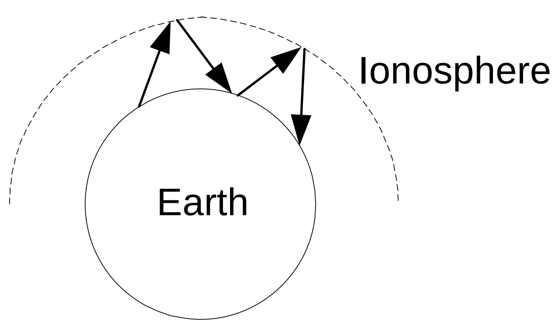
Lecture 1: Overview. NorCal 40A. Direct Conversion vs. Superhet Receivers.

The overall objective of this course is to learn and understand practical aspects of analog wireless communication electronics.

We will accomplish this with a very thorough analysis of the NorCal 40A transceiver (= transmitter + receiver). This radio was designed by Wayne Burdick and the kit is produced by Bob Dyer at Wilderness Radio.

The NorCal 40A is a QRP (= low power) and CW (= continuous wave) "rig." It operates in the "40-m band," which designates the wavelength of the carrier waveform. With $\lambda = c_0 / f$, then $f \approx 7.5$ MHz.

This frequency is within the HF (= high frequency) band, which extends from 3 to 30 MHz. In this band, worldwide communications is possible since the Earth's ionosphere acts to reflect the signal back towards the ground.



A block diagram of the NorCal 40A is shown in Fig. 1.13. The transmitter is on the left half, the receiver on the right. Notice the different frequencies at various stages in the circuit.

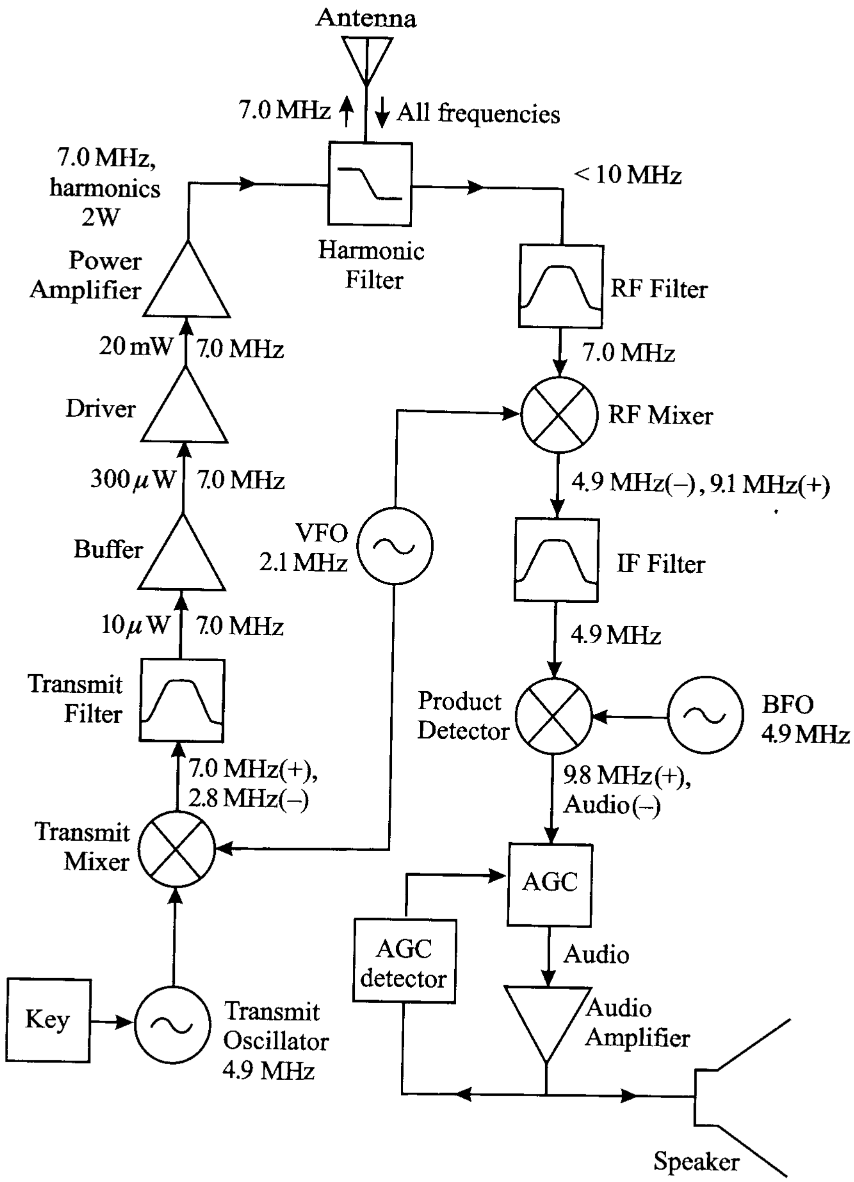
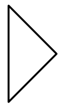
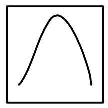
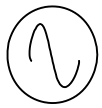
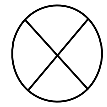
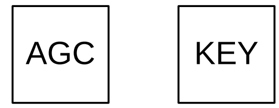


Figure 1.13. Block diagram for the NorCal 40A. Sum frequencies are noted by + signs, and difference frequencies by – signs. Adapted from Appendix C of the *NorCal 40A Assembly and Operating Manual*, by Wayne Burdick, published by Wilderness Radio. Used by permission.

This block diagram is constructed on a system level. Each shaped section in the diagram serves a specialized purpose.

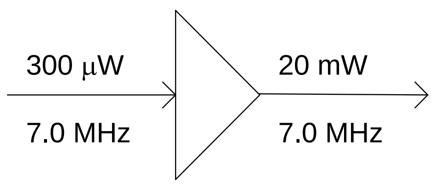
There are five types of system blocks in Fig. 1.13:

1. Amplifiers: 
2. Filters: 
3. Oscillators: 
4. Mixers: 
5. Misc.: 

We will briefly discuss the first four of these.

(1) Amplifiers. These are used both in the transmitting and receiving stages of the transceiver.

Take, for example, the Driver Amplifier:



The amplifier has amplified the transmitted signal by

$$\begin{aligned}\text{Driver Gain} = G &= 10\log_{10}\left(\frac{P}{P_i}\right) \text{ dB} \\ &= 10\log_{10}\left(\frac{20 \text{ mW}}{300\ \mu\text{W}}\right) \approx 18 \text{ dB}\end{aligned} \tag{1.23}$$

This amplifier is followed by the Power Amplifier [$G = 10\log_{10}(2/0.020) = 20$ dB] to give an output power of 2 W into a "well-matched" antenna (2 W is considered QRP).

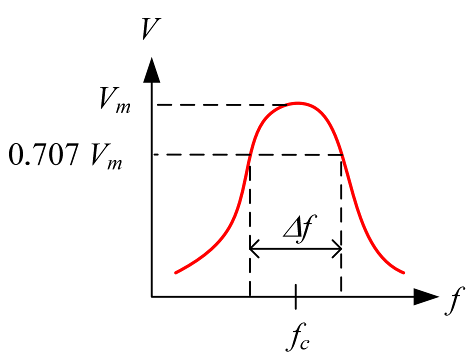
This type of gain is called an operational power gain. Later in the course we will almost exclusively use another type of gain called transducer (maximum available) power gain. (We talk more about this type of gain and others in EE 481 *Microwave Engineering*.)

(2) Filters. These devices are a common topic in early EE courses. Filters play an **extremely** important role in analog communication electronics.

In the NorCal 40A, there are three bandpass and one low pass filter. One of the bandpass filters (the IF Filter) is constructed from four quartz crystals and has a very, very large Q for discrete component filters ($Q_{\text{loaded}} \approx 12{,}000$). Recall that

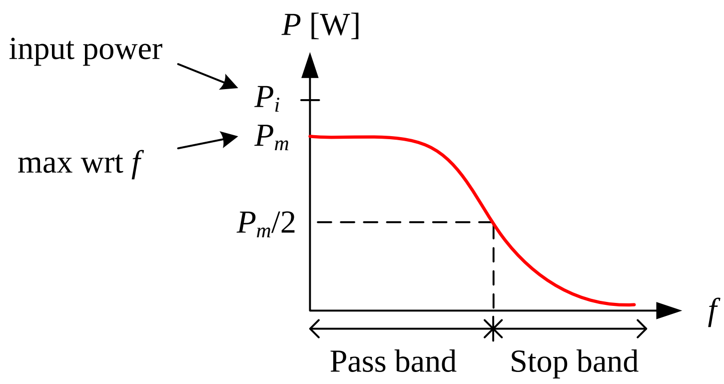
$$Q = \frac{f_c}{\Delta f}$$

where



Filters are typically characterized by two factors:

(i) Loss L in the "pass band." Take a low pass filter for example:



So, in the pass band

$$L \equiv \frac{P_i}{P_m} \quad \text{or} \quad L \equiv 10\log_{10}\left(\frac{P_i}{P_m}\right) \text{ dB} \tag{1.30}$$

We see that loss L is the inverse of gain.

(ii) Rejection factor R in the "stop band."

$$R \equiv \frac{P_m}{P} \quad \text{or} \quad R \equiv 10\log_{10}\left(\frac{P_m}{P}\right) \text{ dB} \tag{1.32}$$

where P = power at some frequency f in the stop band.

(3) Oscillators. These provide nearly sinusoidal signals at a single frequency. There are three oscillators in the NorCal 40A:

(i) Transmit Oscillator at 4.9 MHz,
(ii) Variable Frequency Oscillator (VFO) near 2.1 MHz,
(iii) Beat Frequency Oscillator near 4.9 MHz.

(4) Mixers. These are circuits that shift a signal's frequency either up or down. This shifting is accomplished by "combining" the signal with another.

This "combining" operation is signal multiplication and is usually accomplished either with nonlinear circuits or with time-varying circuits. (The NorCal 40A uses the latter.)

As an example of mixing, let's take the product of

$$V_1(t) = \cos(2\pi f_1 t) \qquad \text{and} \qquad V_2(t) = \cos(2\pi f_2 t)$$

as $V(t) = V_1(t) \cdot V_2(t)$.

Using the trig. id. $\cos\alpha\cos\beta = \frac{1}{2}\cos(\alpha+\beta) + \frac{1}{2}\cos(\alpha-\beta)$

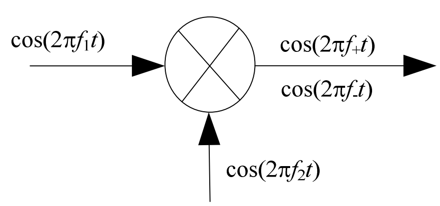
then

$$V(t) = \frac{1}{2}\cos(2\pi f_+ t) + \frac{1}{2}\cos(2\pi f_- t) \tag{1.25}$$

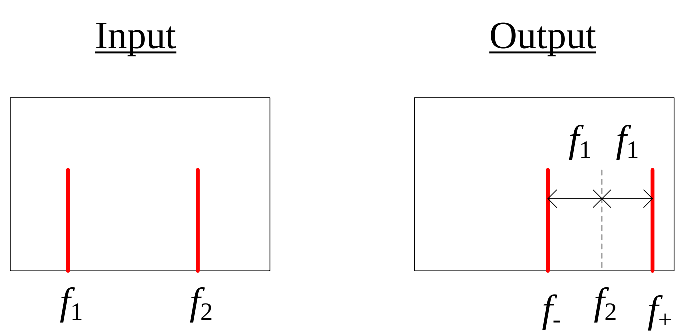
where f_+ = sum frequency = $f_1 + f_2$

f_- = difference frequency = $|f_1 - f_2|$

Consequently, through multiplication we have produced an output signal containing two frequency components:



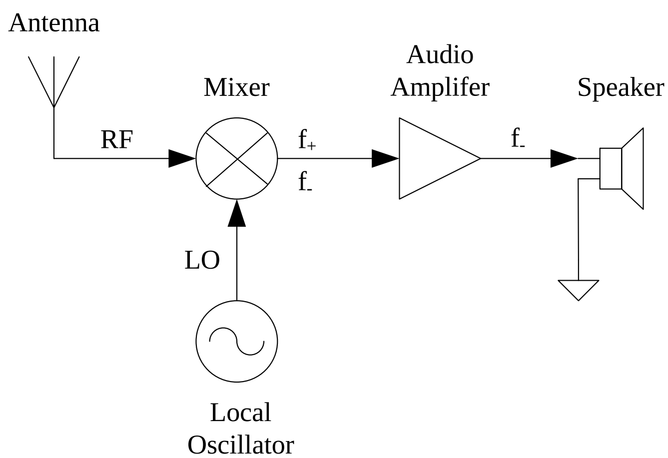
On a spectrum analyzer:



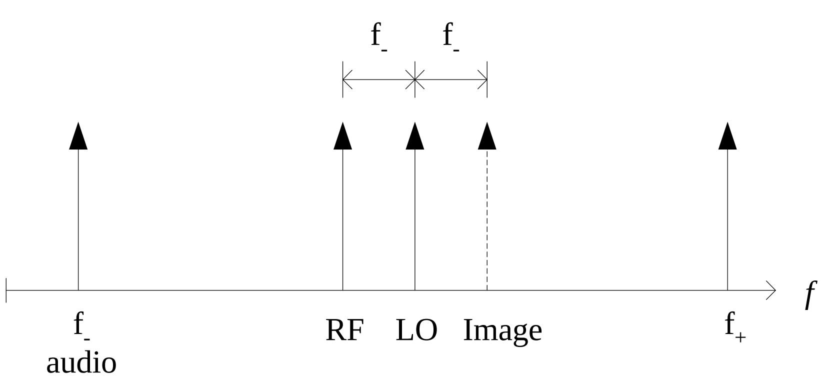
Notice that the output signal does not contain frequency components of either the input sign (f_1 or f_2)! How amazing. Only signal components at f_- and f_+ are present. (In reality there will likely be very small signals at f_1 and/or f_2 that "bleed" through.)

Direct Conversion Receivers

As an application of mixers, consider the "direct conversion" receiver shown in Fig. 1.8:



The signal frequencies at different points in the receiver can be drawn graphically as:



The Audio Amplifier amplifies the low frequency f_- signal while filtering out the sum frequency f_+. In the NorCal 40A, the audio frequency ≈ 600 Hz and the RF ≈ 7 MHz. Therefore:

LO ≈ 7 MHz and Sum = RF + LO ≈ 14 MHz.

This simple receiver has one major problem, which is the "image." The audio signal is the difference signal for RF and LO mixer inputs. *If* a signal is also being received at the "image" frequency shown above (at the same time as the desired RF signal), then a second audio tone will be produced at the output as the difference signal between the image and the LO frequencies.

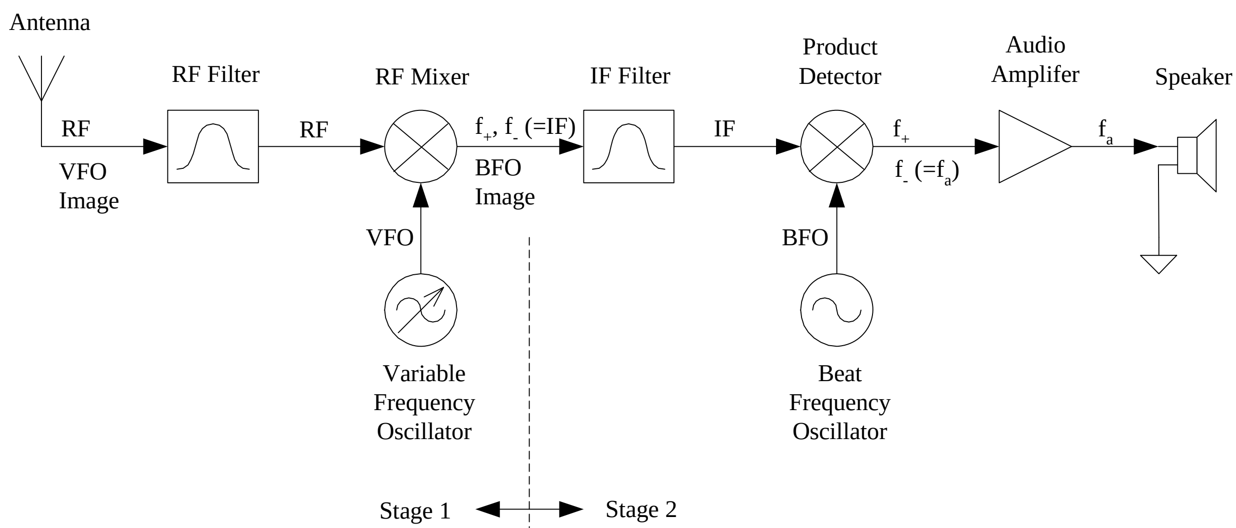
This is BAD since you would then hear two "stations" simultaneously and there would be no way to separate them.

One way to circumvent this problem is to place a filter before the mixer to remove the image, as shown in Fig. 1.10. However, one would need a very high-Q bandpass filter, most likely requiring quartz crystals. But then we couldn't change frequencies to tune in other stations because it's difficult to make such filters with a variable center frequency.

Superheterodyne Receivers

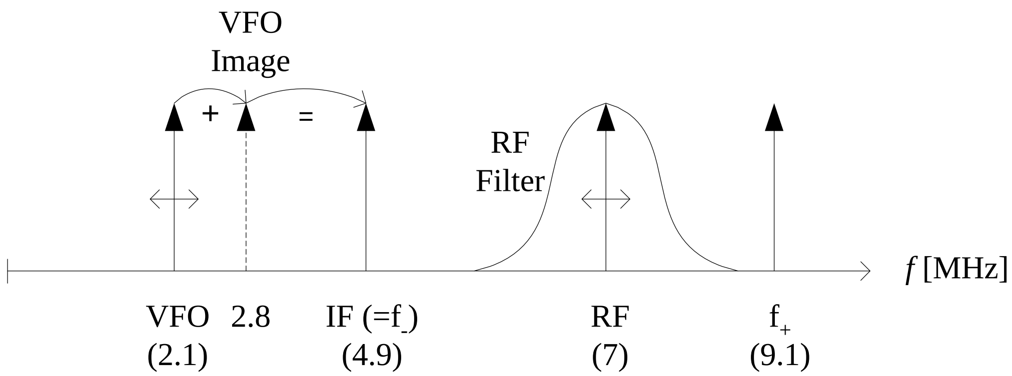
This problem with the direct conversion receiver can be overcome using superheterodyne receivers. This circuit was invented by Howard Armstrong in the early 1920's. The superhet receiver is "perhaps the most important invention in the history of communications," as stated in the text. Incidentally, Mr. Armstrong also invented frequency modulation (FM). A very talented engineer!

A block diagram of the superhet receiver is shown in Fig. 1.11:



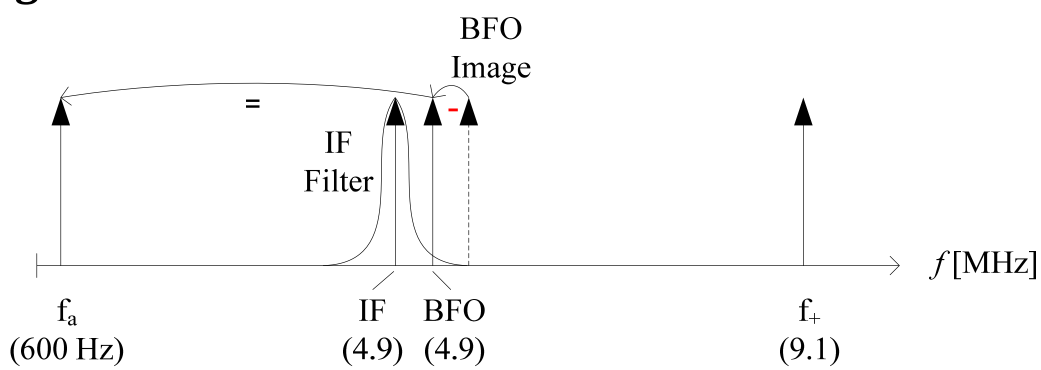
Consider the various frequencies present in the circuit beginning at the antenna:

- **Stage 1**



The RF Filter easily filters out the “VFO Image” at 2.8 MHz. The IF signal is then fed to the IF Filter and the Product Detector:

- **Stage 2**



The IF Filter needs to have a very large Q. Its job is to filter out the sum frequency signal (f_+ = 9.1 MHz) and the “BFO Image” (if there is one at ≈ 4.9 MHz).

Notice we can easily tune this receiver by varying the VFO frequency: the intermediate frequency is ALWAYS equal to the

IF. Consequently, we can construct a very high-*Q* filter centered at the IF that doesn't need to be tuned. Brilliant!

The loaded *Q* of the IF Filter in the NorCal40A is approximately 12,000. That's large!