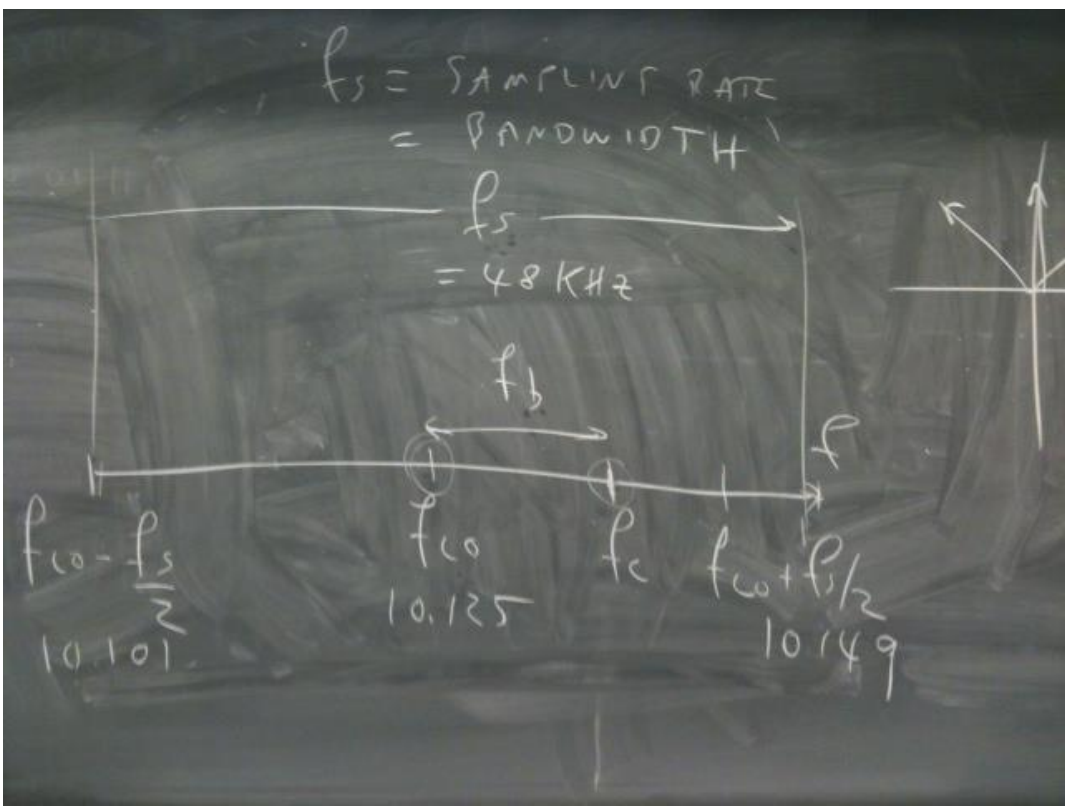
Radio tuning, selecting a particular signal with software using the Softrock IQ analog receiver.

The Softrock receiver is designed to receive radio frequency (RF) signals at any frequency f_c in the range $f_{LO} \pm f_s / 2$ MHz, where f_{LO} is the local oscillator (LO) frequency set to about 14.047 MHz and f_s is the sampling rate of the soundcard. If $f_s = 48$ KHz, then the frequency range is 14.023 – 14.071 MHz. Selecting a signal at a particular frequency f_c is called “tuning” the radio.

The Softrock receiver operates by generating two local oscillator signals at f_{LO} and mixing (multiplying) it with a desired radio frequency (RF) carrier wave $\hat{r}(t) = e^{j2\pi f_c t}$ at f_c to yield a complex baseband signal $\tilde{r}(t) = I(t) + jQ(t)$ at the difference frequency $f_b = f_c - f_{LO}$, where we write

$$\hat{r}(t)e^{-j2\pi f_{LO}t} = e^{j2\pi f_c t}e^{-j2\pi f_{LO}t} = e^{j2\pi f_b t} = \cos 2\pi f_b t + jsin 2\pi f_b t = I(t) + jQ(t)$$

$I(t)$ and $Q(t)$ can be sampled by the sound card and processed by the computer, provided that f_c is close enough to f_{LO}, i.e. the difference is less than half the sampling rate, $| f_c - f_{LO} | < f_s / 2$ or $f_{LO} - f_s / 2 < f_c < f_{LO} + f_s / 2$. The difference frequency $f_b = f_c - f_{LO}$, where $| f_b | < f_s / 2$



In this figure, 10.101 should be 14.023, 10.125 should be 14.047, 10.149 should be 14.071

The Softrock receiver function is to shift a 48 KHz wide slice of spectrum from 14.023 – 14.071 MHz centered at $f_{LO} = 14.047$ MHz down to -0.024 to +0.024 MHz (positive and negative frequencies centered around zero Hz). The complex baseband signal $\tilde{r}(t) = e^{j2\pi f_b t}$ can represent positive and negative frequencies, since f_b can be positive or negative and $| f_b | < 24$ KHz.. The 48 KHz slice of spectrum may contain many different signals at various frequencies within the 48 KHz range (recall waterfall plot in lab 0).

If the RF carrier wave is turned on and off to transmit information in e.g. Morse code, then we wish to listen to (or digitally decode) the complex baseband signal $\tilde{r}(t) = \cos 2\pi f_b t + \text{j} \sin 2\pi f_b t$ and no other signals.

If f_b is outside the audio range we want to listen to, or f_b is not the frequency expected at the digital decoder input, then we multiply $\tilde{r}(t)$ by a complex exponential $e^{-j2\pi f_d t}$ at frequency f_d to obtain another complex baseband signal

$$\tilde{r}_2(t) = e^{j2\pi f_b t} e^{-2\pi f_d t} = e^{j2\pi (f_b - f_d)t} = e^{2\pi f_E t}$$

at frequency $f_E = f_b - f_d$, where f_E is chosen to be the frequency for listening (or for the decoder).

In effect, we have shifted the spectrum twice, once by f_{LO} using analog circuits and a second time by f_d using software to get the exact frequency we want to listen to (for Morse code) or for a digital decoder.

Table of frequencies used above

f_s sampling rate of computer sound card

f_{LO} local oscillator frequency (fixed frequency crystal analog oscillator near 14 MHz)

f_c carrier frequency of desired signal at radio frequency near 14 MHz (passband)

$(f_{LO} - f_s / 2) < f_c < (f_{LO} + f_s / 2)$ passband frequency range

$f_b = f_c - f_{LO}$ desired signal obtained by converting to baseband

$(-f_s / 2) < f_b < (f_s / 2)$ baseband frequency range (centered at 0 Hz)

Conversion (spectrum shifting) is done by complex multiply

$$\hat{r}(t) e^{-j2\pi f_{LO} t} = e^{j2\pi f_c t} e^{-j2\pi f_{LO} t} = e^{j2\pi f_b t} = \cos 2\pi f_b t + j sin 2\pi f_b t = I(t) + jQ(t)$$

f_E desired frequency for listening or for decoder (could be zero or not)

$f_d = f_b - f_E$ digital local oscillator in baseband used for tuning into desired signal

f_d is controlled by tuning knob or mouse

Spectrum shift is done by complex multiply

$$\tilde{r}_2(t) = e^{j2\pi f_b t} e^{-2\pi f_d t} = e^{j2\pi (f_b - f_d)t} = e^{2\pi f_E t}$$

More generally, if the RF signal contains information encoded in its amplitude and phase, then the RF signal $\hat{r}(t) = a(t)e^{j\phi(t)}e^{j2\pi f_c t}$ is multiplied by the complex local oscillator

$e^{-j2\pi f_{LO}t|} = \cos 2\pi f_{LO}t - jsin2\pi f_{LO}t$

to yield

$$\hat{r}(t)e^{-j2\pi f_{LO}t} = [a(t)e^{j\phi(t)}e^{j2\pi f_c t}]e^{-j2\pi f_{LO}t} = a(t)e^{j\phi(t)}e^{j2\pi f_b t} = I(t) + jQ(t)$$

where the received complex baseband signal is

$$\tilde{r}(t) = I(t) + jQ(t) = a(t)\cos\phi(t)cos2\pi f_b t + \mathrm{j}\ a(t)\sin\ \phi(t)sin2\pi f_b t$$

If we want to receive the information contained in $a(t), \phi(t)$ then we multiply $\tilde{r}(t)$ by a complex exponential $e^{-j2\pi f_b t}$ at exactly $-f_b$ to obtain $\tilde{r}(t)e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}$ centered at $f_E = 0$, followed by a low pass filter to filter out any other signals. We have shifted the spectrum twice, once by f_{LO} using analog circuits and a second time by f_b using software to receive the desired signal. In this case, the decoder uses $f_E = 0$