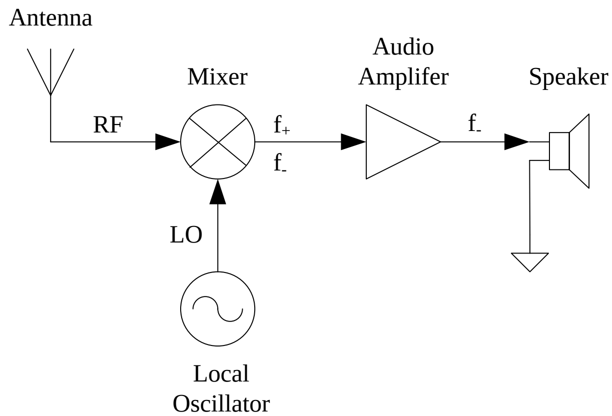
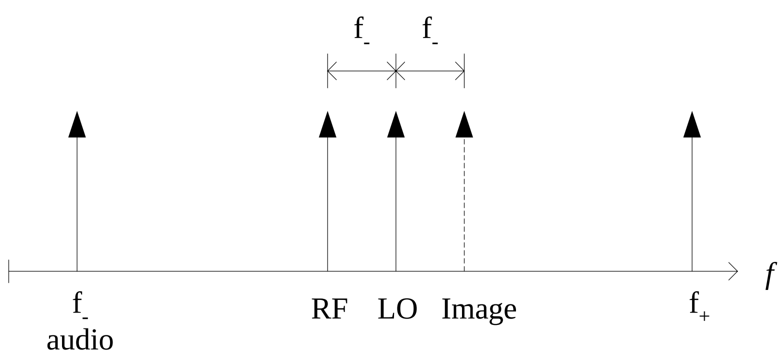
Lecture 28: Superheterodyne Receivers. Spurious Responses of Mixers

Recall from Lecture 1 that a direct conversion receiver has the following simplified system diagram:



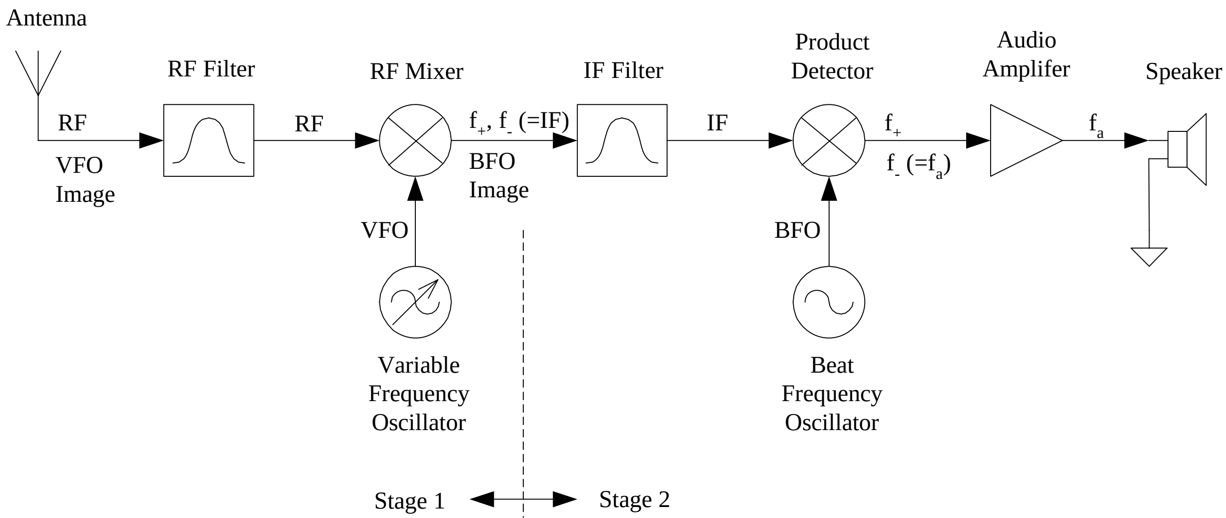
The frequencies internal to the direct conversion receiver are:



From the last lecture, we can now understand that while f_+ and f_- are the intended output signals, other frequency components will also be present at the mixer output due to HO harmonics produced in the mixing process.

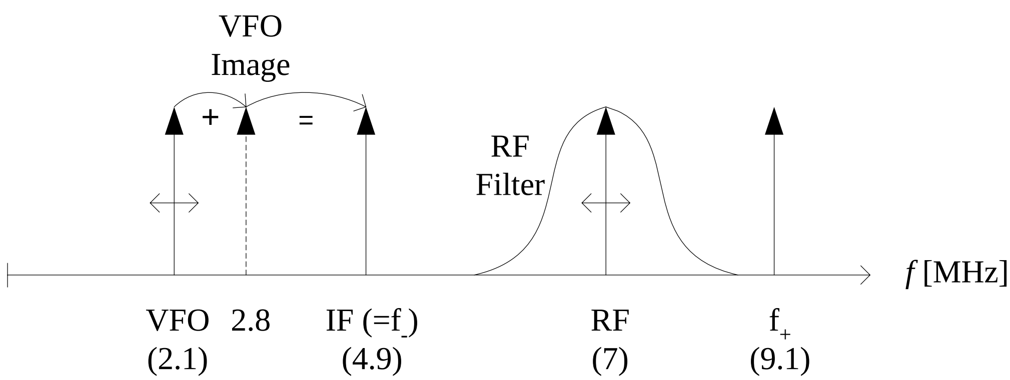
As we'll see shortly, these HO harmonics are **not** the same as "spurious responses of the receiver", known as "spurs."

The superheterodyne receiver does not have the same troubles with image frequencies as the direct conversion receiver does:

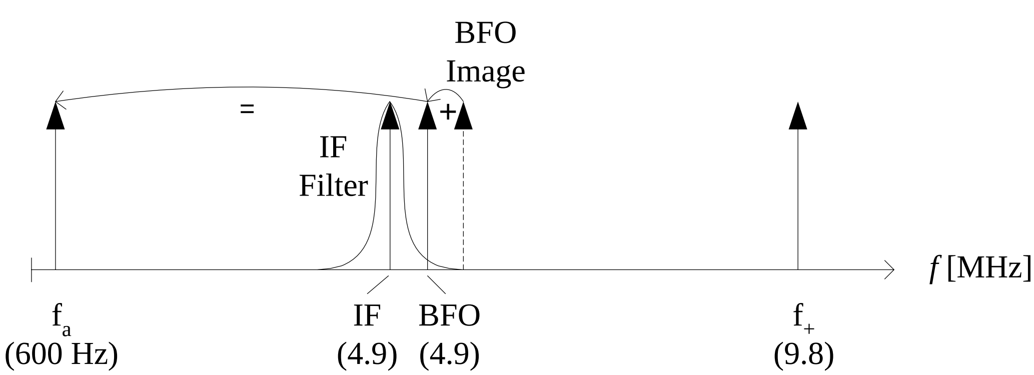


The frequencies internal to the superheterodyne receiver are:

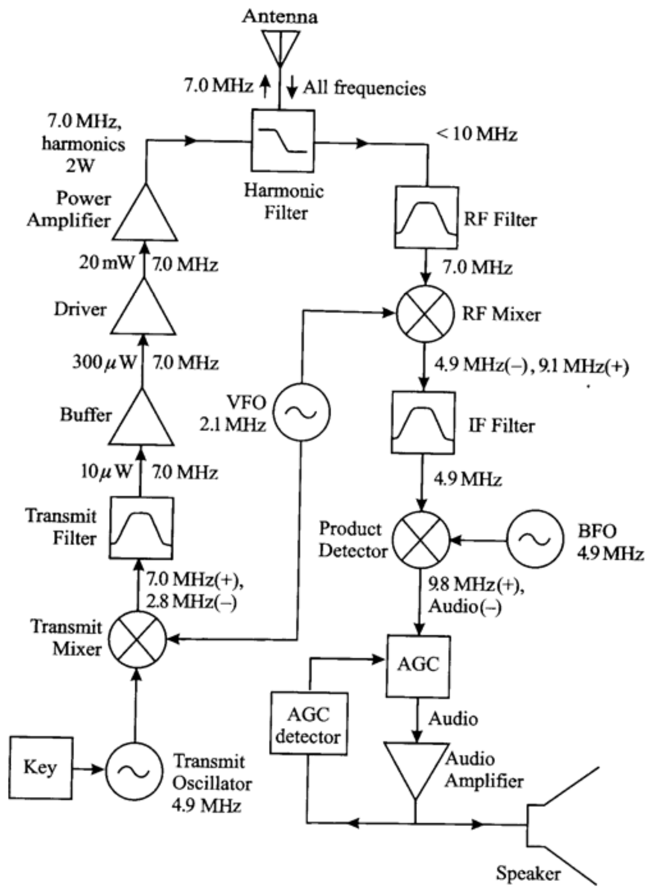
Stage 1:



Stage 2:



From Fig. 1.13 in the text, the NorCal 40A system diagram is:



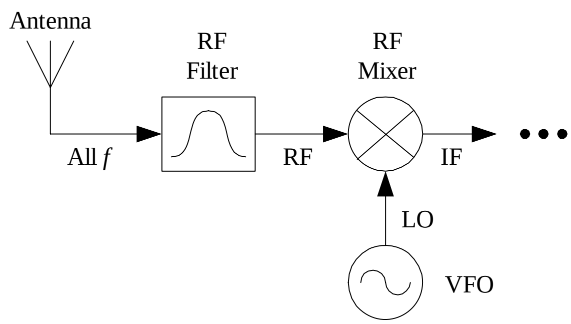
Spurious Responses of Receivers (Spurs)

In addition to the image frequencies, there are additional spurious output responses from the receiver (called "spurs") caused by signals mixing with higher harmonics of the LO.

By definition, a spur is an unintended output signal from a receiver. For example, the VFO and BFO images shown in the diagrams on page 2 are spurs.

Recall that in the Gilbert cell, the LO (or more precisely a *square wave* at the LO frequency) multiplies the RF signal in the time domain.

This process will inevitably produce spurs due to the presence of HO harmonics produced by mixing. Let's consider these HO spurs from the RF mixer. In this case:



We ask: What RF frequencies can mix (i.e., multiply) with the **third** harmonic of the LO (VFO) to produce an output at the frequency f_{if}? Mathematically, we are asking:

$$f_{if} = 3f_{lo} - f_{3\downarrow}$$

or rearranging,

$$\boxed{f_{3\downarrow} = 3f_{lo} - f_{if}} \qquad (12.16)$$

If a received antenna signal is present at this frequency $f_{3\downarrow}$, we will hear it at the same time we hear the intended signal at f_{rf}. Not good. So once again, we need to filter this spur out.

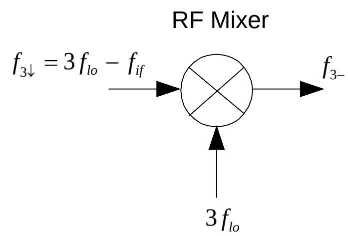
The other third harmonic spur is located at the frequency

$$\boxed{f_{3\uparrow} = 3f_{lo} + f_{if}} \qquad (12.18)$$

So, spurs at $f_{3\downarrow}$ and $f_{3\uparrow}$ are in fact the "image frequencies" of the third harmonic of the LO.

To *verify* that these two frequencies can generate spurious responses from the receiver, consider the following:

- For $f_{3\downarrow}$ –

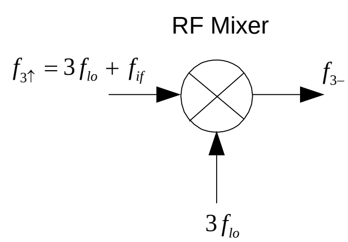


$$f_{3-} \underbrace{=}_{(12.13)} \left|3f_{lo} - f_{rf}\right| = \left|3f_{lo} - f_{3\downarrow}\right|$$

$$= \left|3f_{lo} - \left(3f_{lo} - f_{if}\right)\right| = f_{if}$$

So indeed, we see a signal at $f_{3\downarrow}$ would generate a spurious signal at f_{if} from the RF mixer.

- For $f_{3\uparrow}$ –



$$f_{3-} \underbrace{=}_{(12.13)} \left|3f_{lo} - f_{rf}\right| = \left|3f_{lo} - f_{3\uparrow}\right|$$

$$= \left|3f_{lo} - \left(3f_{lo} + f_{if}\right)\right| = f_{if}$$

Again, we see that a signal at $f_{3\uparrow}$ would generate a spurious signal at f_{if} from the RF mixer.

There are also possible spurs from higher-order mixer products:

$$\boxed{f_{5\downarrow} = 5 f_{lo} - f_{if}} \tag{12.19}$$

$$\boxed{f_{5\uparrow} = 5 f_{lo} + f_{if}} \tag{12.20}$$

and so on.

How many and which spurs are potentially troublesome for a receiver depend on the specific construction of the receiver (its IF, RF, VFO, etc.).

Let's look closely at the NorCal 40A and identify the troublesome spurs.

1. VFO image: $\quad f_i \underbrace{=}_{(12.14)} f_{if} - f_{lo} = 4.9 - 2.1 = 2.8 \text{ MHz}$

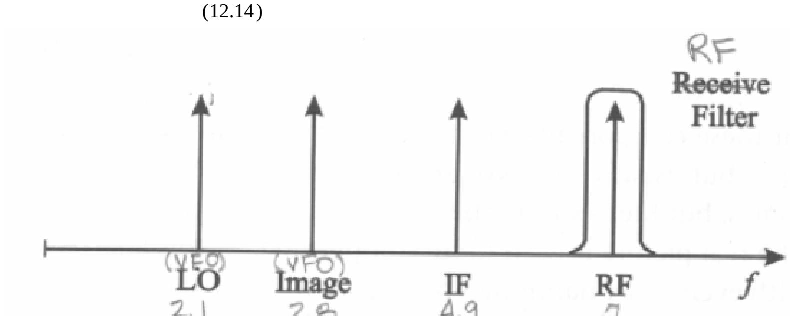


Figure 12.4. Mixer frequencies and the image frequency. A band-pass filter centered on the RF frequency prevents a signal at the image frequency from reaching the mixer.

2. Third VFO harmonic spurs:

$$f_{3\downarrow} = 3 f_{lo} - f_{if} = 3 \cdot 2.1 - 4.9 = 1.4 \text{ MHz}$$

(This spur is in the AM radio frequency band.)

$$f_{3\uparrow} = 3f_{lo} + f_{if} = 3 \cdot 2.1 + 4.9 = 11.2 \text{ MHz}$$

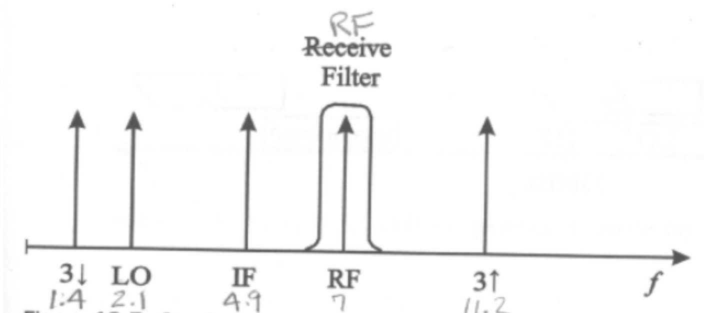


Figure 12.5. Spurious responses caused by mixing with the third harmonic of the LO.

The RF Filter does a good job of filtering out both of these third harmonic spurs. However, $f_{3\downarrow}$ can be very strong and consequently heard on occasion.

3. Fifth VFO harmonic spurs:

$$f_{5\downarrow} = 5f_{lo} - f_{if} = 5 \cdot 2.1 - 4.9 = 5.6 \text{ MHz}$$
$$f_{5\uparrow} = 5f_{lo} + f_{if} = 5 \cdot 2.1 + 4.9 = 15.4 \text{ MHz}$$

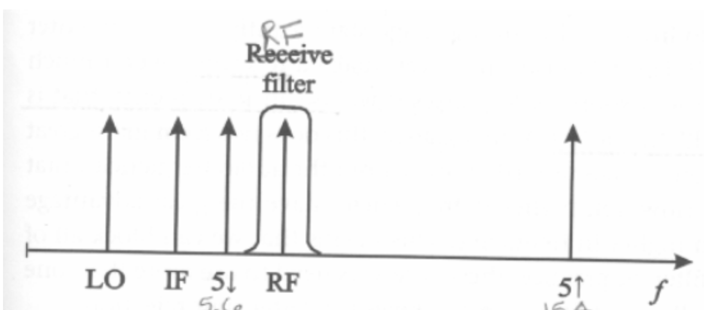


Figure 12.6. Spurious responses caused by mixing with the fifth harmonic of the LO.

Of all the spurs, it turns out that $f_{5\downarrow}$ is the one closest to the intended RF signal. It causes the largest spurious response in the

NorCal 40A since it is difficult to filter out while at the same time continuing to receive the intended RF signal.

In Prob. 28, you will work to locate two of the strongest spurs in the NorCal 40A, both of which are related to the RF Mixer. These are the image frequency f_i of the RF Mixer and the fifth VFO-harmonic spur $f_{5\downarrow}$ of the RF Mixer.

Later in Prob. 29, you will locate and measure the dB reduction of $f_{3\downarrow}$ from the RF Mixer. However, you will be measuring the output voltage from the Product Detector. Consequently, what you are actually measuring is how much of this RF Mixer spur "bleeds through" the Product Detector.