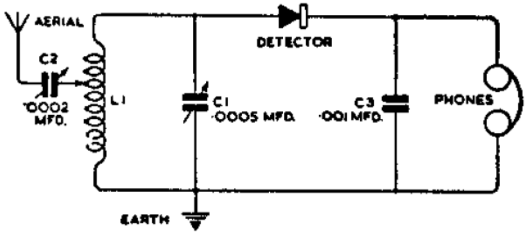
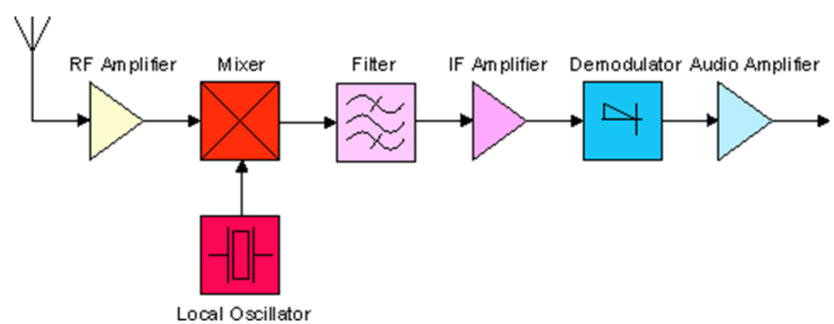


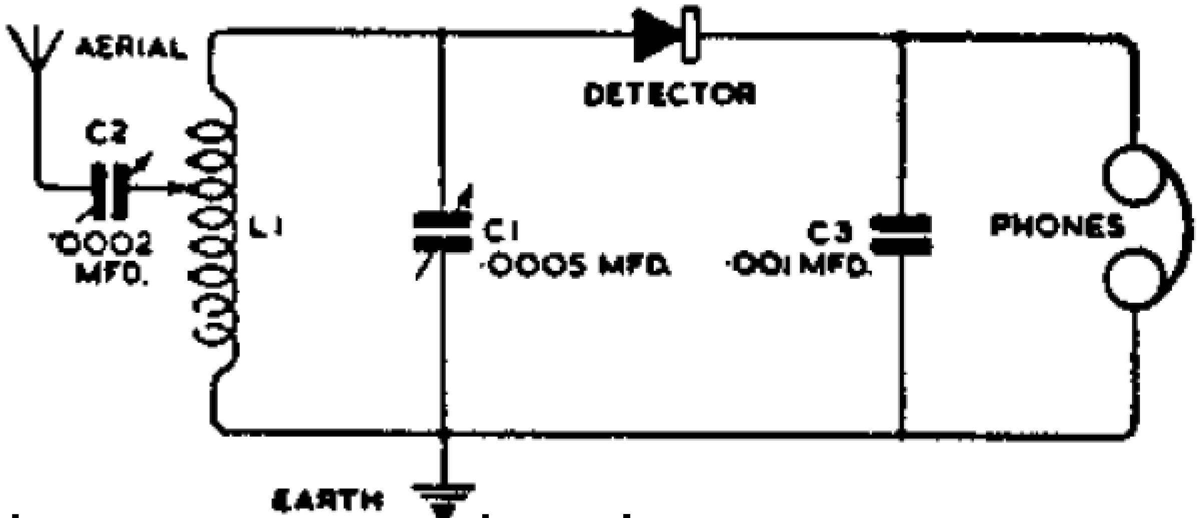
Receiver Basics



Author - Jack Tiley
AD7FO
Date – January 2011

The Simplest Receiver

The Crystal Set

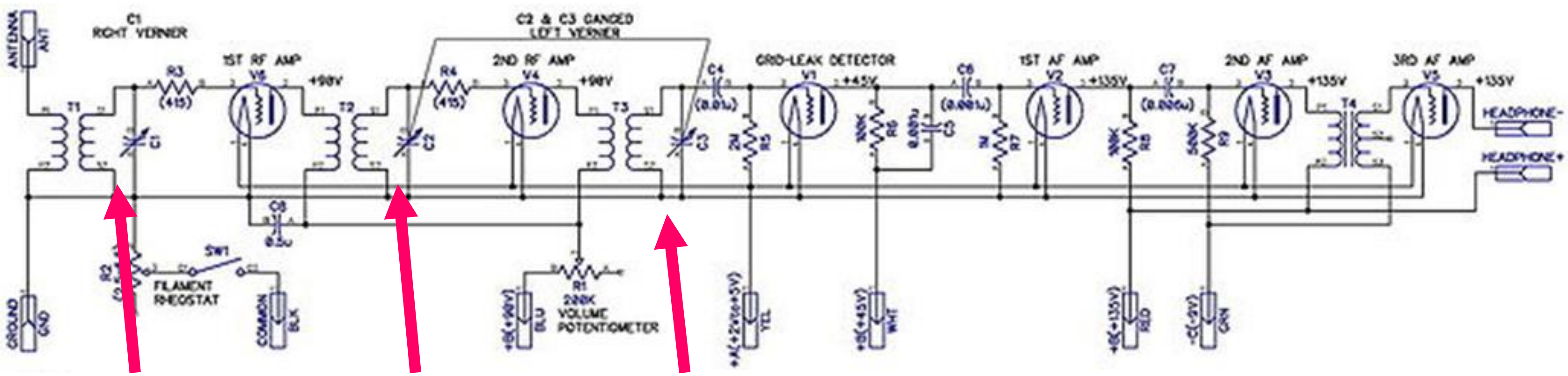


- Requires a strong signal
- Poor signal separation or selectivity
- Requires High Impedance Headset

Crystal Set Improvements

- Higher Q components for sharper tuning
- Audio amplifier instead of directly driving headphones (will also allow the use of low impedance headsets)
- A good Ground system
- A long antenna wire

Multiple Tuned RF Receiver



A TRF receiver includes multiple RF stages followed by circuits to detect and amplify the audio signal.   Generally, 2 or 3 RF Tuned RF Amplifiers are required to filter and amplify the received signal to a level sufficient to drive the detector stage.

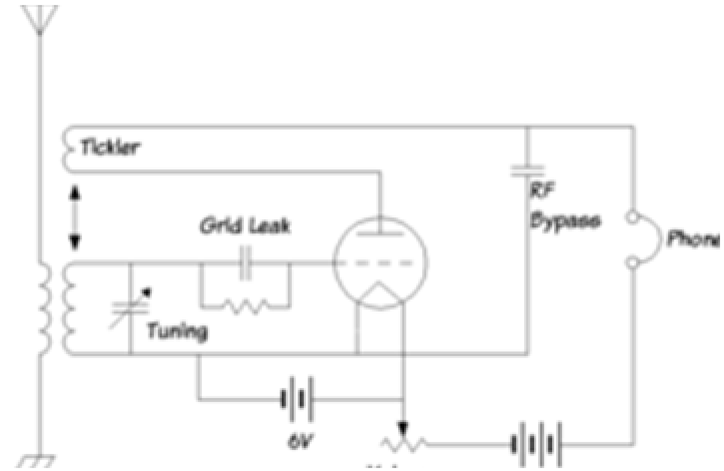
Prevalent in the early 20th century, it can be difficult to operate because each stage must be individually tuned to the station's Frequency.

TRF Receiver Limitations

- Requires careful RF tuning of multiple separate controls.
- Better but not good selectivity
- Sensitivity was poor requiring strong signals and a good antenna and ground system.

Super Regenerative Receivers

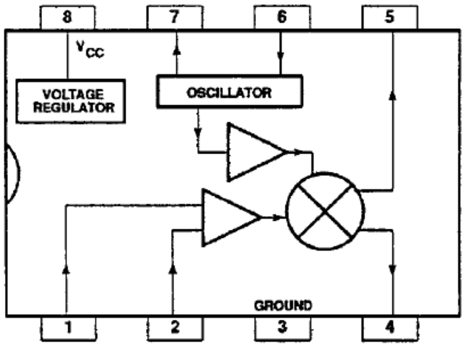
A Super regenerative circuit is a tuned amplifier with positive feedback sufficient to keep it at or near oscillation

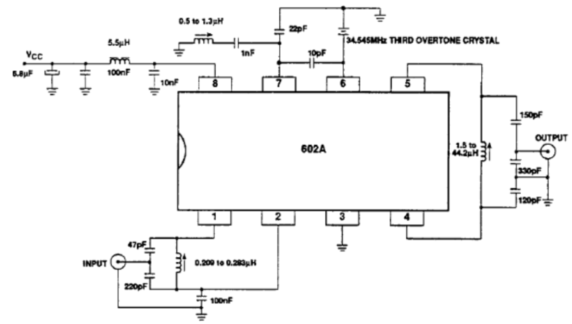


Their use of positive feedback builds up the input signal to very high levels greatly increasing both the selectivity and sensitivity of a simple receiver.

For AM signals, the detector is kept operating just below oscillation. For single sideband and the unmodulated RF used in Morse code reception, the circuit is operated at a level above oscillation to provide the necessary "beat note" (heterodyne).

Direct Conversion Receivers

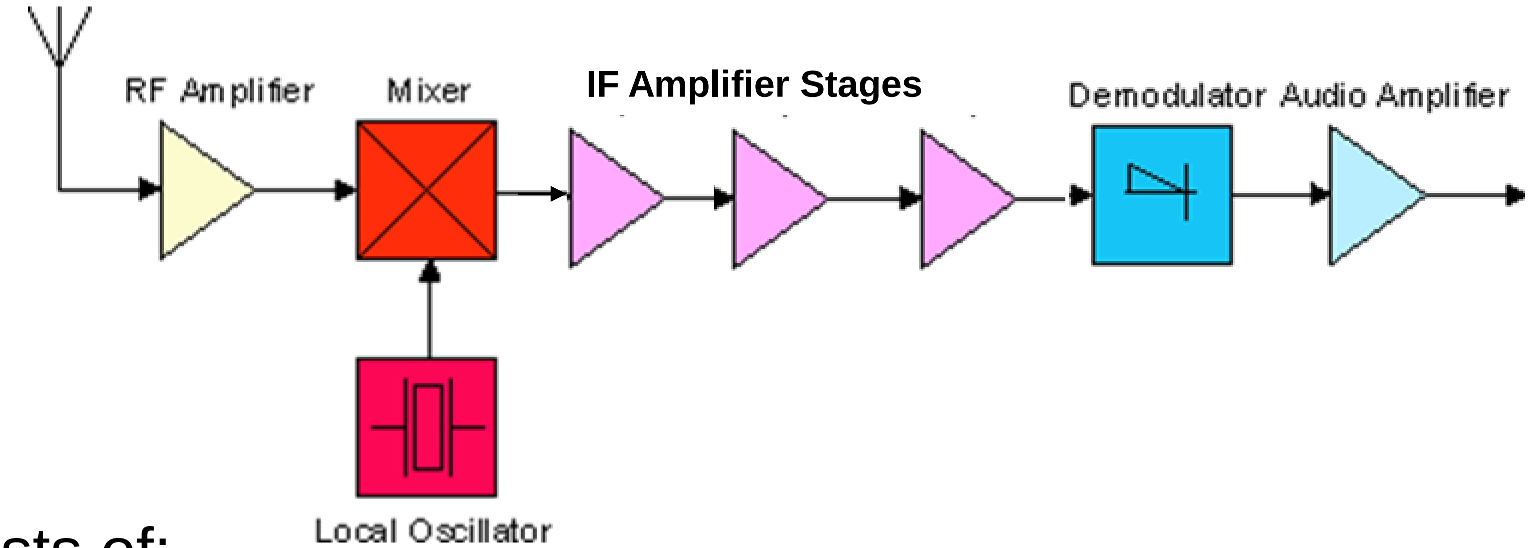




Direct conversion receivers convert the received RF signal directly to base band without IF amplifier stages. These receivers are capable of good sensitivity and require fewer parts. The stability of the local oscillator used for the down conversion process is important since any drift directly effects the output.

There a number of kits available to build direct conversion receivers.

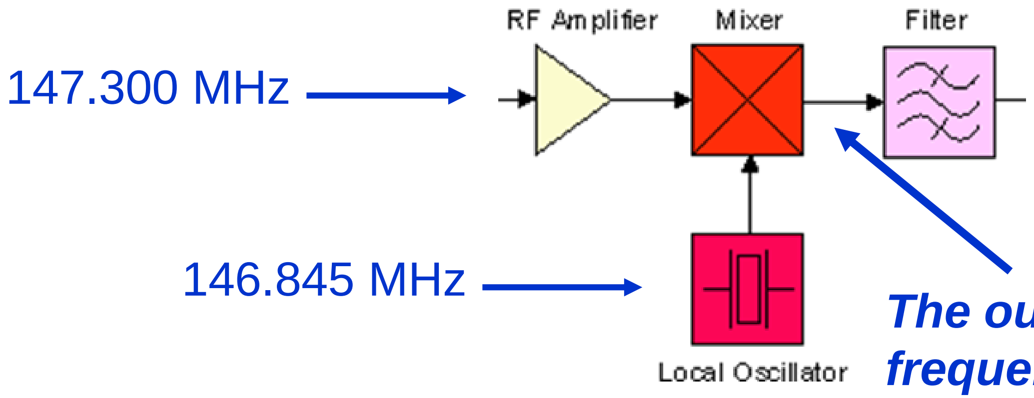
The Super Heterodyne Receiver



Consists of:

- An optional tuned or wide band low noise RF amplifier
- A mixer, and local oscillator that converts the incoming signal to a fixed intermediate Frequency
- A narrow band IF amplifier (multiple stages)
- A detector (AM, FM, CW) followed by an audio amplifier

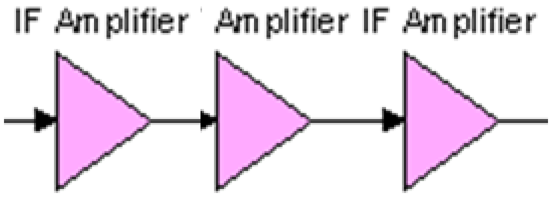
The RF Amp, Mixer and LO



The output of the mixer is the input frequency + and - the Local Oscillator frequency

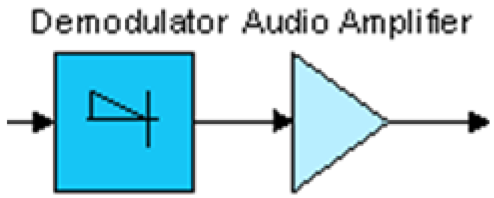
If the input frequency is 147.30 MHz and the Local oscillator frequency is 146.845 the IF filter input frequencies will be 147.30 -146.845 or 455KHz and 147.30 +146.845 or 294.145 MHz. The filter stage(s) following the mixer will reject the 294.145 MHz signal and pass the 455 KHz Signal

The IF Amplifier



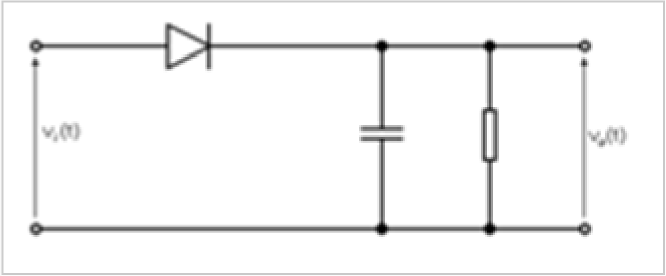
- The input and output of the IF amplifier will be the IF Frequency, typically, 455 KHz.
- The IF amplifier will have multiple tuned amplifier stages for a total of ~ 60 to 90 dB if gain.
- The advantage of the IF amplifier is that it is narrow band at a single frequency and once initially tuned there is no additional tuning needed.
- IF amplifiers can be designed with specific band widths and shape factors to allow separation of close adjacent signals.

The Demodulator and Audio Amplifier

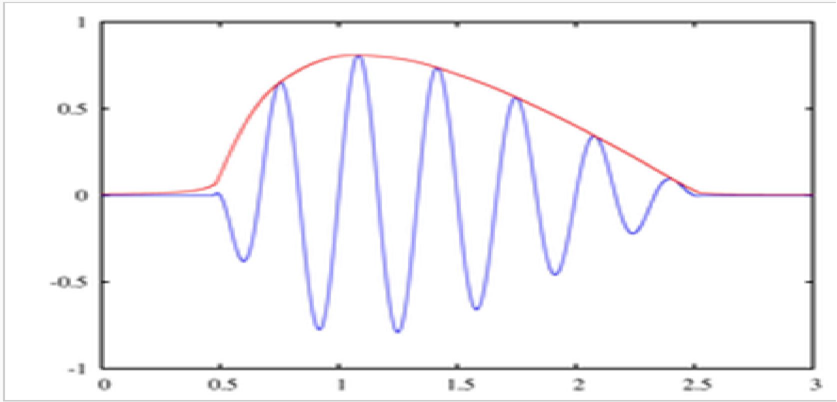


- The demodulator recovers the modulation information from the signal that was down converted to the IF.
- The demodulator can be an AM, FM, or SSB detector or mixed with a beat frequency oscillator for CW.
- The Audio amplifier increases the detected signal to a sufficient level to drive a speaker or headphones.
- In the audio amplifier circuitry is where we will find Squelch control, and CTCSS (tone) decoding.

AM Detectors



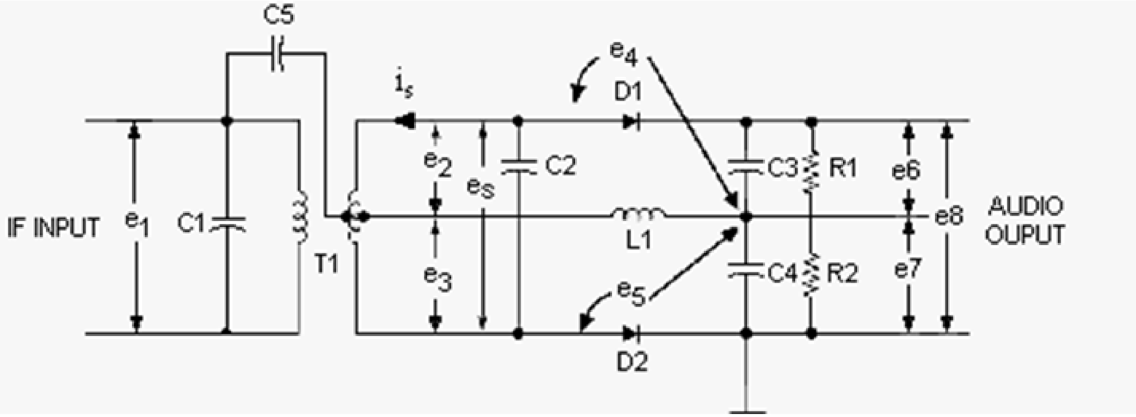
A simple envelope demodulator circuit.

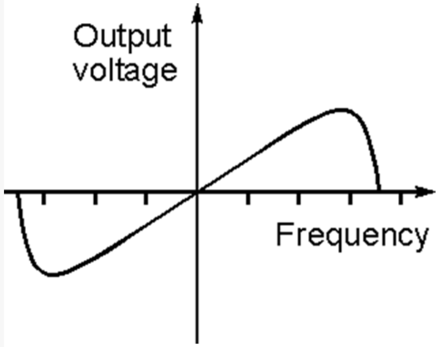


A signal in blue and the magnitude of its analytic signal in red, showing the envelope effect

- An AM detector is a simple diode and filter circuit that detects changes in the IF signal envelope level level that contains the information that was superimposed on the original transmitted carrier

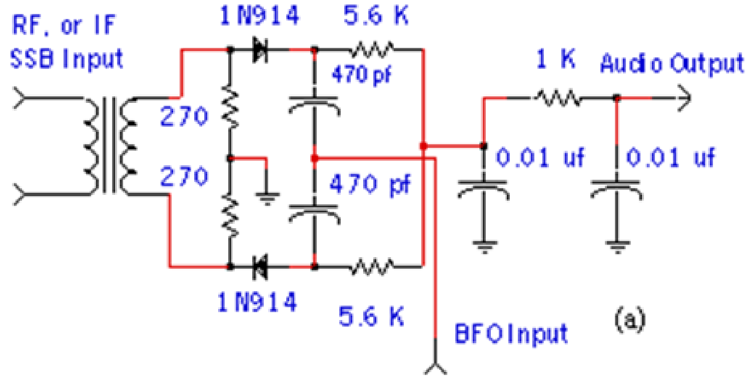
FM Demodulation





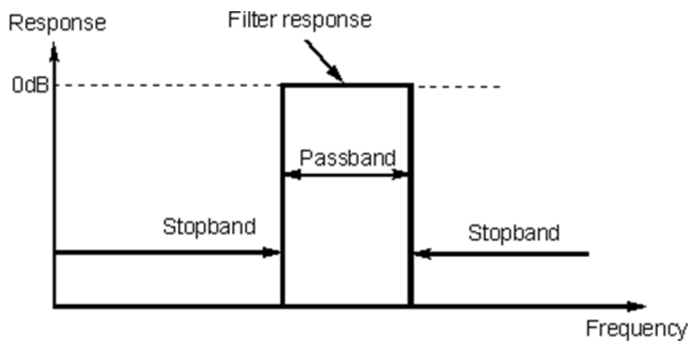
- The Circuit above is the commonly used Foster-Seely Discriminator used to demodulate FM Signals
- AM detectors can demodulate FM signals if they are tuned slightly off frequency.
- Today the commonly available phase lock loop circuits on a chip are used to demodulate FM Signals

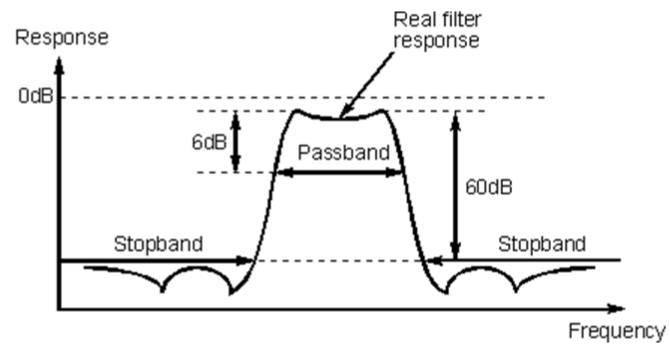
SSB Product Detectors

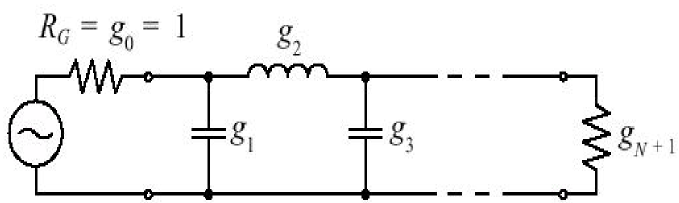


- A product detector is used to detect SSB signals. The BFO Input is used to regenerate the reference carrier that was removed in the SSB Generation process at the transmitter.
- This circuit can also be used to demodulate CW signals.

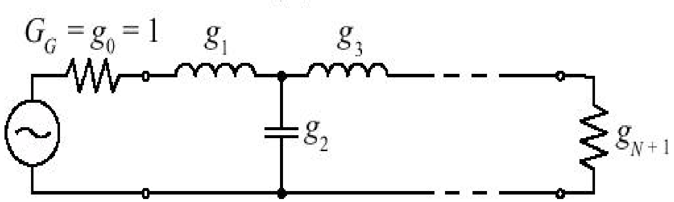
Filters


Response
Filter response
0dB
Passband
Stopband
Stopband
Frequency

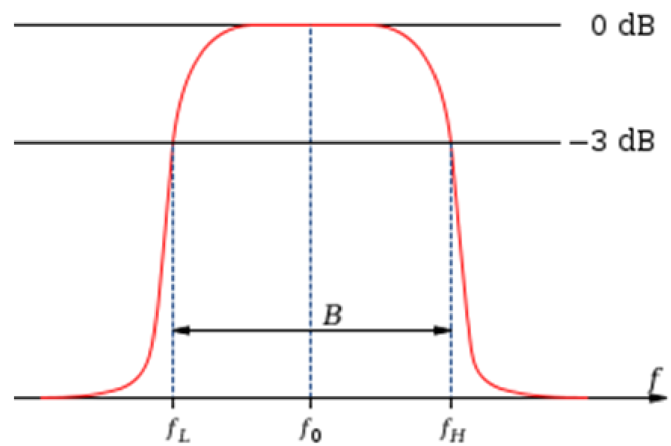

Response
Real filter
response
0dB
6dB
Passband
60dB
Stopband
Stopband
Frequency


$R_G = g_0 = 1$
g_2
g_1
g_3
g_{N+1}

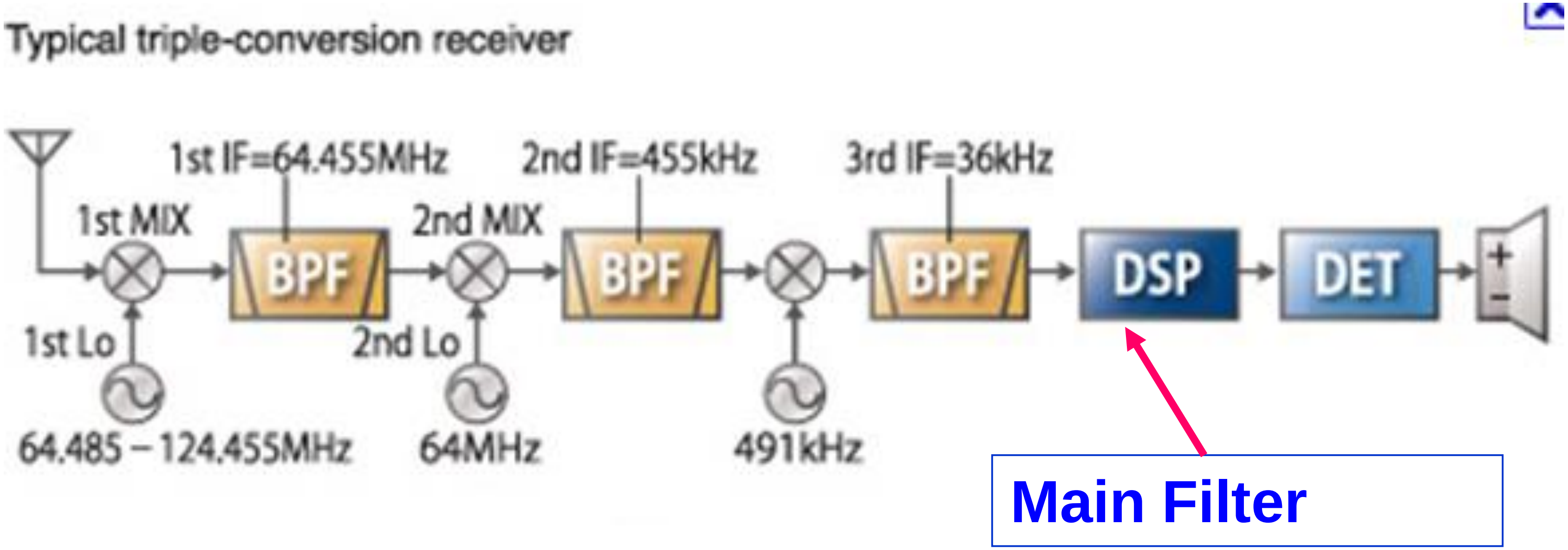
(a)


$G_G = g_0 = 1$
g_1
g_3
g_2
g_{N+1}

(b)

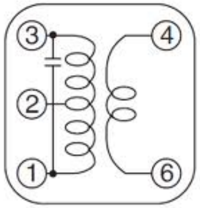

0 dB
−3 dB
B
f
f_L
f_0
f_H

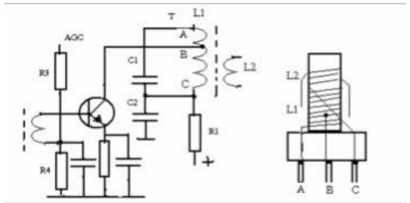
Filters In The Receiver



The main filter is found after two or possibly three conversion stages. These are the filters that provide the high selectivity for voice, and CW operation. These are frequently high cost options to the receiver.

Simple LC IF Filters



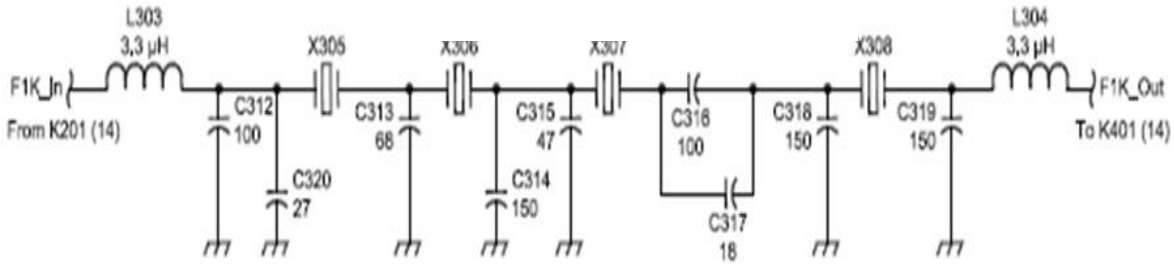


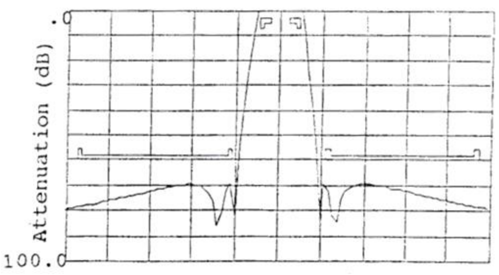
The simplest type of RF filter is an ordinary L-C tuned circuit. In many older radio receivers using discrete amplifying elements (transistors or tubes), take the form of transformers that couple the individual stages in an IF amplifier chain.

Often there are two or three stages with tuned circuits that make it possible to achieve sufficient selectivity for a medium wave AM or VHF FM broadcast radio.

For a good quality communications receiver it is rarely possible to be able to achieve the required degree of selectivity using just L-C filters.

Crystal Filters



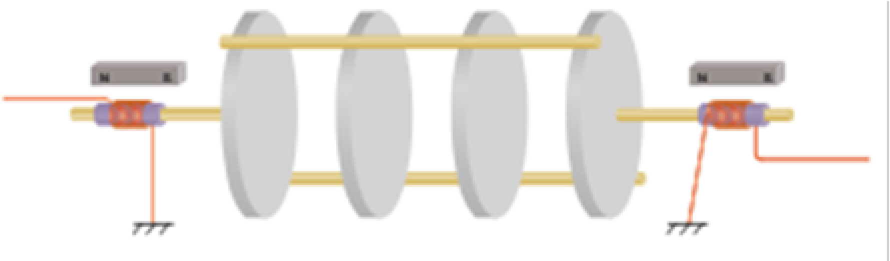


- Crystal filters provide the main selectivity in of most of today's high performance communications radio receivers   These crystal filters provide high degrees of selectivity.
- The crystals in the RF filters are made from a substance called quartz.   Originally natural deposits were used to manufacture the crystals but today quartz crystals are grown synthetically under controlled conditions.
- The crystals use the piezo-electric effect for their operation. This effect converts a mechanical stress into a voltage and vice versa.

Mechanical Filters

When high performance filters are needed there is another type which can be considered, mechanical filters. They are still in use but not nearly as popular as crystal filters these days. The Collins Radio Company (now Rockwell Collins) was one of the first manufacturers of these devices, introducing their first designs in 1952.

Mechanical Filters



- In essence mechanical filter operation is very similar to that of a crystal, At either end of the filter assembly there are transducers which convert the signals from their electrical form to mechanical vibrations, and back again at the other end. These vibrations are applied to a series of discs which are mechanically resonant at the required frequency.
- Operation of these mechanical filters is normally confined to frequencies between about 50 kHz and 500 kHz.
- one of their main mechanical filter advantages is that exceedingly narrow bandwidths can be achieved relatively easily,

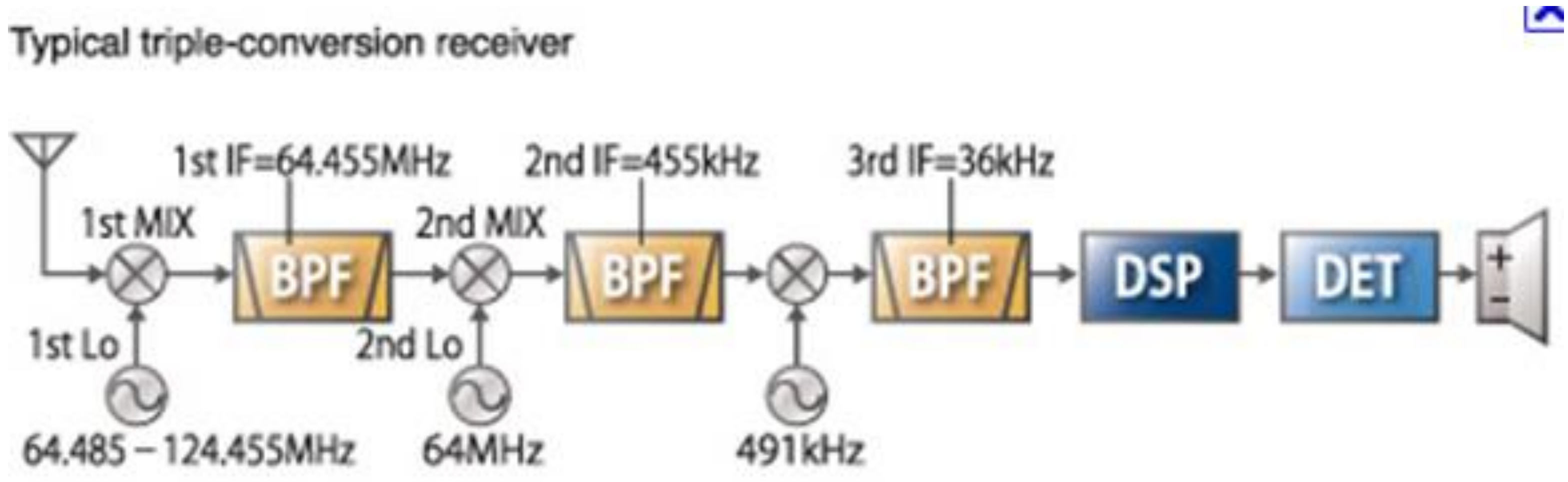
Ceramic Filters

- Quartz is not the only substance to exhibit the piezo-electric effect combined with a sharp resonance. A number of ceramics are also used successfully to perform this function.
- Ceramic filters are made from a specialized family of ceramics, and the elements for filters are normally in the form of a small disc. They operate in exactly the same way as crystal filters, the signal being linked to the mechanical resonances by the piezo-electric effect.
- Generally ceramic filters have a much wider bandwidth and a poorer shape factor than their crystal counterparts.

Monolithic Filters

- With more items being integrated onto single chips these days it is hardly surprising to find that a similar approach is being adopted for crystal filters.
- Instead of having several separate or discrete crystals in an RF filter is possible to put a complete filter onto a single quartz crystal, hence the name monolithic crystal filter.

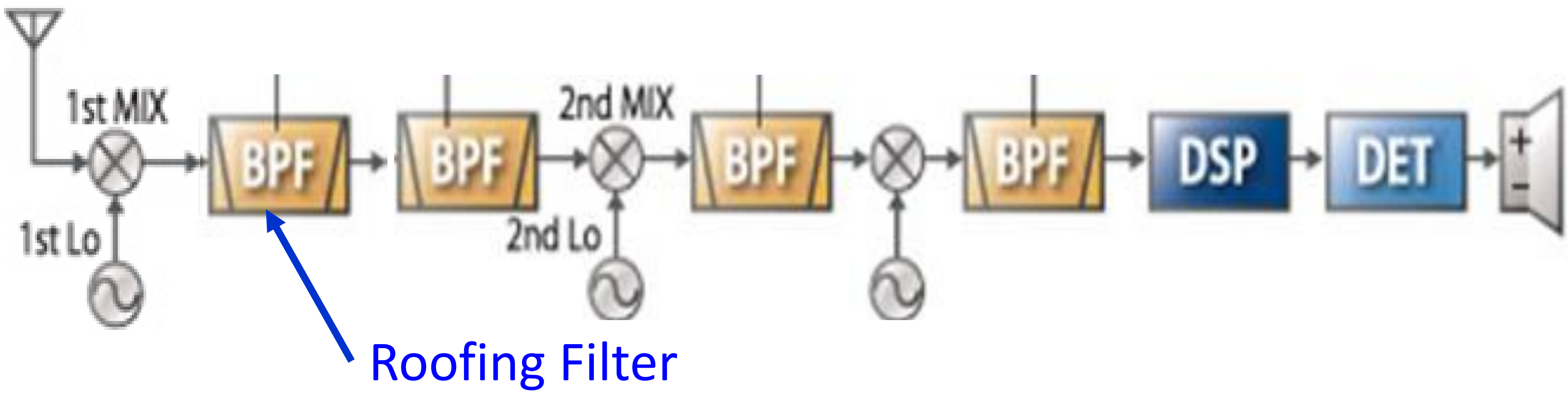
Roofing Filters



A strong signal which is outside the pass-band of the main receiver filter can cause overloading especially in the early IF stages before the main filter.

To overcome this problem a wider bandwidth filter (Roofing Filter) is placed early in the first IF stages to reduce the level of any strong off channel signals.

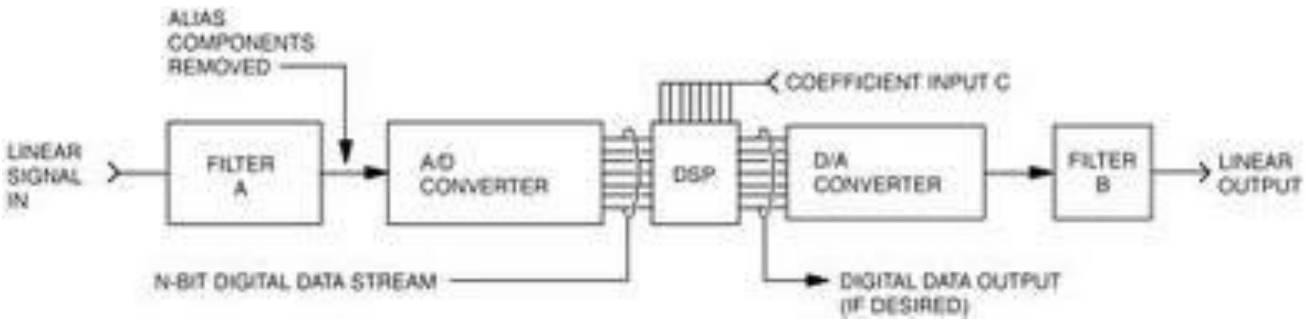
Roofing Filters

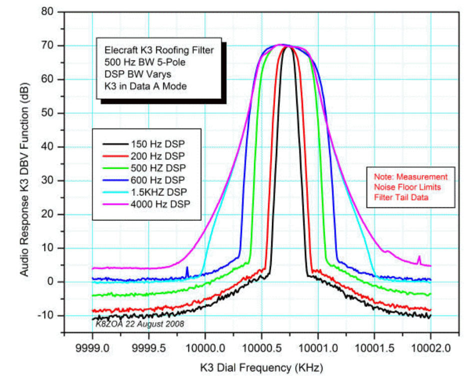


Roofing filters are often found soon after the first mixer to reduce the effects of any strong off-channel signals in multi-conversion superheterodyne receivers.

The main filter is Usually found after two or possibly three conversion stages.

DSP Filtering





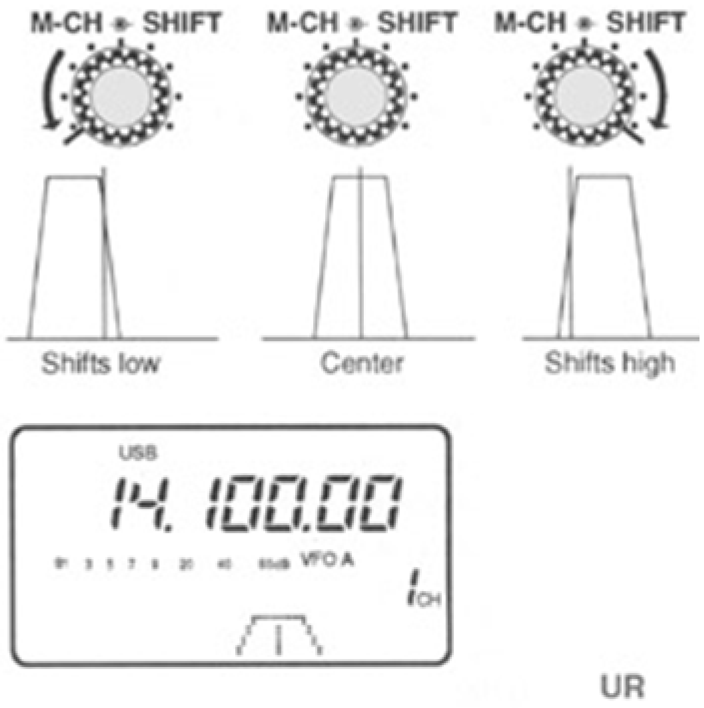
- Based on combining ever increasing computer processing speed with higher sample rate processors, Digital Signal Processors (DSP’s) continue to receive a great deal of attention in new product design.

- By utilizing DSP’s capable of sequencing and reproducing hundreds to thousands of discrete elements, they can simulate large hardware structures at relatively low cost.

IF Shift

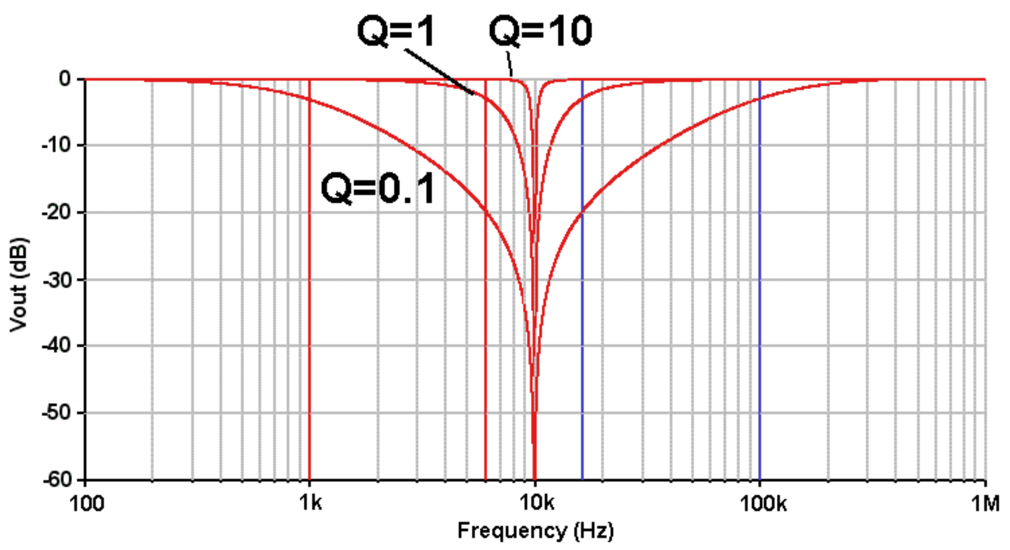
- IF SHIFT - This shifts the center of the receiver’s pass band.

- Shifting the IF allows you to avoid a signal that is close to yours by not letting it in the “window” of the receiver’s pass band.



Notch Filters

This is another good filter for reducing nearby interference. Unlike a window, it acts like a cover and blocks the signal that is in your receive window.

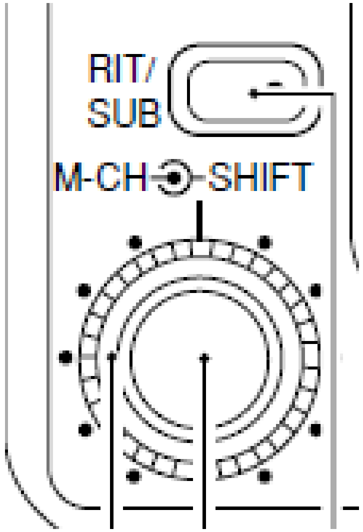


Impulse Noise Filters/Blanking

Noise Blanking refers to the process of eliminating repetitive, pulse-type noise from a received signal. "Noise Blankers" became popular due to interference caused by the "Russian Woodpecker" on the HF bands during the 70s and 80s; this was a kind of radar that sounded like a woodpecker when received by a shortwave radio. Noise blanking can also help to remove noise caused by an automobile engine, and other, similar interference.

Receive Incremental Tuning

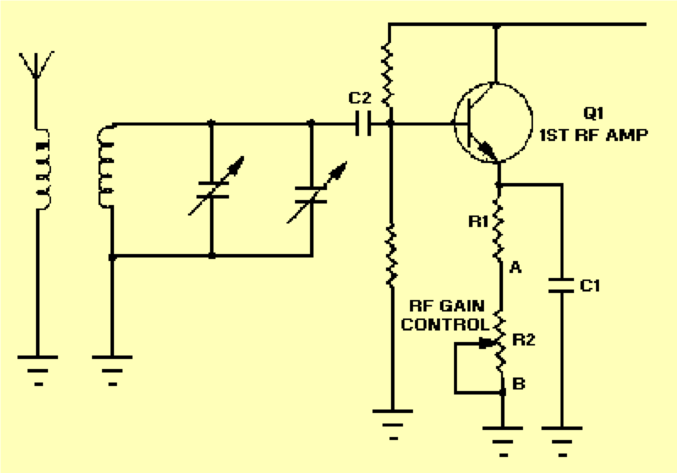
- **RIT –** This stands for Receive Incremental Tuning and is used to fine tune a station you are listening to without changing your transmit frequency. This is sometimes called a Clarifier.



RF Gain

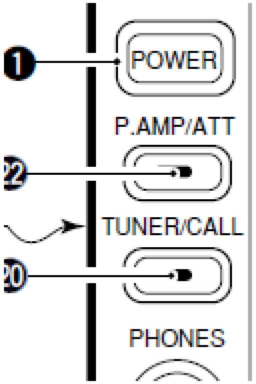
RF GAIN – This allows adjusting the fgront end gain gain of the receiver amplifier circuits.

This allows you to make the receiver less sensitive by 10 to 20 dB so that you can reduce the level of really strong signals to prevent receiver overload.



Receiver Preamp/Attenuator

- Attenuator - A fixed attenuator in front of the receiver to prevent overload when receiving strong local signals.
- Pre amplifier – a fixed gain amplifier in front of the receiver to increase sensitivity for receiving weak signals



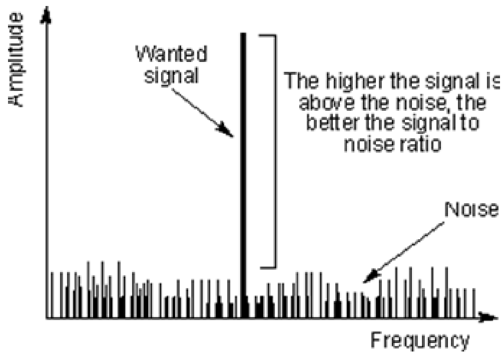
Measuring Receiver Sensitivity

- Receiver sensitivity is one of the important specifications for any radio receiver
- The key factor in determining the sensitivity performance of the whole receiver is the RF amplifier. By optimizing its performance, the performance of the whole of the receiver can be improved.

Signal to Noise Ratio

There are a number of ways in which the noise performance, and hence the sensitivity of a radio receiver can be measured.

The most obvious method is to compare the signal and noise levels for a known signal level, i.e. the signal to noise (S/N) ratio or SNR. Obviously the greater the difference between the signal and the unwanted noise, i.e. the greater the S/N ratio, the better the radio receiver performance.

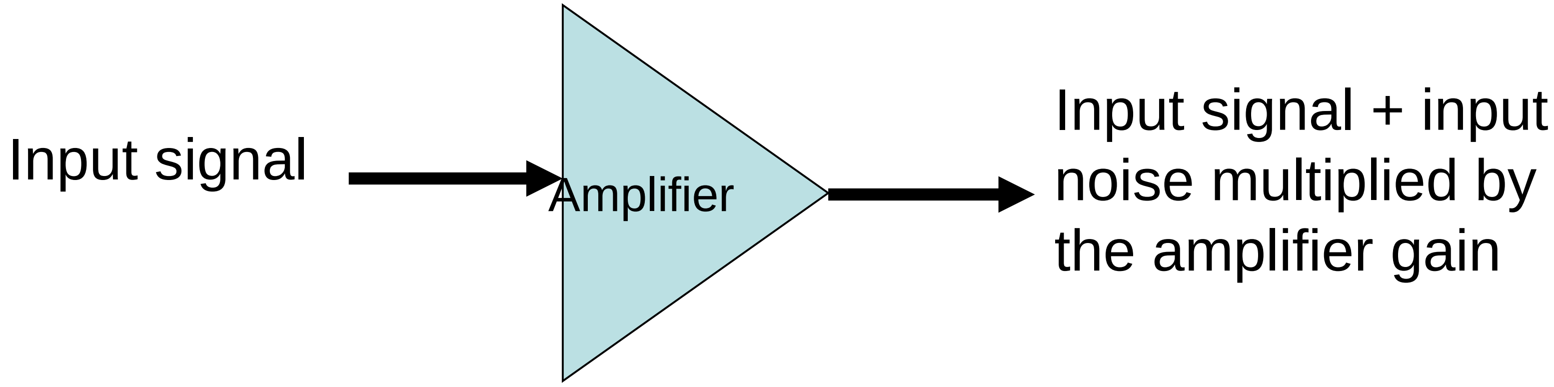


Sensitivity would be expressed as what level of input would give a specific S/N ratio.

Example: 1µV for 10dB signal to noise

Noise figure

The noise floor is the theoretical minimum signal that can be heard. In reality since the signal must be amplified the and the amplifier adds its own noise the minimum level will be greater than the noise floor. The measure of added noise is expressed as the noise figure of the receiver. Since the added noise is small only the contribution of the first or second stage of the receiver contribute to the overall receiver noise figure.



Noise Floor

Every component generates RF noise!!!

While noise can emanate from many sources, when looking purely at the receiver, the noise power is dependent upon the temperature, and bandwidth. The minimum equivalent input noise for the receiver can be calculated from the following formula:

Noise Power = k T B

Where:
P is the power in watts
K is Boltzmann's constant (1.38 x 10^-23 J/K)
B is the bandwidth in Hertz
T is temperature in degrees Kelvin

Using this formula it is possible to determine that the minimum equivalent input noise for a receiver with a 1 Hz bandwidth at room temperature (290K) is -174 dBm therefore the best sensitivity possible for a 2 m/70 cm FM receiver is ~ -132 dBm or .056µV. Most radios have sensitivities around .1µV.

SINAD Sensitivity

SINAD stands for Signal-to-noise and distortion ratio. It is a measure of the quality of a signal from a communications device, defined as:

$$\text{SINAD} = \frac{\text{Signal Power} + \text{Noise Power} + \text{Distortion Power}}{\text{Noise Power} + \text{Distortion power}}$$

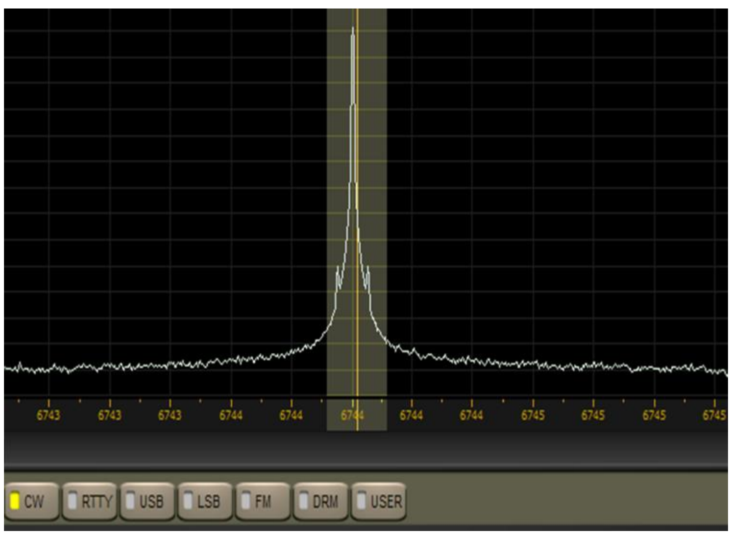
SINAD is the primary way of specifying sensitivity for VHF and UHF FM radios

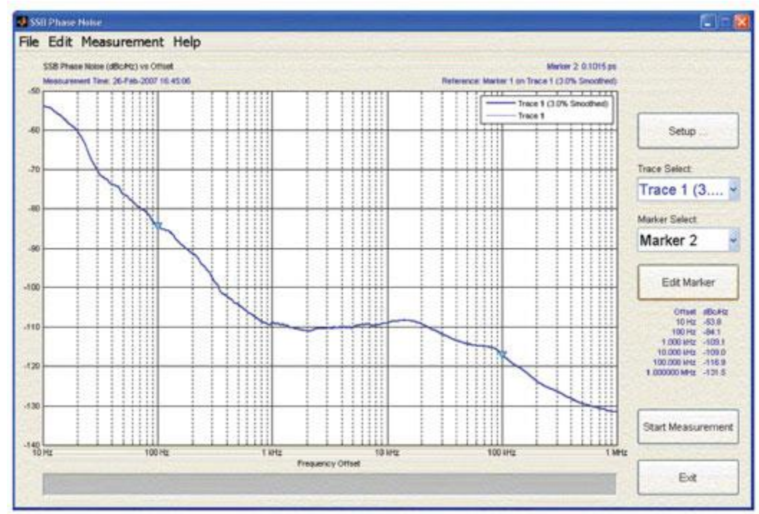
Example:

A receiver would have a sensitivity of .15 µV for 12 dB SINAD

Phase Noise

Phase noise is the Frequency Domain representation of rapid, short-term, random fluctuations in the phase of a signal, caused by time domain instabilities. Generally speaking, this is refered to this as the phase noise of an oscillator

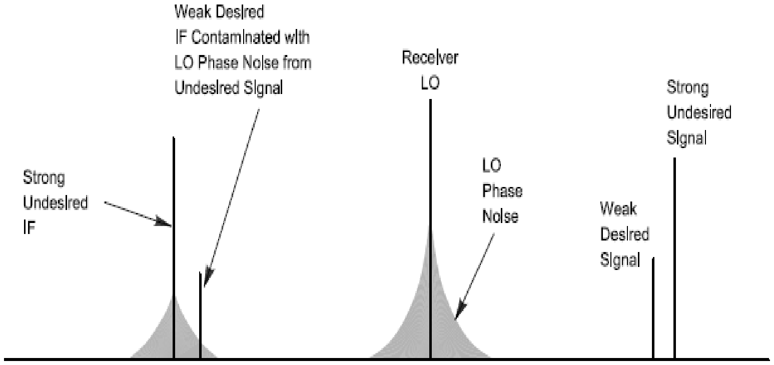




The Effect of LO Phase Noise

Superheterodyne receivers use one or more local oscillators to convert an input frequency to an intermediate frequency before the signal is demodulated. In the ideal receiver, these frequency conversions would not add any noise or distortion to the received signal.   A local oscillator with significant phase noise will limit the receiver’s ability to recover the weaker close in signals.

The local oscillator phase noise cannot be decreased except by improving the performance of the oscillator.



Questions?