Radio Receivers

Al Penney
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

- Passband
- Stopband
- Filter Skirt
- Real filter response

Response

Frequency
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!
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
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

Antenna → Radio Frequency Amplifier → Mixer → Filter

Mixer:
- High Frequency Oscillator
- Intermediate Frequency Amplifier

Filter:
- Audio Frequency Amplifier
- Detector

Speaker Or Headphone
Superheterodyne Receiver

Antenna → Radio Frequency Amplifier → Mixer → Filter

Mixer:
- High Frequency Oscillator
- Intermediate Frequency Amplifier

Filter:
- Audio Frequency Amplifier
- Detector

Speaker Or Headphone
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

Antenna → Radio Frequency Amplifier → Mixer → Filter

Mixer

High Frequency Oscillator

Intermediate Frequency Amplifier

Speaker or Headphone

Audio Frequency Amplifier

Detector
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

Antenna ➔ Radio Frequency Amplifier ➔ Mixer ➔ Filter

- High Frequency Oscillator
- Intermediate Frequency Amplifier
- Speaker Or Headphone
- Audio Frequency Amplifier
- Detector
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

Antenna → Radio Frequency Amplifier → Mixer → Filter

- High Frequency Oscillator
- Intermediate Frequency Amplifier

- Speaker
- Or
- Headphone

Audio Frequency Amplifier → Detector
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

Antenna → Radio Frequency Amplifier → Mixer

High Frequency Oscillator → Intermediate Frequency Amplifier → Detector

Audio Frequency Amplifier → Speaker Or Headphone
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.
Antenna → Radio Frequency Amplifier → Mixer → Filter

- High Frequency Oscillator
- Intermediate Frequency Amplifier

3800 kHz signal

→ Speaker

Or Headphone → Audio Frequency Amplifier

Detector
3800 kHz signal

3800 kHz + 455 kHz = 4255 kHz
A 3800 kHz signal enters the system from the Antenna. After passing through the Radio Frequency Amplifier, it is sent to the Mixer. The output from the Mixer is then filtered through the Filter.

3800 kHz + 455 kHz = 4255 kHz

4255 kHz is then sent to the High Frequency Oscillator and 4255 kHz + 3800 kHz = 8055 kHz. This is then sent to the Audio Frequency Amplifier.

4255 kHz – 3800 kHz = 455 kHz

The output from the Audio Frequency Amplifier is sent to the Speaker or Headphone.
Antenna

Radio Frequency Amplifier

Mixer

Filter

High Frequency Oscillator

Intermediate Frequency Amplifier

Speaker Or Headphone

Audio Frequency Amplifier

Detector

3800 kHz signal

3800 kHz

4255 + 3800 = 8055 kHz

and

4255 – 3800 = 455 kHz

3800 kHz + 455 kHz = 4255 kHz
Antenna

Radio Frequency Amplifier

Mixer

Filter

High Frequency Oscillator

Intermediate Frequency Amplifier

Speaker

Audio Frequency Amplifier

Or

Headphone

Detector

3800 kHz signal

3800 kHz

3800 kHz + 455 kHz = 4255 kHz

4255 + 3800 = 8055 kHz

and

4255 – 3800 = 455 kHz

455 kHz

455 kHz
A 3800 kHz signal enters the radio system. It is amplified by the radio frequency amplifier. After amplification, the signal is mixed with a 455 kHz signal, resulting in an intermediate frequency of 4255 kHz.

The high frequency oscillator generates a 455 kHz signal, which is also mixed with the 3800 kHz signal, producing a new intermediate frequency of 8055 kHz.

The 455 kHz signal is used as a reference for the detector, which demodulates the audio frequency (AF) information.

The audio information is then amplified by the audio frequency amplifier and can be heard through the speaker or headphone.
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.
Radio Frequency Amplifier

Mixer

Filter

High Frequency Oscillator

3800 kHz + 455 kHz = 4255 kHz

4255 + 3800 = 8055 kHz

and

4255 – 3800 = 455 kHz

3800 kHz + 455 kHz = 4255 kHz
Radio Frequency Amplifier

Mixer

Filter

3800 kHz

4255 + 3800 = 8055 kHz
and
4255 – 3800 = 455 kHz
4710 – 4255 = 455 kHz

4255 kHz

3800 + (2 x 455)
= 4710 kHz

3800 kHz

4710 kHz

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

Antenna → Radio Frequency Amplifier → Mixer → Filter

- High Frequency Oscillator
- Intermediate Frequency Amplifier

Speaker Or Headphone
- Audio Frequency Amplifier

Product Detector
- Beat Freq Oscillator
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
Questions?
Two Section Tuning Capacitor

- Rotor
- Stator