Superheterodyne Receiver Tutorial

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1 ABSTRACT

This paper discusses the basic design concepts of the Superheterodyne receiver in both single and double conversion forms, together with potential problems associated with each architecture.

2 INTRODUCTION

This tutorial will describe a simple receiver architecture based on the super-heterodyne method of frequency translation.

A simple receiver could consist of an RF amplifier, band-pass filter and some form of demodulator. There is however a problem with this scheme in that the band-pass filter needs to be (1) Very narrow) and (2) tuneable.

We only want a single carrier and so the filter needs to be wide enough to allow the carrier (and it's associated modulation side-bands) to pass through the filter whilst rejecting everything else. Secondly the narrow filter has to be tuneable over the frequencies of interest.
This is a very difficult requirement especially if the wanted signal is very high frequency.

A possible solution to this problem is to use the super-heterodyne receiver.

3 SUPERHETERODYNE RECEIVER

In a superheterodyne (superhet) receiver the RF is filtered through a wideband bandpass filter to a mixer. Also feeding the mixer is a local oscillator that is tuneable and differs from the input RF signal by a fixed amount – known as the Intermediate frequency (IF).

Therefore, to tune for a particular input signal the Local Oscillator (LO) is tuned accordingly. As the output of the mixer will always be the fixed IF frequency then highly selective fixed low-frequency IF filters can be used.

The bock diagram of the superhet is shown in **Figure 1**.

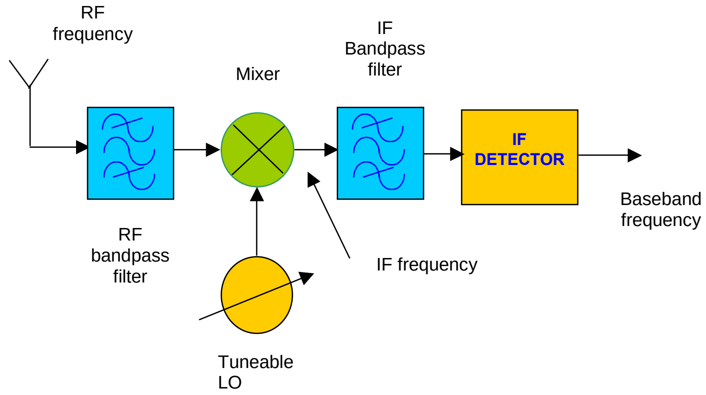

Figure 1 Basic single conversion superheterodyne receiver

The IF signal is generated by mixing the RF (**ω_{RF}**) with a single LO (**ω_{LO}**) carrier as shown by the equation below:

$$V_{IF} = V_{LO}\cos\varpi_{LO}.t * V_{RF}\cos\varpi_{RF}.t$$

This multiplication will produce two products the sum of the frequencies and the difference in frequencies ie the IF frequency we want:

$$V_{IF} =$$

$$\frac{V_{LO}.V_{RF}}{2}\left(\cos\left[(\varpi_{LO} - \varpi_{RF}.) - \phi\right] + \cos\left[(\varpi_{LO} + \varpi_{RF}.) + \phi\right]\right)$$

The IF filters will only select the wanted difference frequency (IF=LO-RF) and reject the much higher sum frequency (RF+LO).

The diagram shown in **Error! Reference source not found.** shows graphically the frequencies produced as a result of the mixing process:

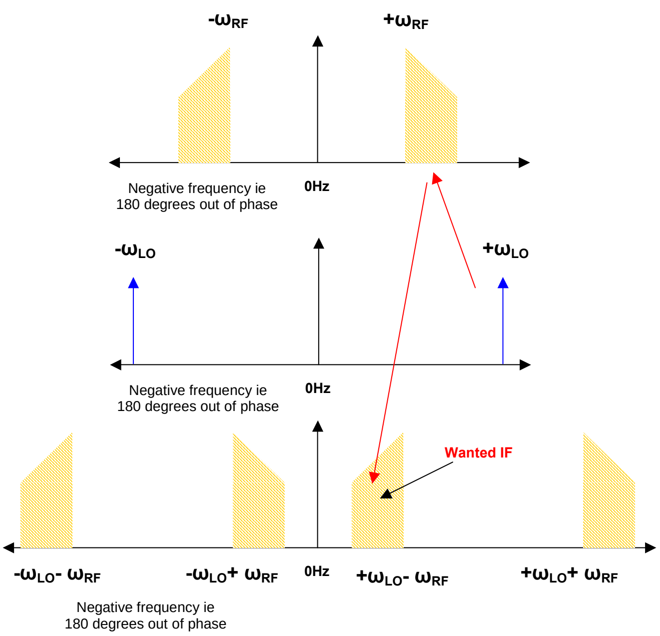

Figure 2 Frequencies produced in the superhet as a result of the mixing process.

It is important to note that the frequency band is reversed after mixing ie the highest RF signal becomes the lowest IF and the lowest RF signal becomes the highest IF. This frequency translation is also shown in **Error! Reference source not found.**, by the shaped passbands.

The wanted IF will be the ϖ_{LO} - ϖ_{RF} passband as indicated, therefore a bandpass filter will be used to select this frequency band and reject all other frequencies.

4 SUPERHET PROBLEMS

Assuming there is no filtering at the front end of the receiver then not only will the LO mix with the wanted RF to form an IF but also will mix with a RF frequency 2 IF's above the wanted as shown in Error! Reference source not found.

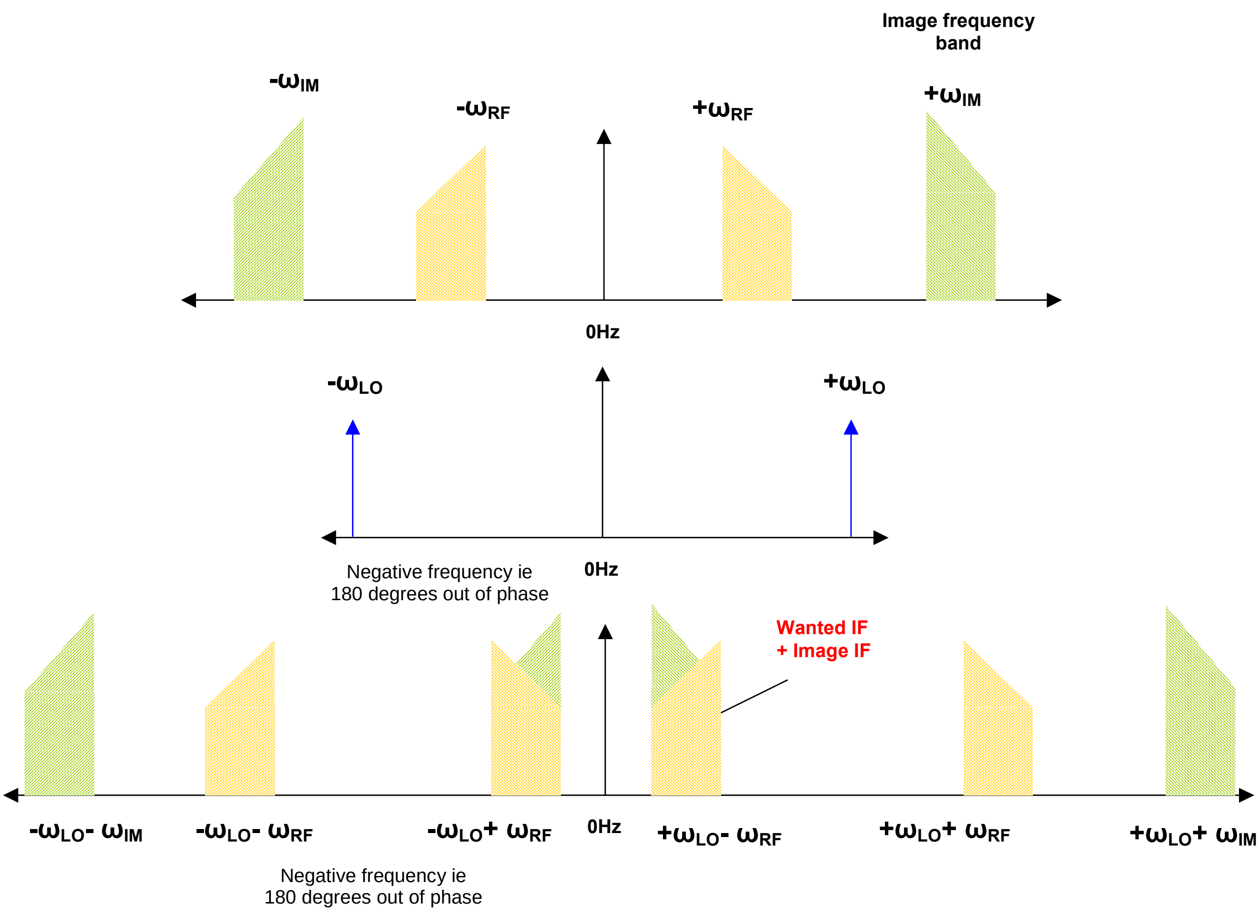

Figure 3 Shows shows the translation of the image band onto the IF band. This will result in RF noise or other unwanted signals at the RF image frequency being added to the IF and could increase the noise figure of the receiver by 3dB.

Figure 3 shows that not only the wanted RF is translated to IF but also the image frequency that will be 2 * IF higher in frequency than the wanted RF signal.

Even without any signal at this image frequency the channel noise will still be translated resulting in a **3**dB increase in the noise figure of the receiver.

Therefore, it is normal to include a band-pass filter at the front end of the receiver to filter out any unwanted signal or noise from the image band. It is always an advantage to make the IF frequency as high as possible to simplify the design of the input band-pass filter. On the other hand it is more difficult to design a very narrow bandpass filter for the IF section if the centre frequency is high.

The LO frequency can be above or below the wanted RF signal band.
When the LO is higher than the RF this is known as ***high side rejection.***

This has an advantage on the design of the LO, for example assume that we have a receiver with a 200MHz IF , a RF bandwidth is 100MHz @ 1300MHz and the LO is set to 1500MHz. This would yield the required IF of 200MHz and the tuning bandwidth ratio of the LO would be (100/1500)*100% = 6%.

If we picked the LO to give ***low side rejection,*** then we would pick the LO to be 200MHz **below** the RF at 1100MHz.

In this case although the LO is at at lower frequency the percentage tuning bandwidth will increase to (100/1100) * 100% = 9%.

As a general rule it much easier to design a high frequency narrow tuning band oscillator than a lower frequency wider tuning band one.

A second advantage of ***high side rejection*** is that the image filter can be a low pass design which is easier to design than a high pass filter.

5 DUAL CONVERSION (DOUBLE SUPERHETERODYNE RECEIVER)

The previous discussion argued that the receiver design of the IF filter is simplified if the center frequency is low but this will reduce the difference between the wanted RF band and the Image band necessitating in the design of a narrow band RF filter which could be difficult.

There would appear to be a design conflict.

This conflict however, can be solved by having more than one frequency conversion typically two – hence the dual conversion term.

This receiver will use two IF frequencies but most importantly allows for a low final IF (for easier filter design) but also a large first IF two separate the RF wanted and Image bands to allow use of a simpler RF band pass filter at the front end.

The simplified block diagram of the dual conversion superhet receiver is shown in **Figure 4**.

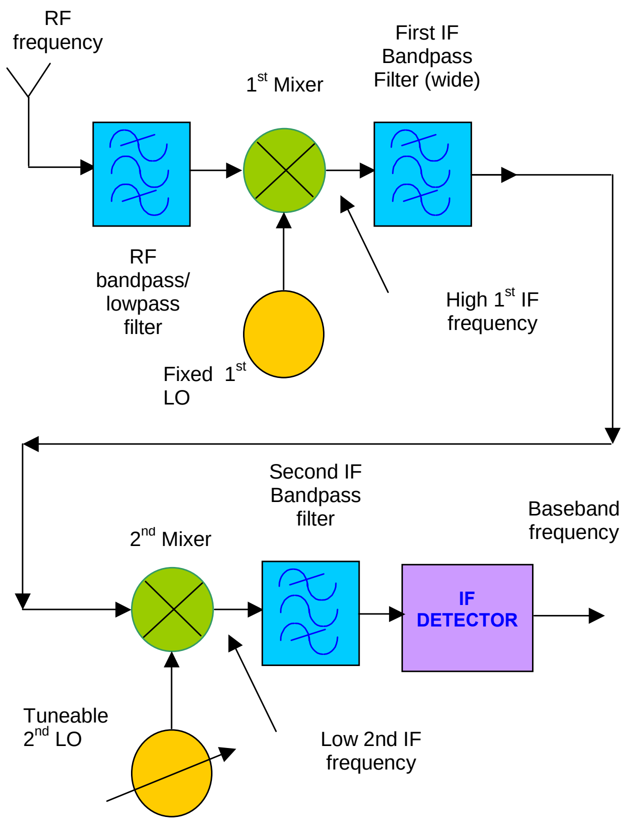

Figure 4 Basic dual conversion superheterodyne receiver. Note to further improve performance (by eliminating unwanted spurious signals from the mixers) filters can be added between the LO's and their associated mixers.

In some applications instead of the difference frequency being used at the first IF the sum frequencies are used. This will make the IF frequency a lot higher (and greatly increases the image separation making design of the second IF filter easier) and if a tunable 1st LO is used it will have a lower percentage tuning bandwidth.

Example: A terrestrial TV tuning receiver is designed to cover the RF frequency range of 45 to 860MHz, with channel spacings of 8MHz and an IF of 40MHz.

(1) Downconverting at 1st IF.

Using high-sided rejection the required LO will be:

85MHz to 900MHz a tuning ratio of (~1:10) ie

LO-RF → 85MHz – 45MHz = 40MHz

LO-RF → 900MHz – 860MHz = 40MHz

The resulting images frequencies are:

Image-LO → 125MHz - 85MHz = 40MHz

Image-LO → 940MHz - 900MHz = 40MHz

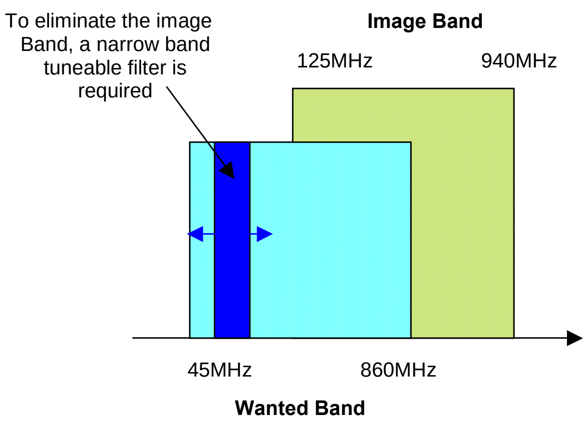

Figure 5 Wanted RF band and resulting image band of the downconverting receiver solution, showing how the image and RF bands overlap requiring the use of a tunable front-end filter.

The diagram of **Figure 5** shows the position of the image and wanted RF bands. A substantial amount of the image pass-band will overlap the wanted RF band requiring a tunable narrow-band front-end filter.

(2) Upconverting at 1st IF

Lets pick an IF frequency of say 1.5GHz. then the required LO will be:

640MHz to 1455MHz a tuning ratio of (~1:2)

LO+RF → 1455MHz + 45MHz = 1500MHz

LO+RF → 640MHz + 860MHz = 1500MHz

The resulting images frequencies are:

IM-LO→ 2955 -1455MHz = 1500MHz

IM-LO → 2140MHz - 640MHz = 1500MHz

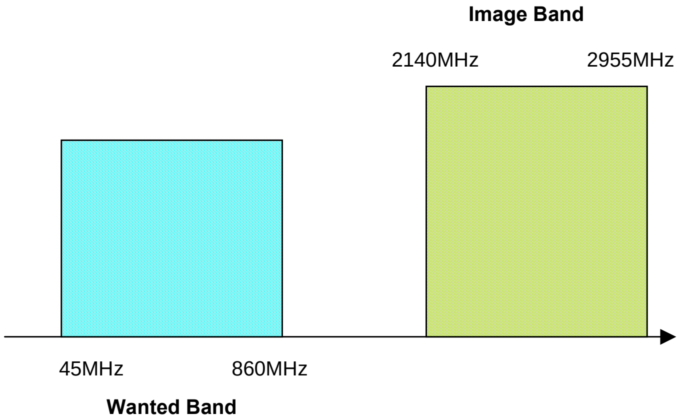

Figure 6 Wanted RF band and resulting image band of the upconverting receiver solution, showing how the image and RF bands are now well spaced from each other.

The diagram of **Figure 6** shows the position of the image and wanted RF bands Now we see that the wanted and image bands are very well separated and in this situation there is no need for an image reject filter.

However without a filter at the input the front-end LNA (Low Noise Amplifier) will be subject to possibly large out of band signals that may degrade the front end or overload it. Therefore, the use of this scheme requires a high linearity front-end.

6 CONCLUSION

This paper was written to give a brief overview of the superheterodyne receiver architecture in both the single and dual conversion variants. Discussion was given to the problem with image frequencies degrading the noise performance of the receiver and ways to improve the image performance, by the use of up-converting to higher intermediate frequencies.

Further tutorials will discuss the Direct Conversion (DC) receiver so popular with systems on a chip design and better (but more complicated) ways of eliminating the image response problem associated with superhets.