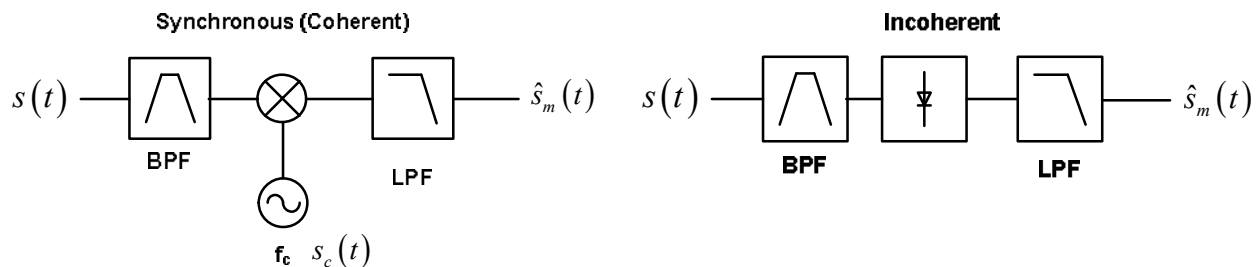


Superheterodyne Radio Receivers

Thus far in the course, we have investigated two types of receivers for AM signals (shown below): coherent and incoherent. Because broadcast transmissions never occur in isolation (i.e., lots of people want to transmit simultaneously), the only way our receivers can recover information from our desired station is via the use of a tunable Bandpass Filter (BPF) before the detector stage. The BPF must have a bandwidth narrow enough to select our desired station and reject all others.

AM Receiver Architectures



Commercial AM Radio in the US

Frequency Range: 535 – 1705 kHz
 Station Bandwidth: 10 kHz
 Maximum Audio Frequency: 5 kHz
 Carrier Spacing: 20 kHz

Consider the following problem. The table above lists the specifications for commercial AM radio in the US. To tune into any given station, the receiver has to have a bandpass filter with a bandwidth equal to the bandwidth of the transmitted signal.

Let's look at the bandwidth of the filter as a percentage of the carrier frequency. In the worst case:

$$\%BW = \frac{BW}{f_c} = \frac{10 \text{ kHz}}{1700 \text{ kHz}} = 5.9\%$$

We can also define something called the “Quality Factor” of the filter, also known as the “Q” of the filter:

$$Q \approx \frac{f_c}{BW} = \frac{1700 \text{ kHz}}{10 \text{ kHz}} = 170$$

Note that $\%BW$ and Q are basically inverses of each other.

What's the problem? The problem is that $Q \gg 10$ is extremely hard to achieve. The problem will be much worse as we get to higher center frequencies (FM @ 100 MHz; Cellular @ 1-2 GHz; Satellite @ 10-30 GHz).

The solution: We need a way to shift our RF signal to a lower frequency, where it is much easier to implement a BPF that will reject all other stations. That process is called Heterodyning.

Heterodyning

In 1918, Edwin Armstrong invented the idea of a Heterodyne receiver. **Heterodyning** is the translation of a signal from a higher **Radio Frequency (RF)** carrier signal to a lower **Intermediate Frequency (IF)**.

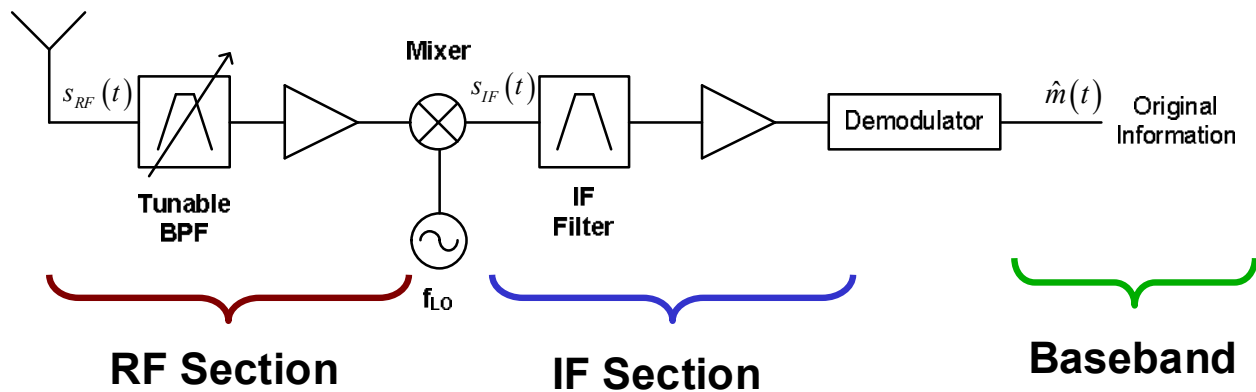
Three Important Frequencies in Heterodyne RX

RF **Radio Frequency**. The center frequency the signal is broadcast on.

IF **Intermediate Frequency**. Fixed frequency inside the RX. The RF signal is downconverted to this frequency.

LO **Local Oscillator**. Tunable frequency inside the RX used to translate the RF signal to the IF frequency.

Structure of the Superheterodyne Receiver



The superheterodyne receiver works by making use of the frequency translation properties of the Fourier Transform:

$$f_{LO} = f_{RF} \pm f_{IF}$$

High Side Injection: $f_{LO} = f_{RF} + f_{IF}$

Low Side Injection: $f_{LO} = f_{RF} - f_{IF}$

Mathematically we can show what happens with a simple AM signal:

$$s_{RF}(t) = [A + \mu m(t)] \cos(2\pi f_c t)$$

Using Low-Side Injection, after mixing, we have:

$$s_{IF}(t) = s_{RF}(t) s_{LO}(t)$$

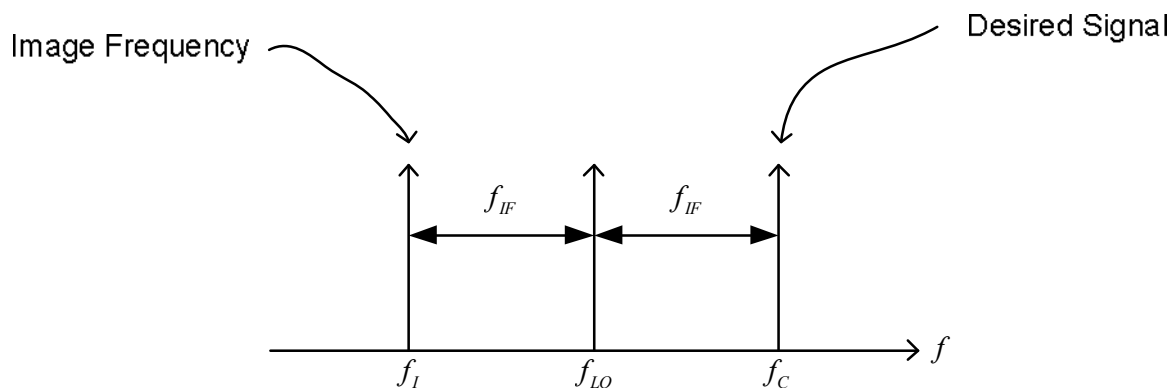
$$s_{IF}(t) = (A[1 + \mu m(t)] \cos(2\pi f_c t)) (\cos(2\pi f_{LO} t))$$

$$s_{IF}(t) = \frac{A}{2} [1 + \mu m(t)] [\cos(2\pi (f_c + f_{LO}) t) + \cos(2\pi (f_c - f_{LO}) t)]$$

Note: $f_c + f_{LO}$ will be rejected by the IF BPF Filter

$f_c - f_{LO}$ will be our IF Frequency

But... $f_{LO} = f_{RF} \pm f_{IF}$. We presumed a -, what happens for a + ?

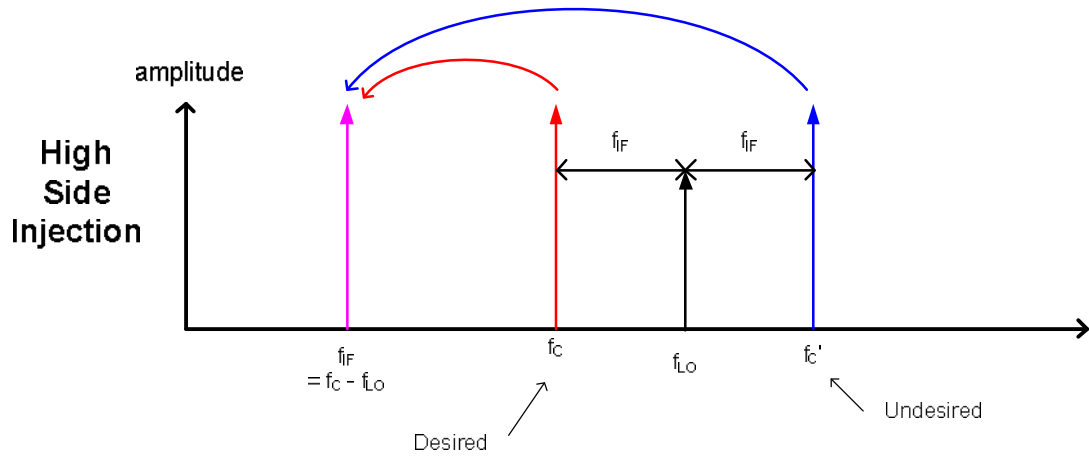
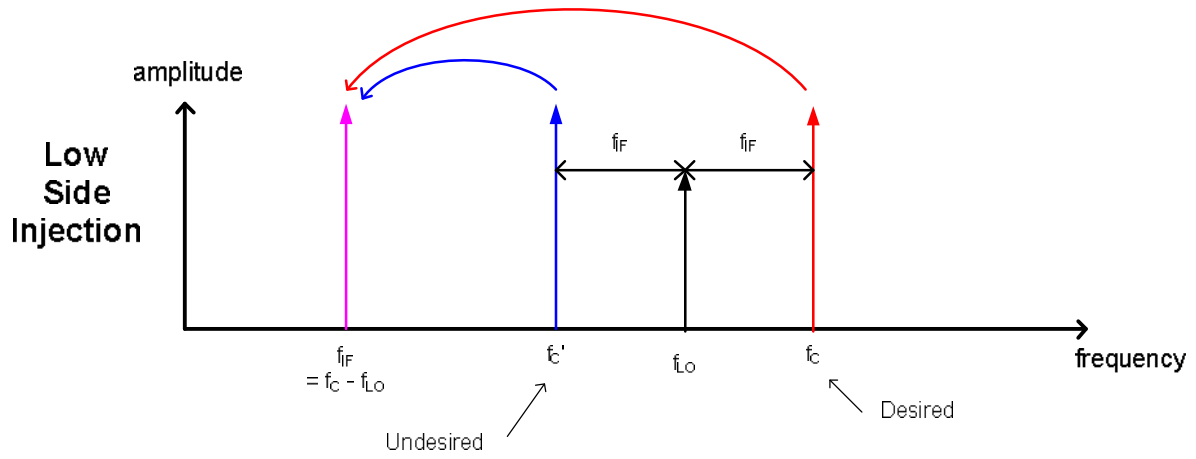


Note That:

- Heterodyning doesn't select **one** frequency, it selects **two**.
- The two frequencies are mirrored about the LO, hence the term **Image Frequency**.
- The primary purpose of the **RF filter** is to reject any signal that might be present on the image frequency.

See the figure on the next page for a graphical illustration of the image frequency problem with superheterodyne receivers.

Illustration of the Image Frequency Problem with Low/High Side Injection



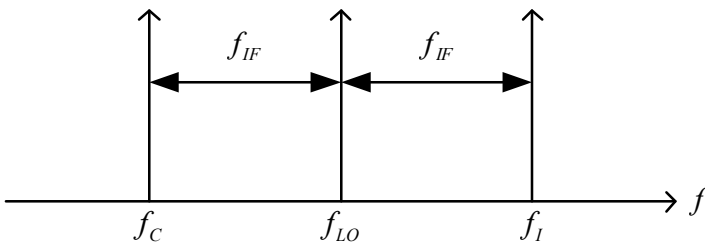
Superheterodyne Example

Broadcast AM, $f_c = 540 \text{ kHz}$

For High-Side Injection, determine the LO Frequency:

$$\begin{aligned} f_{LO} &= f_{RF} + f_{IF} \\ f_{LO} &= 540 \text{ kHz} + 455 \text{ kHz} \\ f_{LO} &= 995 \text{ kHz} \end{aligned}$$

Now determine the Image Frequency (easiest way to keep the bookkeeping straight is to draw a picture):



$$\begin{aligned} f_I &= f_{LO} + f_{IF} \\ f_{LO} &= 995 \text{ kHz} + 455 \text{ kHz} \\ f_{LO} &= 1450 \text{ kHz} \end{aligned}$$

1450 kHz is an In-Band Station!

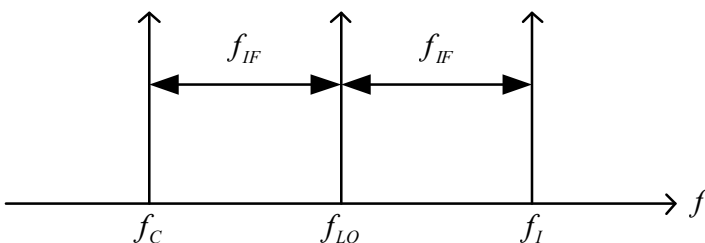
Note: Always mirrored about LO

Now, take the same radio and tune to 1450 kHz

For High-Side Injection, determine the LO Frequency:

$$\begin{aligned} f_{LO} &= f_{RF} + f_{IF} \\ f_{LO} &= 1450 \text{ kHz} + 455 \text{ kHz} \\ f_{LO} &= 1905 \text{ kHz} \end{aligned}$$

Now determine the Image:



$$\begin{aligned} f_I &= f_{LO} + f_{IF} \\ f_{LO} &= 1905 \text{ kHz} + 455 \text{ kHz} \\ f_{LO} &= 2360 \text{ kHz} \end{aligned}$$

Note: Always mirrored about LO

Keep in mind: 2360 kHz is outside the AM band, however, some other service has been assigned that frequency by the FCC.