



Lesson 12

RECEIVERS

ACMA Syllabus February 2024 Chapters 4, 3.5 and 1.7

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Australian Amateur Radio Advance Licence Theory

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Receivers

A radio receiver is an electronic device that receives radio waves and converts the information carried by them to a usable form. An antenna captures radio waves, and the receiver converts these signals to tiny alternating currents. The receiver uses electronic filters to separate the desired radio frequency signal from all the other signals and finally recovers the desired information through demodulation.

Receivers are rated on three criteria, their sensitivity, selectivity and stability,

Sensitivity

Receiver sensitivity indicates how faint an input signal can be to be successfully received by the receiver. Sensitivity is defined as the receiver's ability to detect a signal at the input and give a signal-plus-noise ratio of 10dB above the noise output of the receiver.

Thermal Noise

Thermal Noise or Thermal agitation noise is always present in the electrical equipment and is one of the major sources of noise that can affect the detection of weak signals.

Thermal noise occurs due to the vibration of charge carriers within an electrical conductor and is directly proportional to the temperature. Thermal noise cannot be eliminated but can be reduced by controlling the temperature of devices. The thermal noise power is proportional to the bandwidth and is effectively white noise. The power spectrum equation is shown below.

$$E_n = \sqrt{4 \times K \times T \times R \times BW}$$

E_n = Noise voltage

T = Temperature in Kelvin

R = Resistance in ohms

$K = 1.381 \times 10^{-23}$ (Boltzmann's constant)

BW = Bandwidth in Hertz

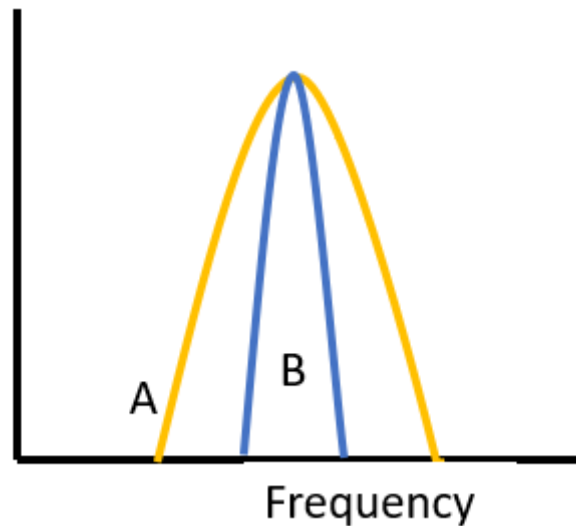
Any circuit element that is above absolute zero will produce thermal noise, also called Johnson noise. A simple fixed resistor can produce white noise in any amplifier circuit, and this can only be reduced by lowering the circuit's temperature. This noise is independent of the resistor's material composition.

Example: Thermal noise levels for room temperature, 20°C or 290°K is the most calculated for a 1 kHz bandwidth as it is easy to scale from here as noise power is proportional to the bandwidth. The most common impedance is 2000 Ω.

$$\begin{aligned} E_n &= \sqrt{4 \times K \times T \times R \times BW} \\ &= \sqrt{4 \times 1.381 \times 10^{-23} \times 290 \times 2000 \times 1000} \\ &= 0.179 \text{ nV} \end{aligned}$$

Selectivity

Selectivity is an important parameter in any radio receiver. Selectivity is necessary for the receiver to be able to select the wanted signal from the unwanted adjacent signal. In the case below, receiver B is more selective than receiver A.



Stability

Frequency stability means the receiver must stay "tuned" to the incoming radio signal and must not "drift" with time or temperature.

The overall receiver gain must be carefully controlled so that spurious emissions are not produced within the receiver.

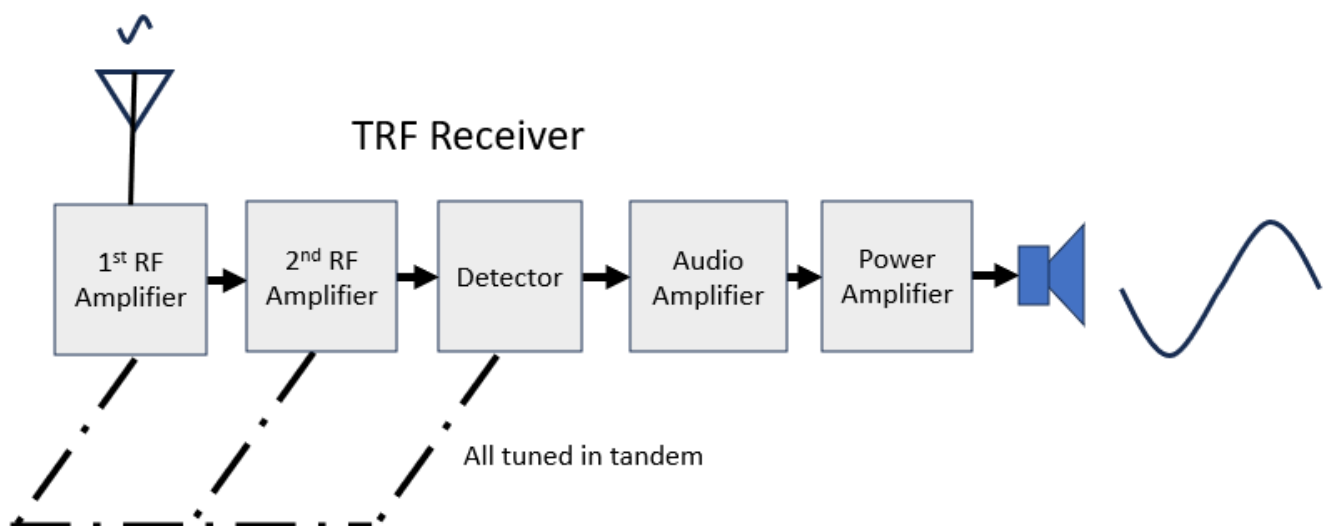
Receiver Configurations

There are a variety of receiver configurations that can be used, and the chosen configuration can have a significant impact on the three criteria.

Tuned Radio Frequency Receiver (TRF).

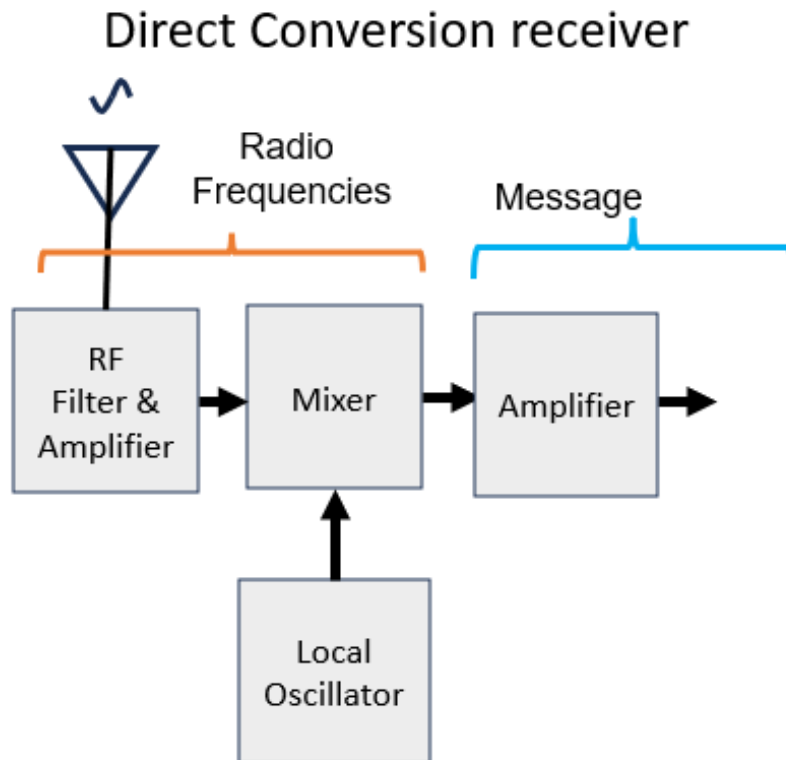
A tuned radio frequency receiver (or TRF receiver) is a receiver composed of one or more tuned radio frequency (RF) amplifier stages followed by a detector (demodulator). This receiver was popular in the 1920s, but it was tedious to operate. Tuning in a station on the radio required each stage of the radio to be individually adjusted to the station's frequency. Later models had ganged tuning.

The receiver relies on the filters in the RF sections of the radio to provide selectivity. These are variable and often at a relatively high frequency. Selectivity can better be achieved by the other types of techniques.



Direct conversion receiver (DCR). The DCR is also known as homodyne, synchrodyne, or zero-IF receiver. The receiver demodulates the incoming radio signal using synchronous detection driven by a local oscillator. intended signal.

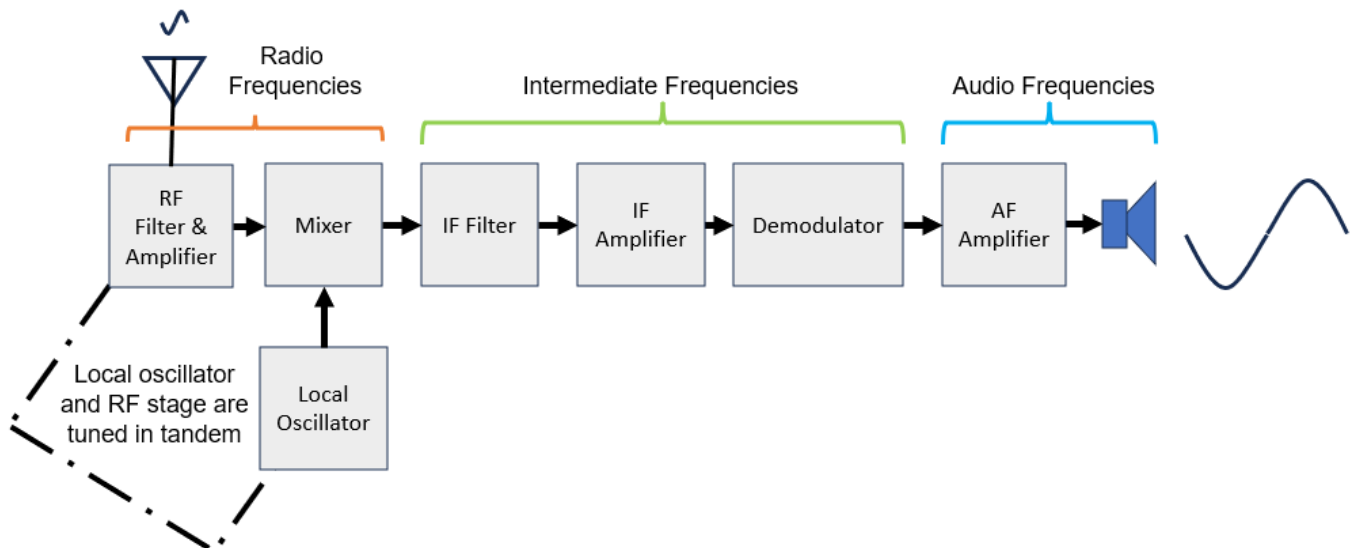
This is a simple circuit, but other issues arise. The DCR is unsuited to receiving AM and FM signals without implementing an elaborate phase locked loop. Improvements in technology and software have revived its use in certain areas including some consumer products.



Superheterodyne Receiver.

The superheterodyne radio receiver has been in widespread use for years, and it is still widely used for high performance applications. A variety of selectivity and filter requirements are applicable for superheterodyne receivers. Selectivity of the front end is required to ensure sufficient image rejection, and the filters in the IF provide the main adjacent channel rejection.

A superheterodyne receiver, often shortened to “superhet”, is a receiver that uses frequency mixing to convert a received signal to a fixed intermediate frequency (IF). This IF can be more conveniently processed than the original carrier frequency. Virtually all modern radio receivers use the superheterodyne principle. Below is a block diagram of a superheterodyne receiver.



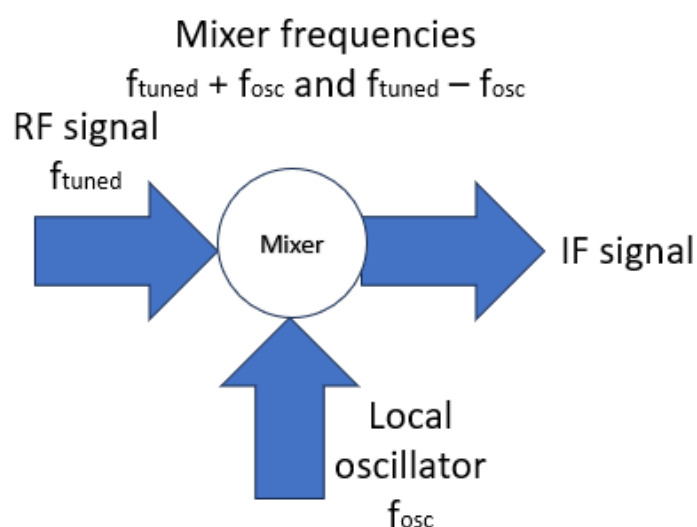
Antenna. Captures the very small signal and passes to the RF Filter for further processing.

RF Filter The signal from the antenna is tuned by one or more tuned circuits. This will block frequencies that are distant from the intended reception frequency. Tuning of one (or more) tuned circuits in the RF stage must track the tuning of the local oscillator.

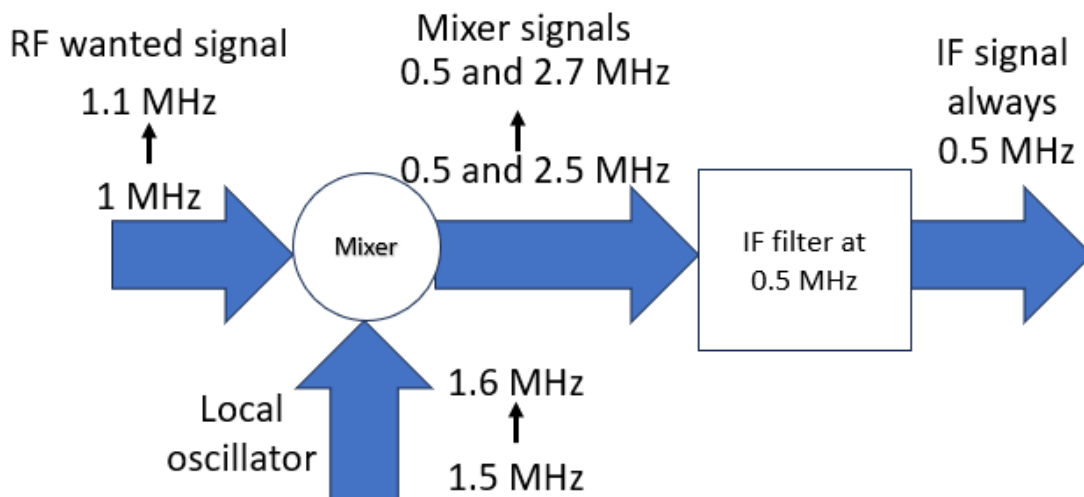
RF amplifier. The received signal is fed to the RF amplifier stage where the signal is boosted.

Local Oscillator This circuit generates a signal with a fixed frequency and the output is then fed to the mixer. When we talk about AM broadcast system, the intermediate frequency (IF) is 455 KHz that simply means that local oscillator should select such a frequency which is 455 KHz above the incoming signal frequency.

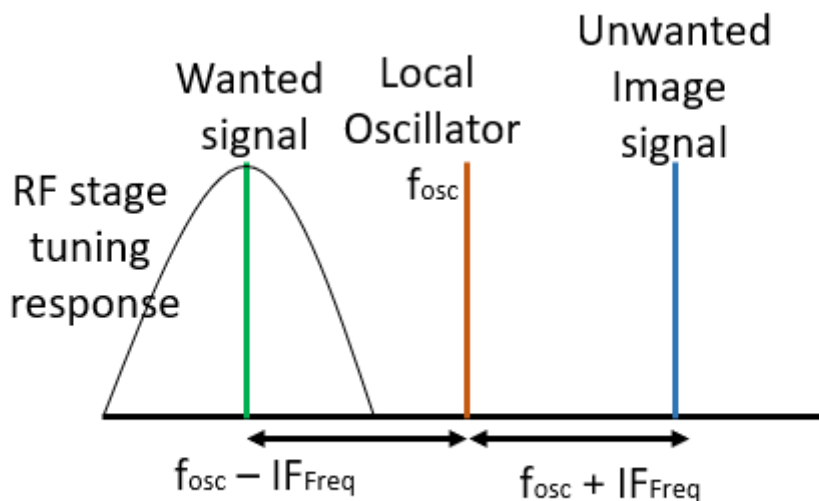
Mixer A mixer combines the carrier frequency with the frequency of the signal generated by the local oscillator.



The tight tolerance filters on the IF stage block the higher frequency.



The local oscillator frequency is always higher than the RF signal by the frequency of the IF.



$$\text{Image frequency} = \text{wanted signal frequency} + (2 \times IF_{freq})$$

Image Frequency

There are two RF frequencies that can produce the same IF frequency. This is called the Image frequency. This frequency is the RF carrier frequency plus 2 x IF frequency.

$$\text{Image} = \text{RF signal} + (2 \times IF)$$

In the case above, RF signals at 2 and 2.1 MHz produce an IF frequency of 0.5 MHz.



With RF stage rejecting the image frequency and the tight tolerances of the IF filters, other signals are treated as noise and blocked. Irrespective of the incoming signals, the RF amplifier and local oscillator must be tuned for that frequency together.

Example: A receiver is tuned to 750 kHz and the oscillator is running at 925 kHz, what is the image frequency?

First calculate IF.

IF is the difference between the oscillator frequency and the incoming signal.

$$IF = 925 \text{ kHz} - 750 \text{ kHz} = 175 \text{ kHz.}$$

$$\text{Image} = \text{Tuned frequency} + (2 \times IF)$$

$$\text{Image} = 750 + (2 \times 175 \text{ kHz})$$

$$\text{Image} = 750 + 350$$

$$\text{Image} = 1100 \text{ kHz}$$

Image rejection specification

If the image rejection specification of a receiver was -60 dB at 30 MHz. This means that if the wanted and unwanted signals are the same level at the input, the unwanted signal would be 60 dB below the wanted signal.

Example: -60 dB at 30 MHz (Assume input voltage of 1)

$$\text{dB} = 20 \text{ Log} (E1/E2)$$

$$30 = 20 \text{ Log} (E2/1)$$

$$1.5 = \text{Log} (E2/1)$$

$$10^{1.5} = E2/1$$

$$29.5 = E2/1$$

29.5 = E2

The receiver reduces the image frequency by nearly 30 times.

IF amplifier. This section basically amplifies the output of the mixer. IF amplifier provides sensitivity(gain) and selectivity (bandwidth requirement) to the receiver. The sensitivity and selectivity are uniform and does not show variations as in the case of TRF receivers because IF amplifiers are independent of that of the received signal frequency. The IF has a narrow bandwidth and rejects all other frequencies, reducing the risk from interference.

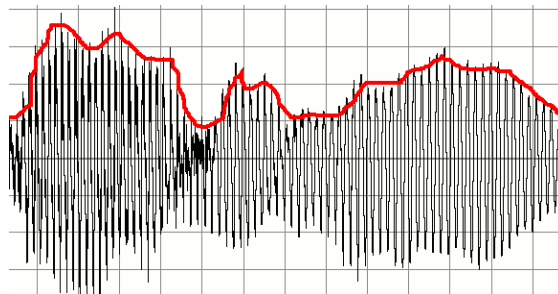
Demodulator. A demodulator is placed after the IF amplifier and the message can be extracted. Demodulation is extracting the original information from a carrier wave. and a demodulator is an electronic circuit that performs this task.

Types of Demodulators

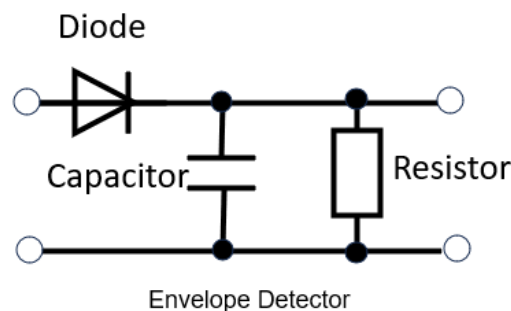
- | | |
|-----------------------------|--|
| • Amplitude modulation (AM) | Envelope detector or synchronous detector |
| • Morse code (CW) | Product detector |
| • Frequency modulation (FM) | Slope detector, Foster-Seely discriminator, Ratio detector or Quadrature detector. |
| • Single Side Band (SSB) | Product detector. |

Envelope Detector.

An envelope detector or peak detector is a circuit that converts a high-frequency amplitude modulated signal and provides a demodulated output. The demodulated signal is shown below in red.



A circuit for an envelope detector is shown below. The time constant of the capacitor and resistor are important to achieve good demodulation.

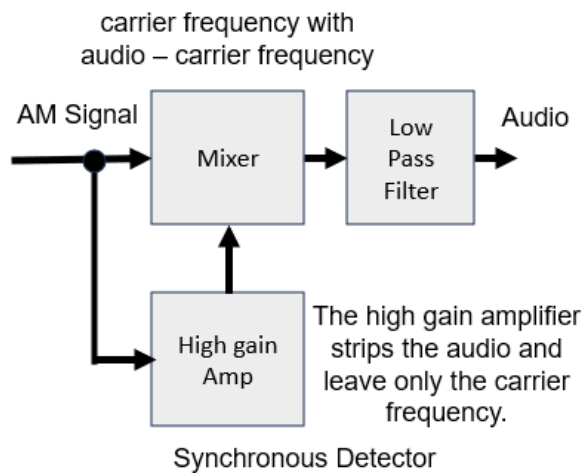


Envelope detectors use either half-wave or full-wave rectification of the signal to convert the AC into a pulsed DC signal. Filtering smooths the final output. Some "ripple" may remain.

Reducing the filter cutoff frequency gives a smoother output but decreases the high frequency response.

Synchronous Detector

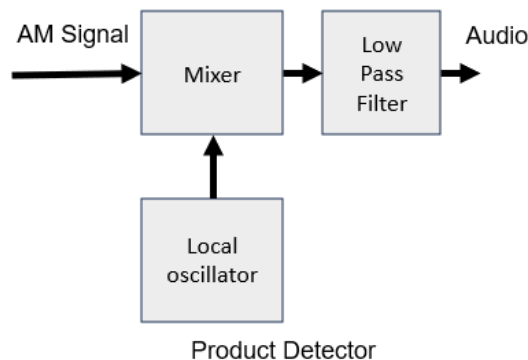
A synchronous detector recovers information from a modulated signal by mixing the signal with a replica of the unmodulated carrier. This system retains the phase of the original signal.



Product Detector

A product detector can be designed to accept either IF or RF frequency input for AM and SSB signals. The product detector takes the product of the modulated signal and a local oscillator.

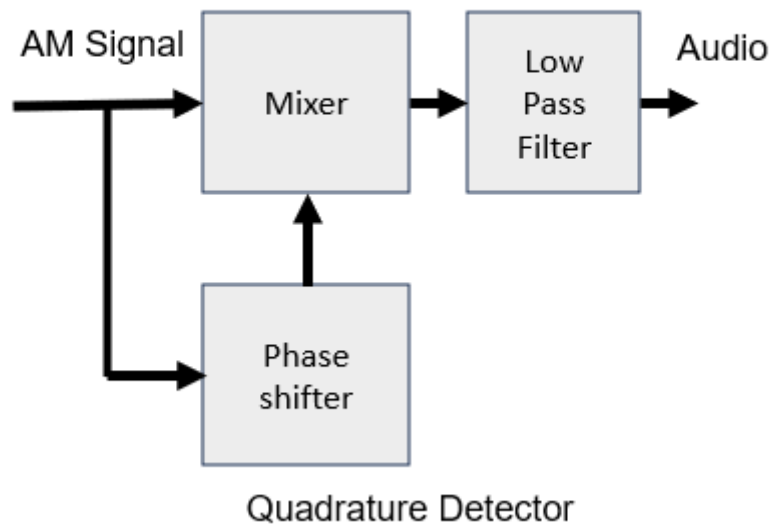
The simplest form of product detector mixes the RF or IF signal with a locally derived carrier (the Beat Frequency Oscillator, or BFO) to produce an audio frequency copy of the original audio signal and a mixer product at twice the original RF or IF frequency. This high-frequency component can then be filtered out, leaving the original audio frequency signal.



Slope Detector

In the FM slope detector, the frequency of the tuned circuit formed by the transformer secondary and C1 is slightly higher than the incoming frequency. The converts the signal from FM to AM. The envelope detector is then used to demodulate the signal.

The downfall of this detector is that it is susceptible to amplitude spikes and the signal strength is reduced.

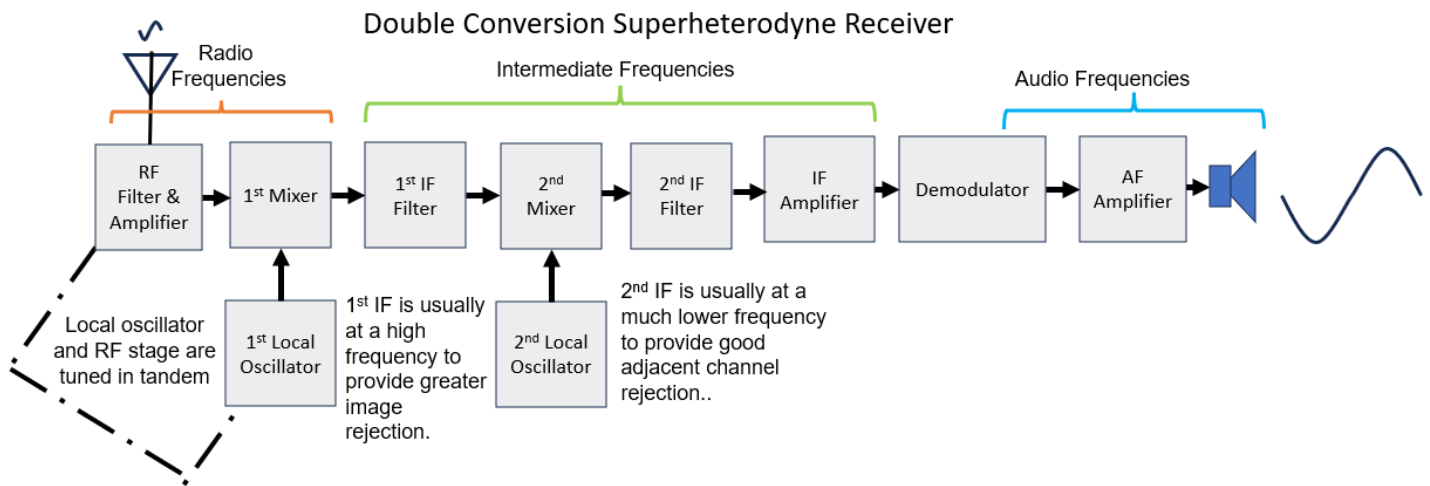


Audio amplifier. The audio signal is fed to the audio amplifier to boost the signal to a particular level.

Power amplifier. Here, the signal is further amplified to a particular power level which can activate the loudspeaker.

Double Conversion Superhet

The double conversion superhet has two IF stages. These improve image rejection and adjacent channel rejection.



Signal Reports

A signal report informs the transmitting station the readability and signal strength of their signal at your receiver.

There are three parts to a signal report.

R - Readability scaled 1 to 5 and judged by the operator.

S - Signal strength of the receiver's meter.

T - Tone on a scale of 1 to 9. Used for morse code only and judged by the operator.

Readability

1. Unreadable
2. Barely readable, occasional words distinguishable.
3. Readable with considerable difficulty
4. Readable with practically no difficulty
5. Perfectly readable

Signal strength.

This reading is a voltage measurement at the antenna input to the receiver. A midscale reading of S9 is triggered by $50\mu\text{V}$ at the antenna. Over S9, the meters indicate as follows:

- +20 means 20dB over S9 (10 times) or $500\mu\text{V}$
- +40 means 40dB over S9 (100 times) or $5,000\mu\text{V}$ (5V)
- +60 means 60dB over S9 (1000 times) or $50,000\mu\text{V}$ (50V)



Wikipedia

Example: Signal report of 5 and 9 means the signal is perfectly readable and signal strength of 9,

Receiver Terms

Capture Effect

This is a phenomenon associated with frequency modulation (FM) and Amplitude Modulation (AM) to a lesser extent.

The capture effect is a characteristic of a FM receiver circuit where two or more signals are transmitted on the same frequency, only the stronger signal will be demodulated. In the FM circuit, the incoming signal is limited in amplitude.

The capture effect is where the weaker signal is not amplified but attenuated. When both signals are nearly equal in strength or are fading independently, the receiver may rapidly switch from one to another and exhibit flutter.

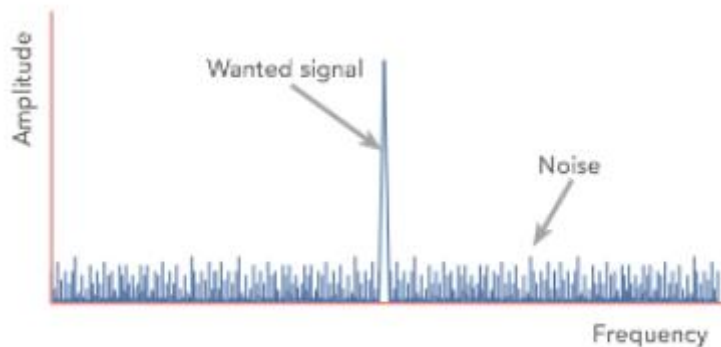
In the case of an FM signal, the capture effect dominates when the stronger signal was about twice as strong as the weaker signal. In AM signals the stronger signal has to be about twenty times that of the weaker signal.

Radio communications between aircraft use AM to prevent the capture effect impacting weaker signals. The pilots need to hear all transmissions on the same channel.

Noise

Radio noise or radio static is unwanted random radio frequency electrical signals. These can be caused by a combination of natural electromagnetic atmospheric noise ("spherics", static) such as lightning, manmade radio frequency interference (RFI) from other electrical devices picked up by the receiver's antenna and thermal noise present in the receiver circuits.

The level of noise in a receiver circuit is measured by the signal-to-noise ratio (S/N), the ratio of the average amplitude of the signal voltage to the average amplitude of the noise voltage.



White noise spectrum

The calculation for the Signal to Noise ratio in dBs is shown below.

$$\text{SNR (dB)} = 10 \text{ Log} \left(\frac{P_{\text{Signal}}}{P_{\text{Noise}}} \right)$$

Example: Signal = 100 mV and Noise = 1 mV

$$\text{SNR} = 10 \text{Log} (0.100 / 0.001)$$

$$\text{SNR} = 10 \text{ Log } 100$$

$$\text{SNR} = 10 \times 2$$

$$\text{SNR} = 20 \text{ dB}$$

Bandwidth

Bandwidth (BW) is the range of frequencies that a signal occupies.

Example: An AM broadcast radio channel has a bandwidth of 10kHz, meaning that it occupies a 10kHz-wide band which are the frequencies from 760kHz to 770kHz.

Automatic Gain Control

Automatic gain control (AGC) is closed-loop feedback regulating circuits in an amplifier. The purpose of the AGC is to maintain a suitable signal amplitude at its output, despite variation of the signal amplitude at the input. The average or peak output signal level is used to dynamically adjust the gain of the amplifiers. AGC is used in most radio receivers to equalise the average volume (loudness) of different radio stations due to differences in received signal strength, as well as variations in a single station's radio signal due to fading. Without AGC the sound emitted from an AM radio receiver would vary to an extreme extent from a weak to a strong signal; the AGC effectively reduces the volume if the signal is strong and raises it when it is weaker. In a typical receiver the AGC feedback control signal is usually taken from the detector stage and applied to control the gain of the IF or RF amplifier stages.

S Meter

An S meter or signal strength meter is an indicator often provided on communications receivers, such as amateur radio or shortwave broadcast receivers. The scale markings are derived from a system of reporting signal strength from S1 to S9 as part of the R-S-T system. The term S unit

refers to the amount of signal strength required to move an S meter indication from one marking to the next.

Analogue S meters are sensitive microammeters. The standard is that a reading of S9 corresponds to a 50 μV signal at the antenna input to the receiver.



Squelch

The receiver squelch is a circuit that acts to suppress the audio output of a receiver in the absence of a strong input signal. Squelch is used in two-way radios and VHF/UHF radio

scanners to eliminate the sound of noise when the radio is not receiving a desired transmission.

Limiter

A limiter is a circuit that allows signals below a specified input power or level to pass unaffected while attenuating (lowering) the peaks of stronger signals. Limiting is any process by which the amplitude of a signal is prevented from exceeding a predetermined value.

Limiters are common as a safety device in live sound and broadcast applications to prevent sudden volume peaks from occurring.

Desensitisation

Desensitisation or receiver blocking is a form of interference in a radio receiver that is unable to receive a weak radio signal that it might otherwise be able to receive. This is caused by a nearby transmitter with a strong signal on a close frequency, which overloads the receiver and makes it unable to fully receive the desired signal.

In a typical receiver, the Minimum Detectable Signal (MDS) level is determined by the thermal noise of its electronic components. When a signal is received, additional spurious signals are produced within the receiver because it is not truly a linear device. When these spurious signals have a power level that is less than the thermal noise power level, then the receiver is operating normally. When these spurious signals have a power level that is higher than the thermal noise floor, then the receiver is desensitised.

Blocking

Blocking is a condition in a receiver where an off-frequency signal (generally further off-frequency than the immediately adjacent channel) causes the signal of interest to be suppressed. Blocking rejection is the ability of a receiver to tolerate an off-frequency signal and avoid blocking. A good automatic gain control design is part of achieving good blocking rejection.

Intermodulation

Intermodulation (IM) or intermodulation distortion (IMD) is the amplitude modulation of signals containing two or more different frequencies. Intermodulation is caused by non-linear behaviour of the signal processing (physical equipment or even algorithms) being used.

Cross modulation

Cross-modulation is an effect in which amplitude modulation (AM) from a strong undesired signal is transferred to a weaker desired signal. A cross-modulation specification ≥ 100 dB would be considered decent performance. This figure is often not given for modern HF receivers, but if the

receiver has a good third-order intercept point, it is likely to also have good cross-modulation performance.

Reciprocal mixing [phase noise].

Reciprocal mixing occurs because of the phase noise which appears on all signals to a greater or lesser degree. The major problem for a receiver is that the phase noise spreads out either side of the local oscillator signal.

Phase noise consists of small random variations in the phase of the signal. These variations are effectively phase modulation and noise sidebands are generated. These spread out either side of the main signal and can be plotted on a spectrum analyser as single sideband phase noise.

Audio amplifier

An audio amplifier is a device that takes an audio signal and amplifies it so that your speakers can play the audio. A receiver includes an audio amplifier, but the receiver also has extra functionalities such as a tuner, preamp, input selection, volume controls, and more.

Low Noise Amplifier

A low-noise amplifier (LNA) is an amplifier that boosts very low-power signal without significantly degrading its signal-to-noise ratio (SNR). Any amplifier will increase the power of both the signal and the noise present at its input, but the amplifier will also introduce some additional noise. LNAs are designed to minimise that additional noise, by choosing special components, operating points, and circuit topologies. Minimising additional noise must balance with other design goals such as power gain and impedance matching. A typical LNA may supply a power gain of 100 (20 decibels (dB)) while decreasing the SNR by less than a factor of two (a 3 dB noise figure (NF)). Although LNAs are primarily concerned with weak signals that are just above the noise floor, they must also consider the presence of larger signals that cause intermodulation distortion.

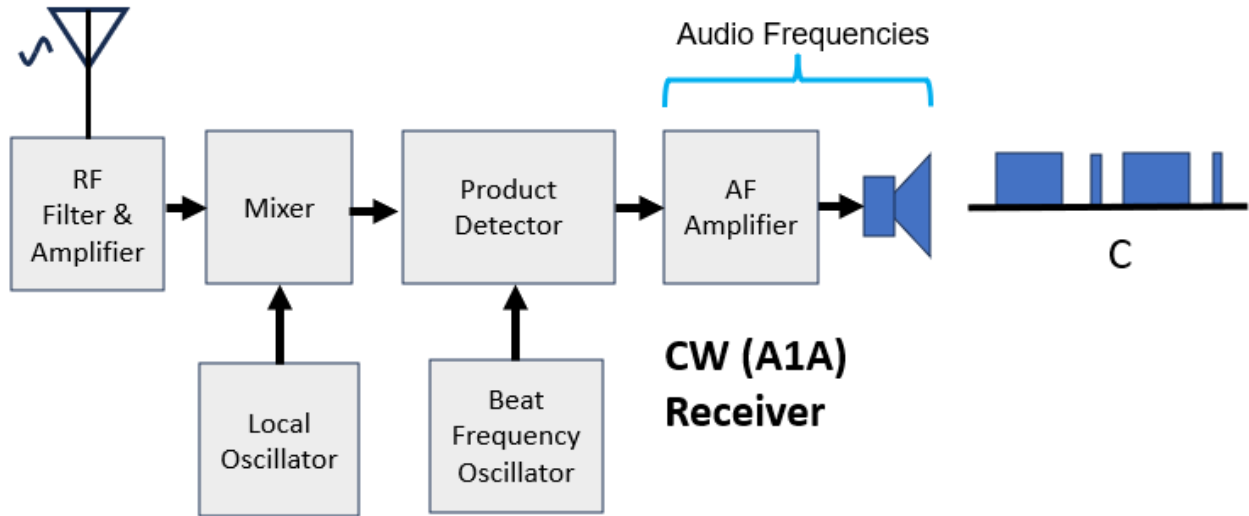
De-Emphasis

Pre-emphasis is undertaken in the transmitter and the de-emphasis is undertaken at the receiver. The purpose is to improve the signal-to-noise ratio for FM reception. A time constant of 75 μ s is specified in the RC or L/Z network for pre-emphasis and de-emphasis. De-emphasis performs the following functions.

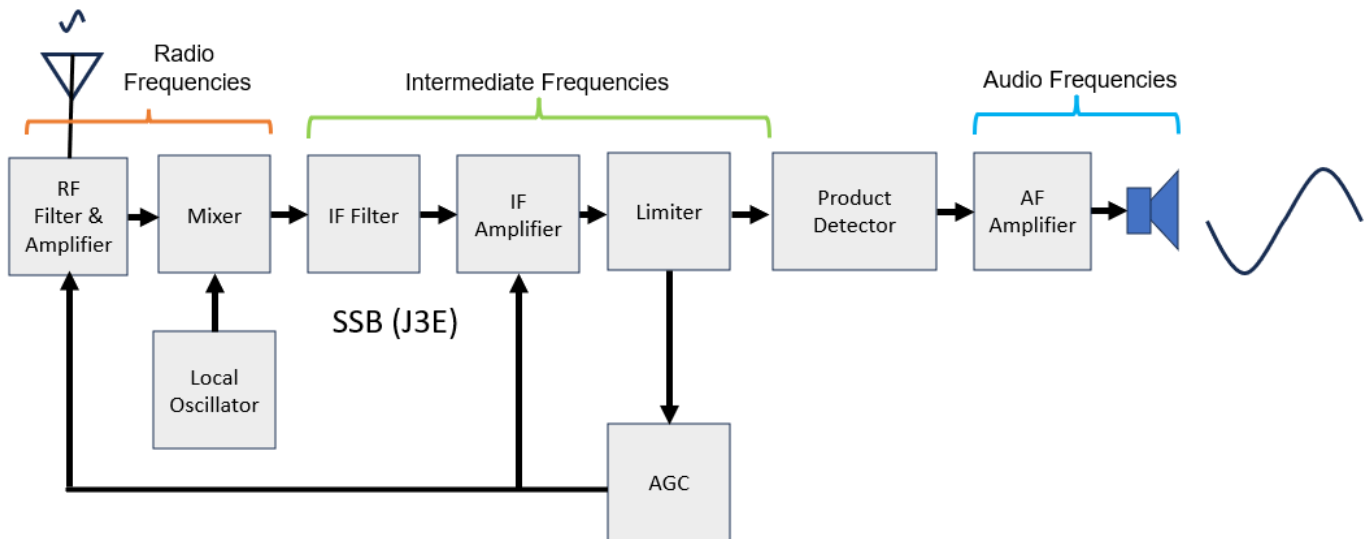
- Applies a low-pass filter to the received signal.
- Attenuates or reduces the boosted high frequencies.
- Rolls-off highs above 2-3 kHz
- Restores original frequency spectrum.
- Reduces noise and distortion picked up during transmission.

Receiver Block Diagrams

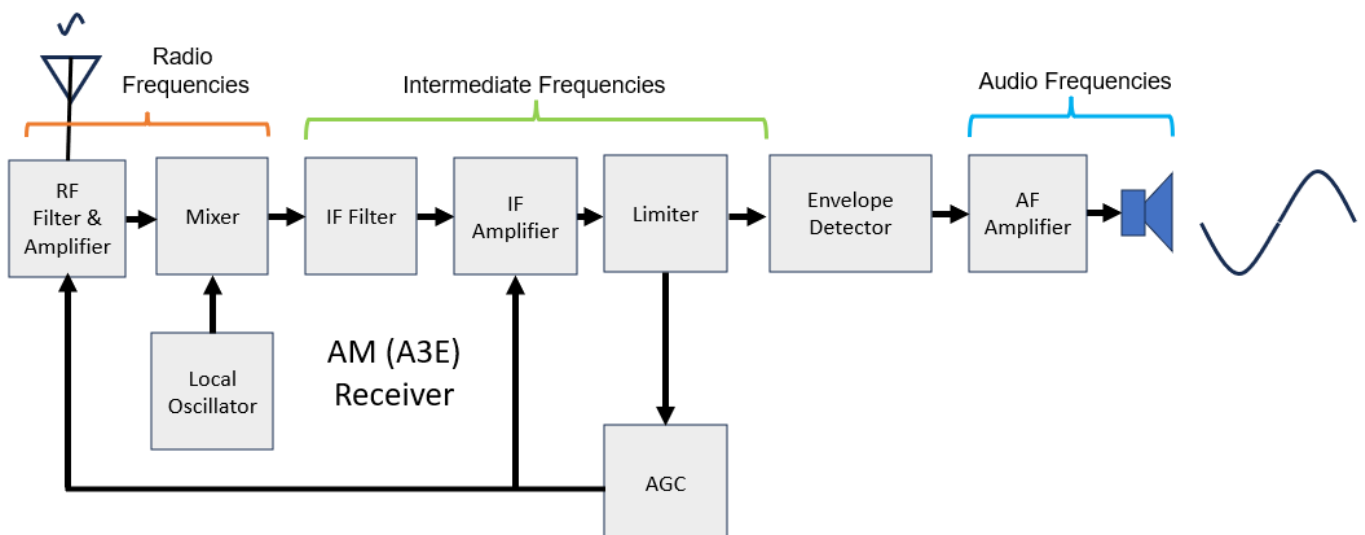
CW A1A



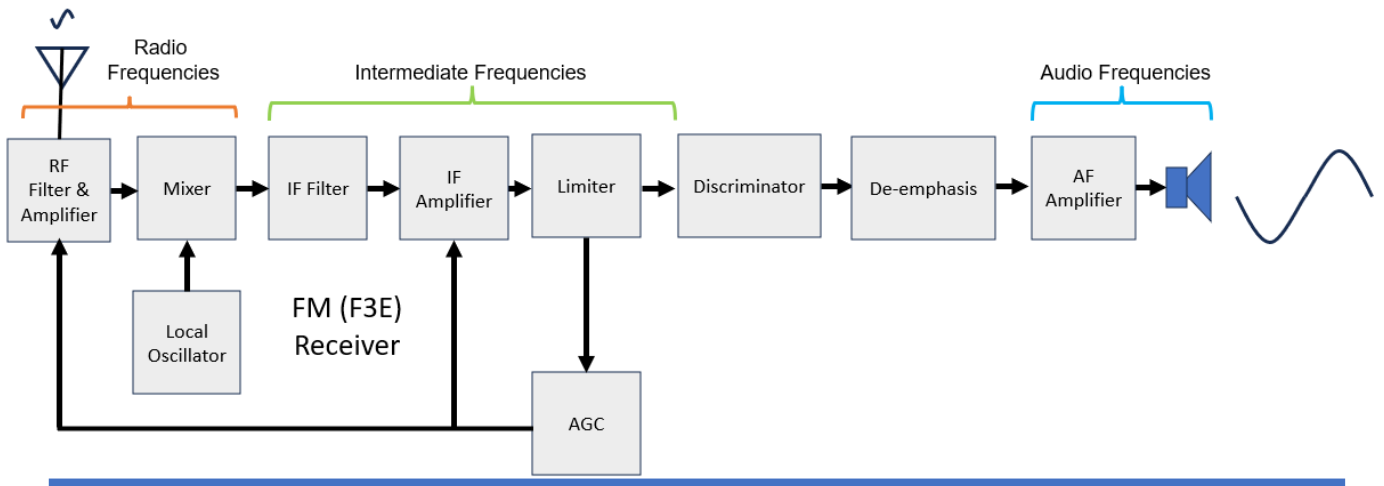
SSB (J3E)



AM (A3E) Receiver



FM [F3E] Receiver



Go to Lesson 12 Questions.



Build your own AM FM Receiver

I am not an agent for these radios, and I don't have any financial connection with the company, but I believe this would make a great learning tool.

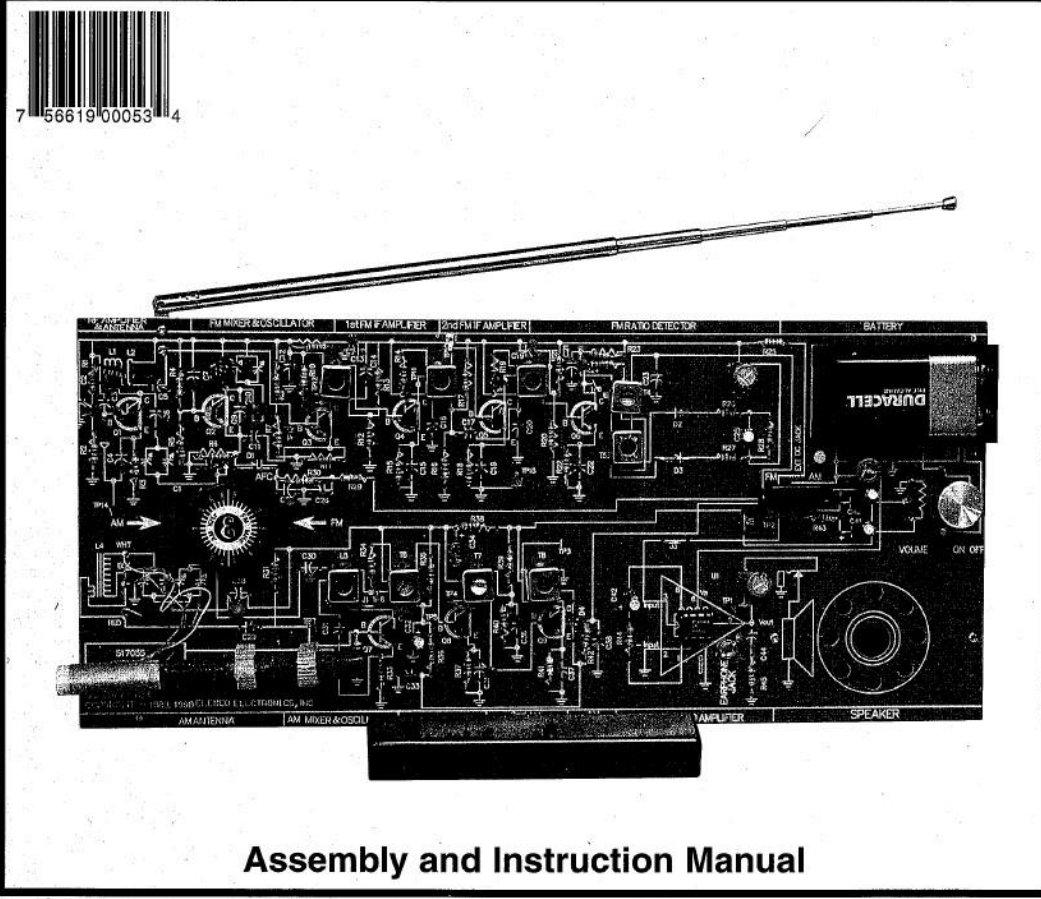
The reasons I like this kit are as follows.

- The construction manual is very comprehensive and explains the operation of each stage.
- Each step is well explained.
- The parts are numbered and easy to identify.

Worth a look.

MODEL AM/FM-108K

INTEGRAL CIRCUIT, 9 TRANSISTORS, 4 DIODES



7 56619 00053 4

Assembly and Instruction Manual

ELENCO®