audio Frequency Amplifier
Detector


3800 kHz signal
3800 kHz
4255 + 3800 = 8055 kHz
and
4255 – 3800 = 455 kHz
Antenna
Radio Frequency Amplifier
Mixer
Filter
High Frequency Oscillator
Intermediate Frequency Amplifier
3800 kHz + 455 kHz = 4255 kHz
Speaker Or Headphone
Audio Frequency Amplifier
Detector



3800 kHz signal
3800 kHz
4255 + 3800 = 8055 kHz
and
4255 – 3800 = 455 kHz
Antenna
Radio Frequency Amplifier
Mixer
Filter
455 kHz
High Frequency Oscillator
Intermediate Frequency Amplifier
3800 kHz + 455 kHz = 4255 kHz
Speaker Or Headphone
Audio Frequency Amplifier
Detector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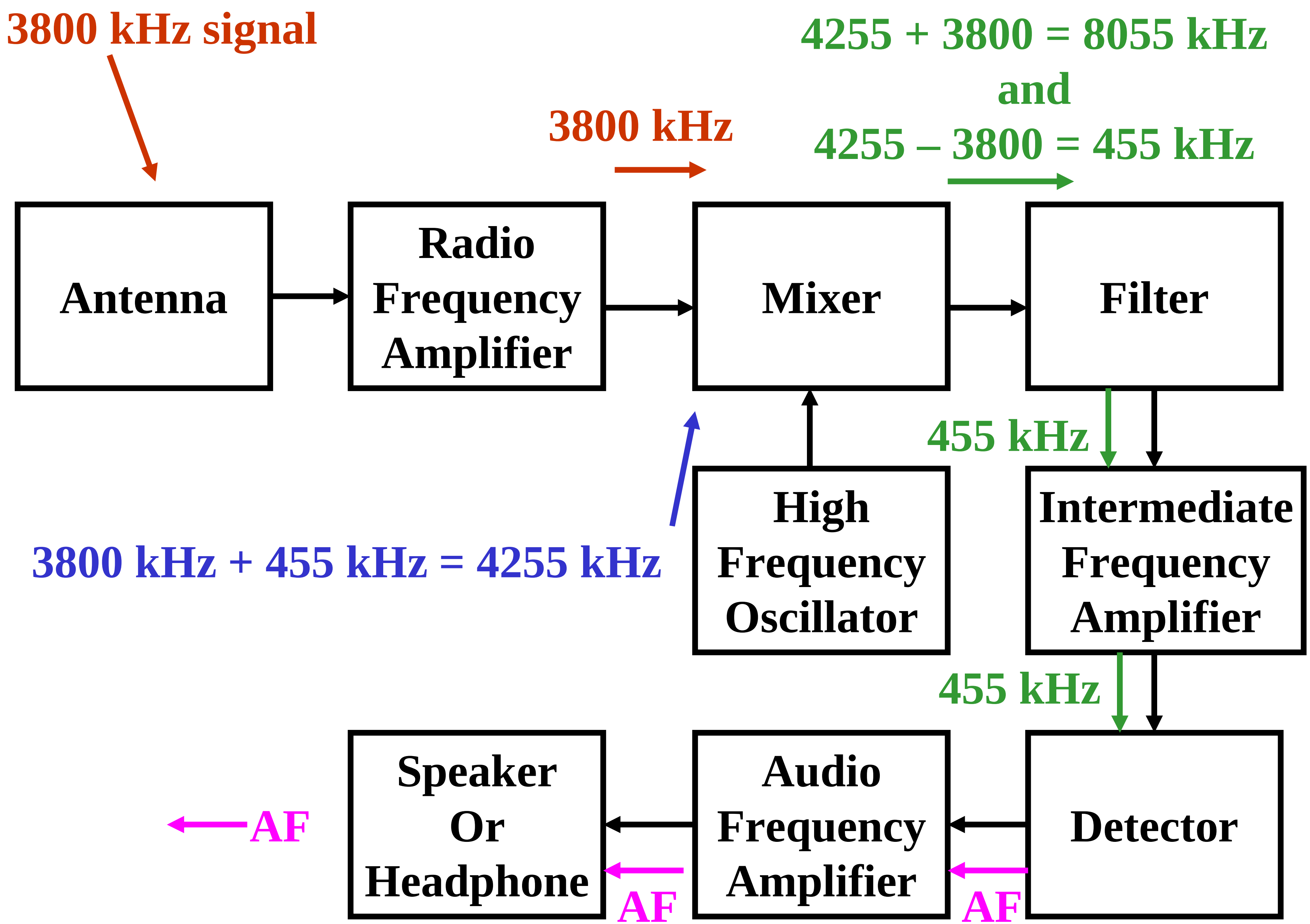
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Antenna
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Filter
455 kHz
High Frequency Oscillator
Intermediate Frequency Amplifier
3800 kHz + 455 kHz = 4255 kHz
455 kHz
Speaker Or Headphone
Audio Frequency Amplifier
Detector
AF
AF
AF

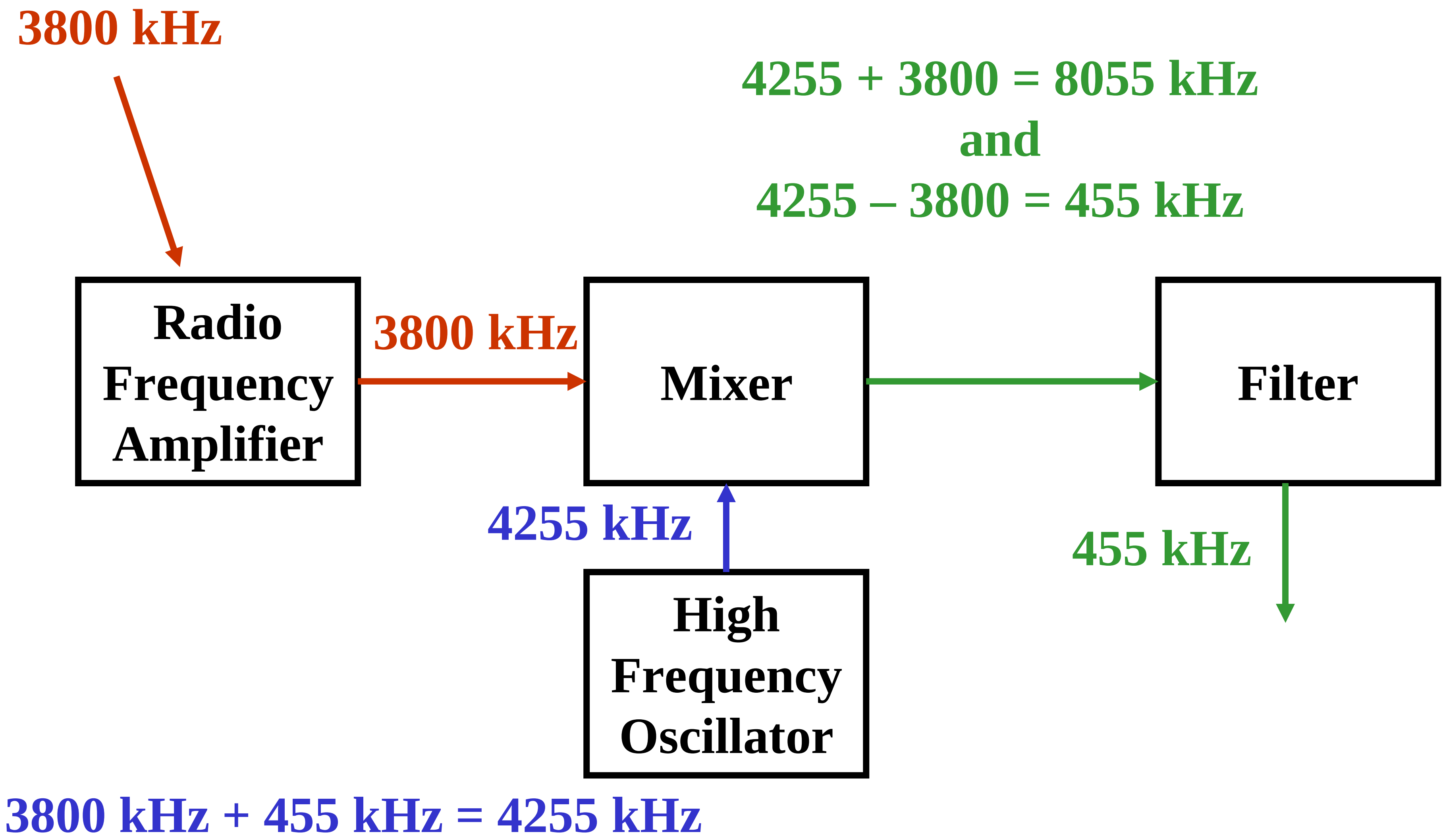
Advantages of the Superhet

- Much **more sensitive, selective** and **stable** than TRF radios.
- By **converting higher frequencies** to the **IF**, we are able to use **more reliable components.**
- Much **easier** to use.

Primary Disadvantage

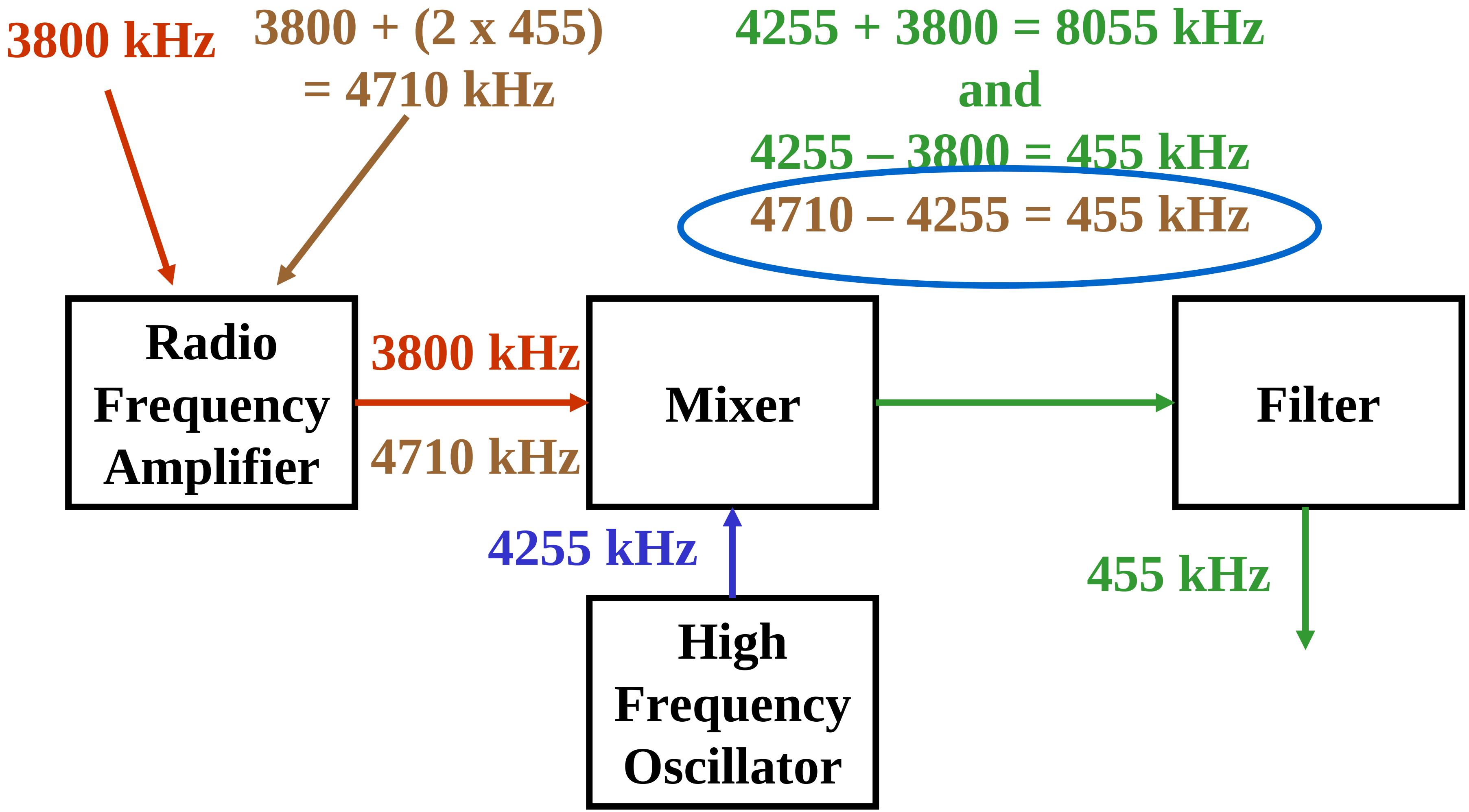
- Superhets have **one big problem** however – they are subject to receiving **images,** or stations that are **not actually on the frequency** we are listening to.
- This occurs when a **station is transmitting** on a frequency **twice the IF** away from the **desired frequency.**

No Image



3800 kHz
4255 + 3800 = 8055 kHz
and
4255 – 3800 = 455 kHz
Radio Frequency Amplifier
3800 kHz
Mixer
Filter
4255 kHz
455 kHz
High Frequency Oscillator
3800 kHz + 455 kHz = 4255 kHz

Image

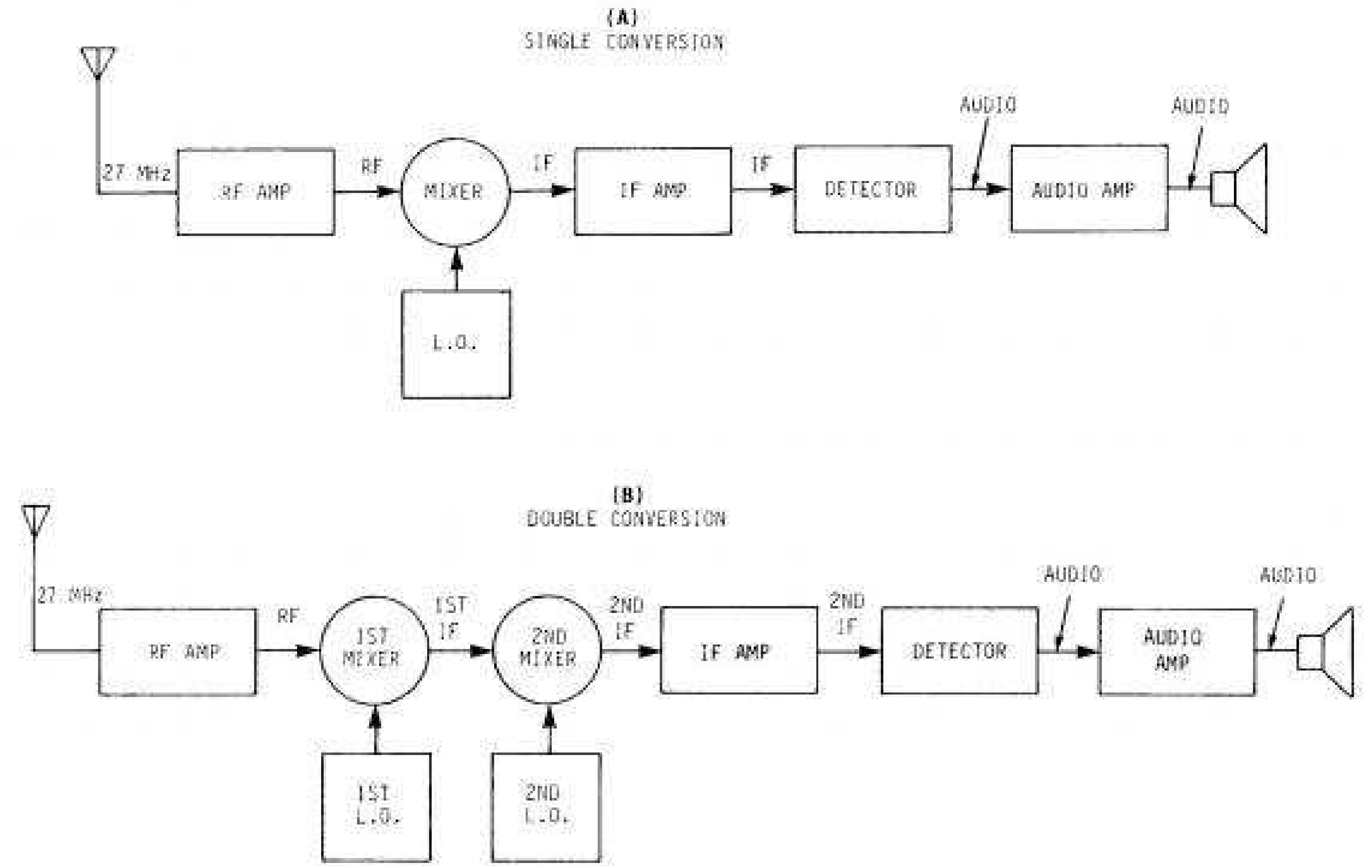


3800 kHz + 455 kHz = 4255 kHz

The Solution!

- More expensive superhets employ **double or triple conversion** to improve **image rejection.**
- The **first IF** is chosen so that it is **larger than the bandwidth** of the **bandpass filters** in the front end of the receiver, and so the image **not make it to mixer stage.**
- The **first IF** signal is then **amplified,** and **converted** again to a **lower IF** to take advantage of the **greater selectivity** available at lower Intermediate Frequencies.

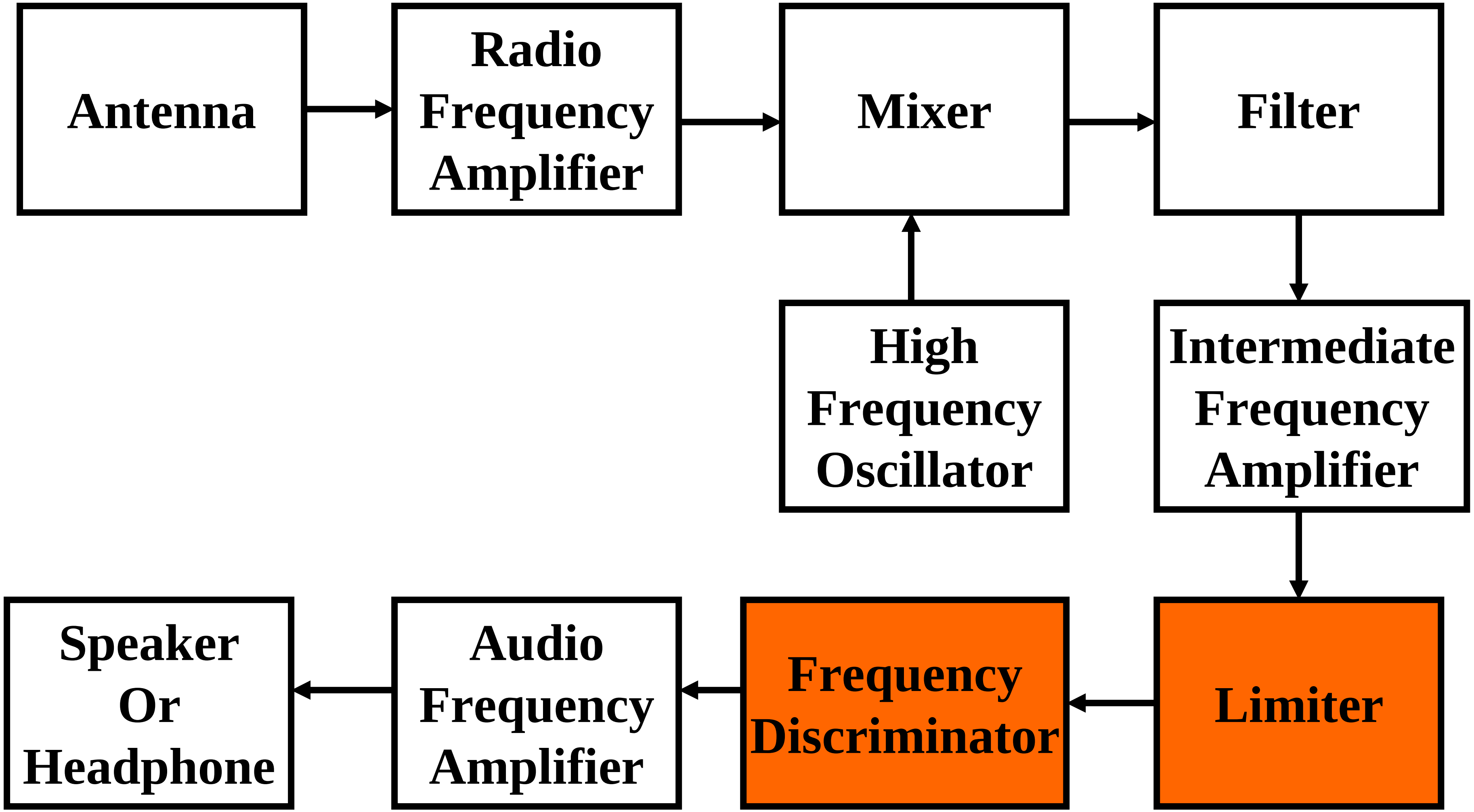
Single versus Dual Conversion Superhet Receiver



FM Receiver

- The **FM receiver** is very similar to an AM receiver up to the IF Amplifier.
- Instead of a Detector however, the FM receiver uses two different stages:
  - **Limiter**
  - **Frequency Discriminator**

FM Receiver



Antenna
Radio Frequency Amplifier
Mixer
Filter
High Frequency Oscillator
Intermediate Frequency Amplifier
Speaker Or Headphone
Audio Frequency Amplifier
Frequency Discriminator
Limiter

Limiter

- The **Limiter Stages** are **high gain amplifiers** that **remove all traces of Amplitude Modulation** from the received signal.
- This gives FM its greatest benefit – a very high **SNR – Signal to Noise Ratio.**
- **Static crashes** are mostly **amplitude modulated,** and so are removed by the Limiter.

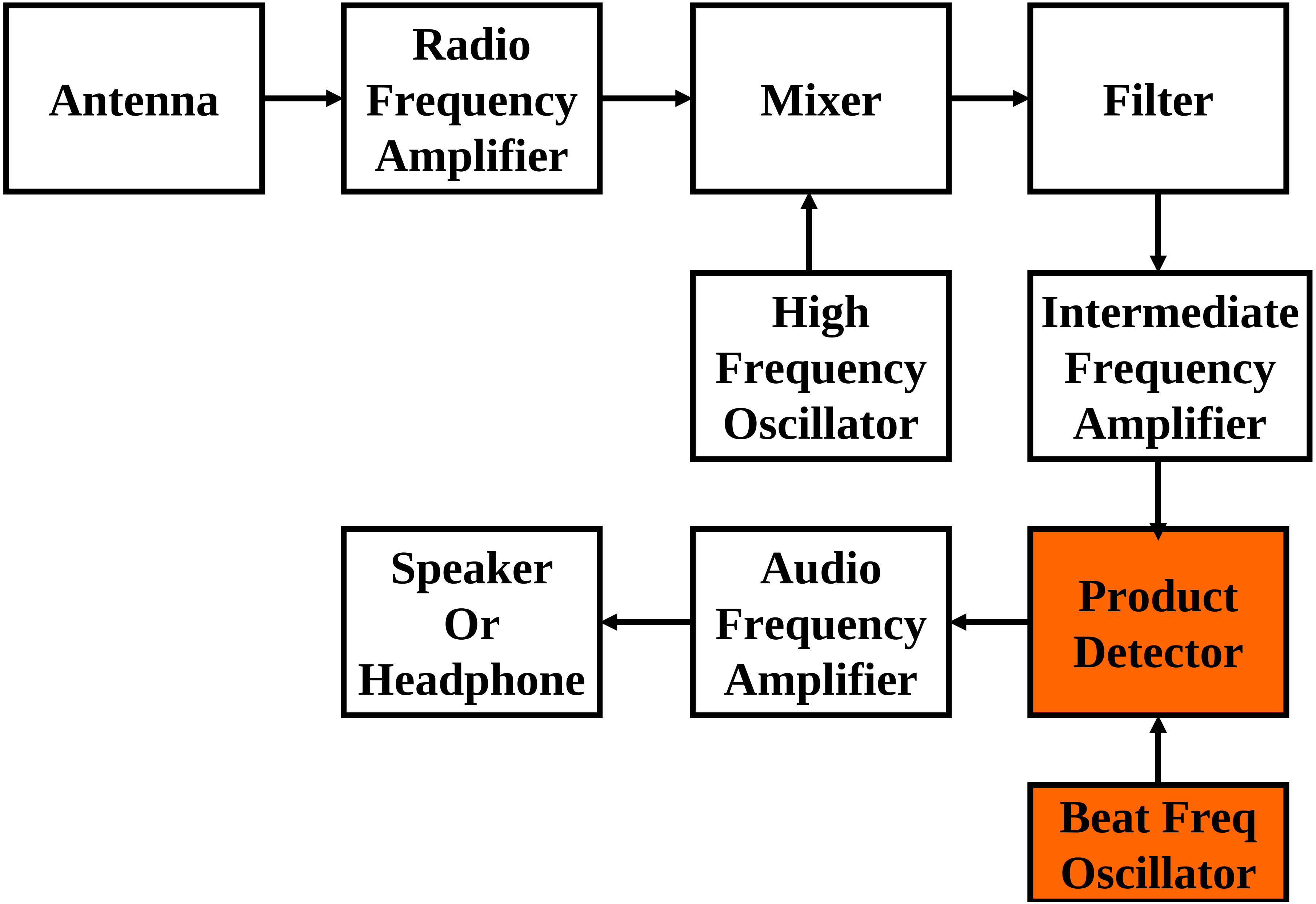
Frequency Discriminator

- The **Frequency Discriminator** converts **frequency variations** into **voltage variations.**
- This is fed to the **Audio Frequency Amplifier** and then the **speaker or headphones.**

Receiving SSB and CW

- The **SSB/CW receiver** is very similar to an AM receiver up to the IF Amplifier.
- Instead of a Detector however, the SSB/CW receiver uses two different stages:
  - **Product Detector**
  - **Beat Frequency Oscillator (BFO).**

SSB / CW Superheterodyne Receiver



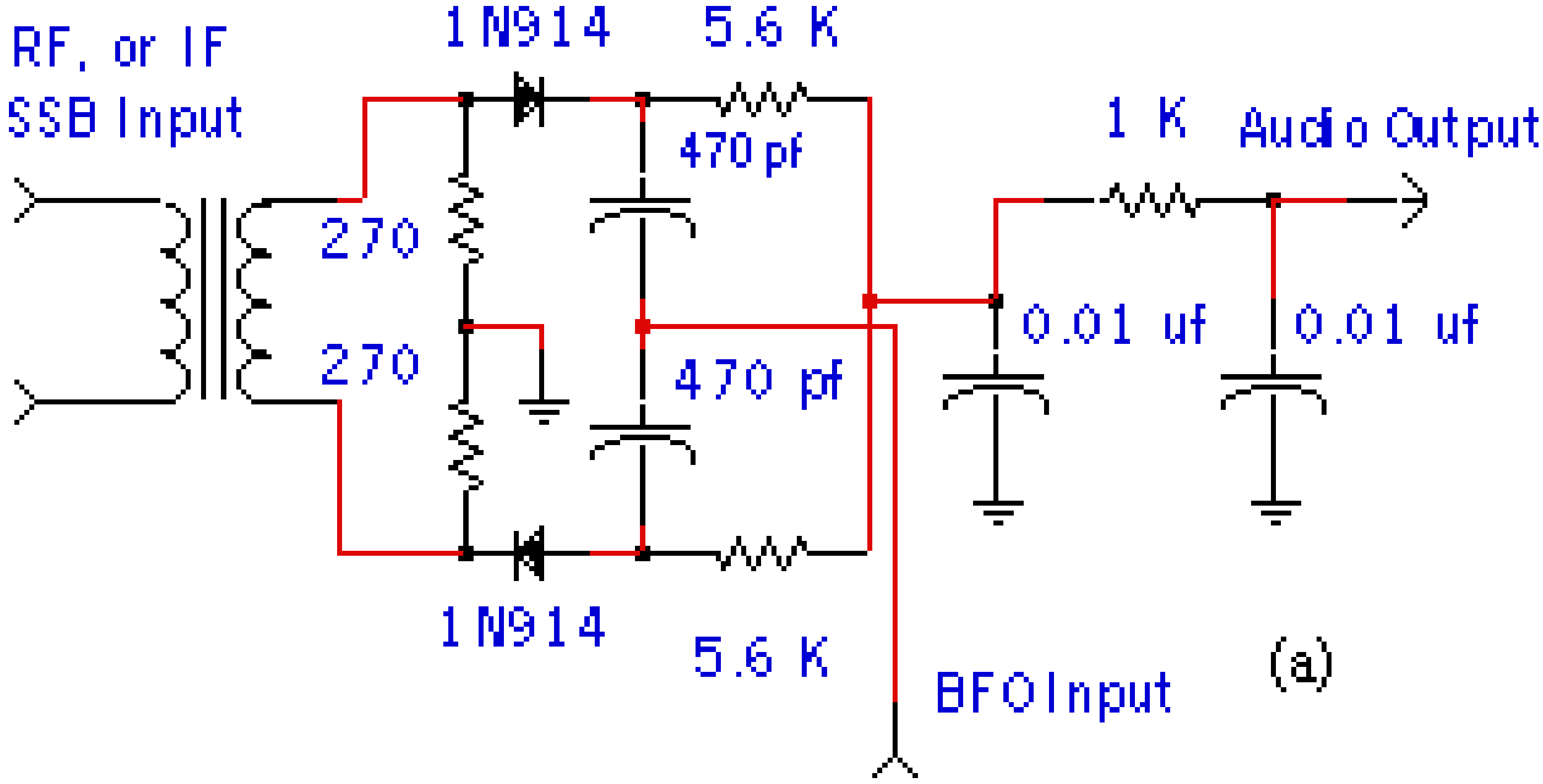
Product Detector

- Because the **carrier** has been **removed** from an SSB transmission, it **must be re-inserted** so that the original audio can be recovered.
- This is accomplished using the **Product Detector.**
- The **source** of the **carrier** is the **Beat Frequency Oscillator (BFO).**

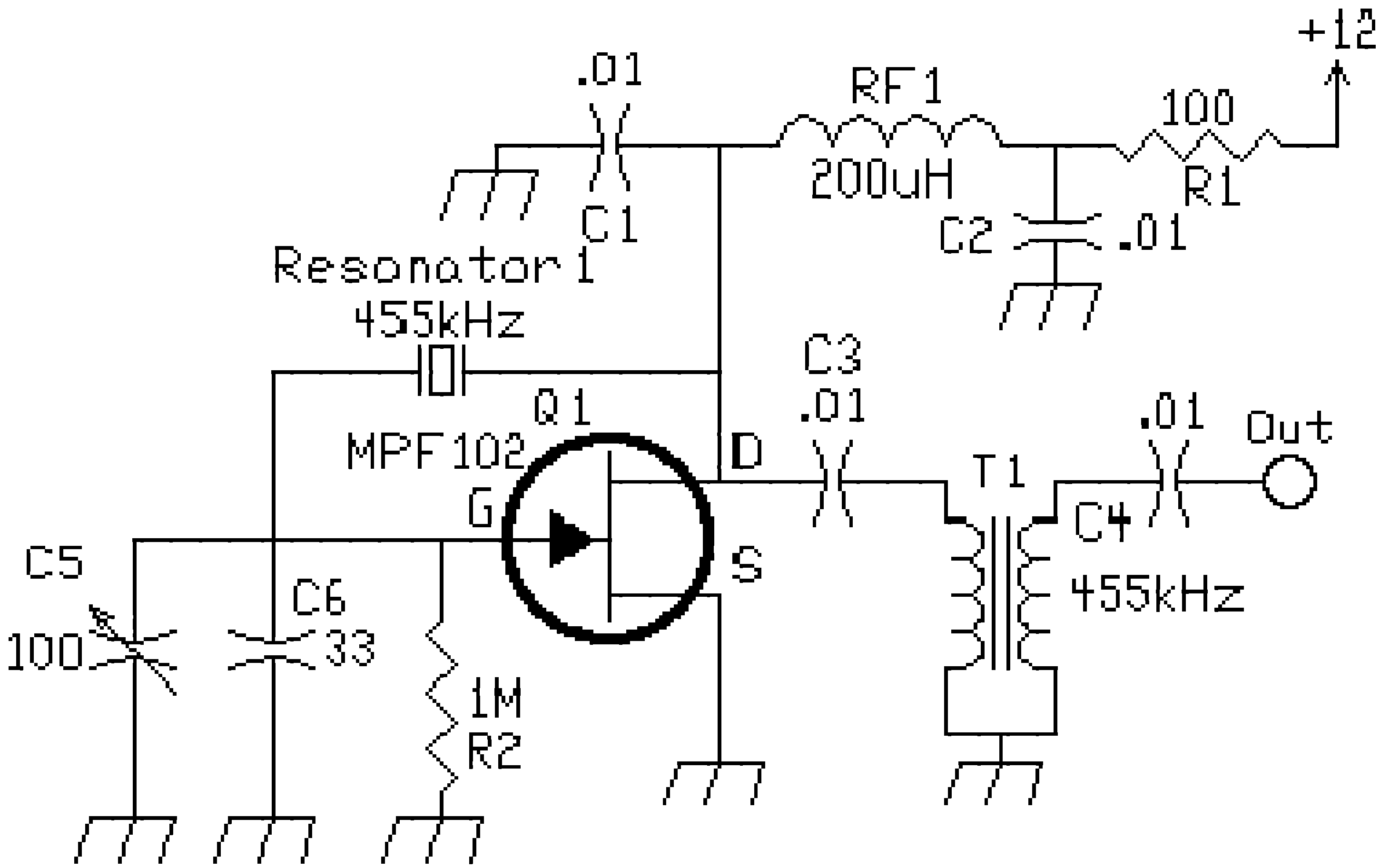
Beat Frequency Oscillator (BFO)

- The **BFO** is an **oscillator** that replaces the **carrier** in an **SSB transmission.**
- **CW transmissions** also require a carrier to **"beat" against (mix with)** to produce an **audio tone.**
- Older receivers use a BFO that could be **varied in frequency** as the **operating mode** is changed from **USB to LSB to CW.**
- Modern radios **automatically switch** the **operating frequency** of the BFO as the mode is changed.

Product Detector



Beat Frequency Oscillator



Audio Filters

- Hams sometimes employed **active or passive external audio filters** with older receivers in an effort to **remove interference** and **improve selectivity.**
- A **Notch Filter** can be used to **remove an interfering carrier signal** (ie: CW signal).
- To **improve CW selectivity,** an audio **bandpass filter** for **750 – 850 Hz** would be appropriate.
- Modern radios incorporate **DSP techniques** even more effectively, at the **IF stages** rather than the audio stages.

MFJ- 784B DSP Filter

Signal Strength Meters

- An **S-Meter** enables you to make comparisons between received signals.
- Unfortunately, even on identical receivers, most S-meters are **not properly calibrated** and will give **different readings** when using the same antenna.
- The scale is divided into **9 increments**, designated **S0 to S9,** up to the **center point of the meter.** The scale is then **graduated in dB,** usually in multiples of 10.
- A **signal strength report** would be **"S6"** or **"S9 plus 15 dB".**

S-Meter Standards

- According to the standards adopted by the **International Amateur Radio Union (IARU)** in 1981, **S9 corresponds to a signal strength of 50 microvolts at the receiver's 50 ohm impedance antenna input.**
- Each **S unit** then reflects a **6dB change in signal strength.**
- This is **rarely achieved,** as S-meters are often **not linear in their response.**
- Still, they give a relative indication of signal strengths!

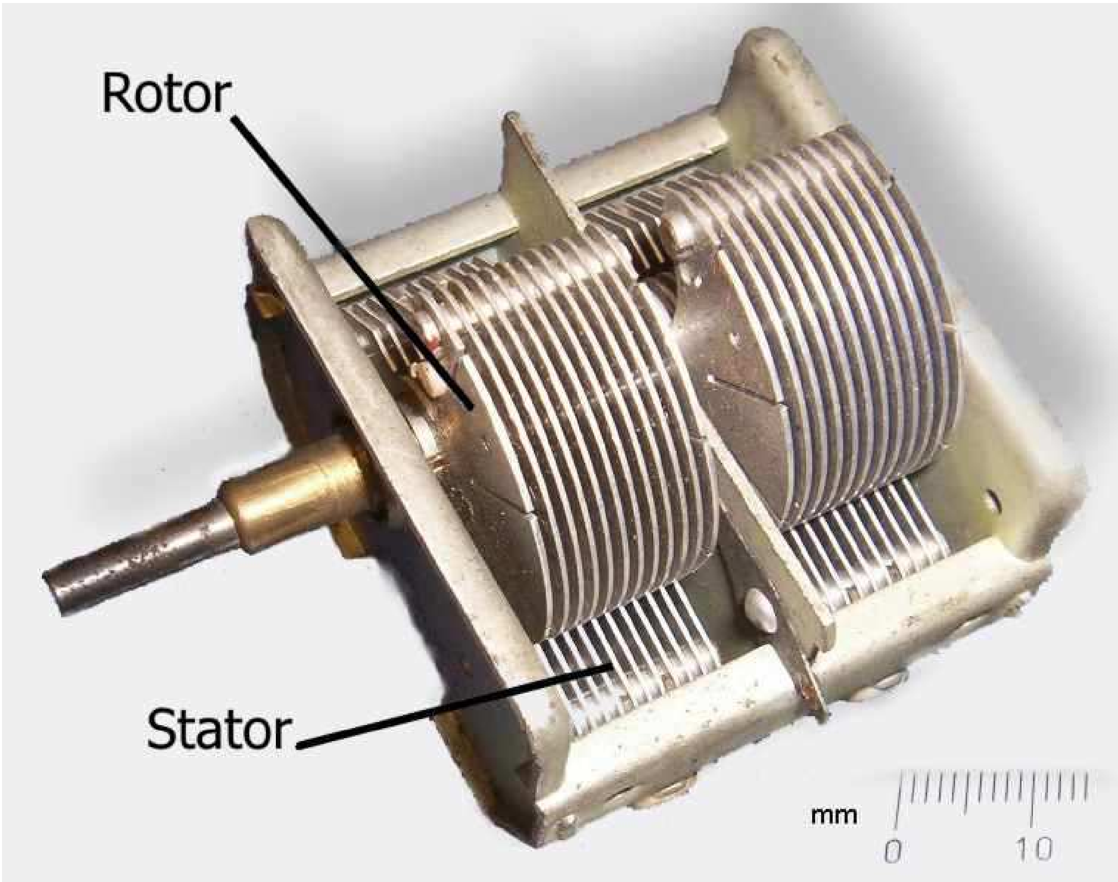
S-Meter

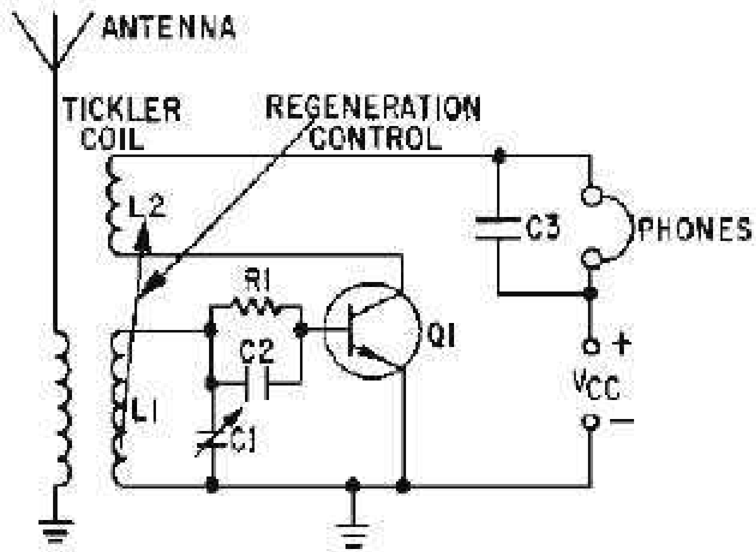

S
1
3
5
7
9
+20
+40
+60
dB
PO
COMP
ID
SWR
ALC
W
dB
A
V
VDD
VR2XMQ Steve


S
1 — 3 — 5 — 7 — 9 — 20 — 40 — 60 dB
0 — 10 — 25 — 50 — 100 — W
FILTER
SWR
1
1.5
2
3
∞
HF TRANSCEIVER
PROC
MONI
CH 1

Questions?

Two Section Tuning Capacitor




ANTENNA
TICKLER
COIL
REGENERATION
CONTROL
L2
R1
C2
L1
C1
Q1
C3
PHONES
+
VCC
–