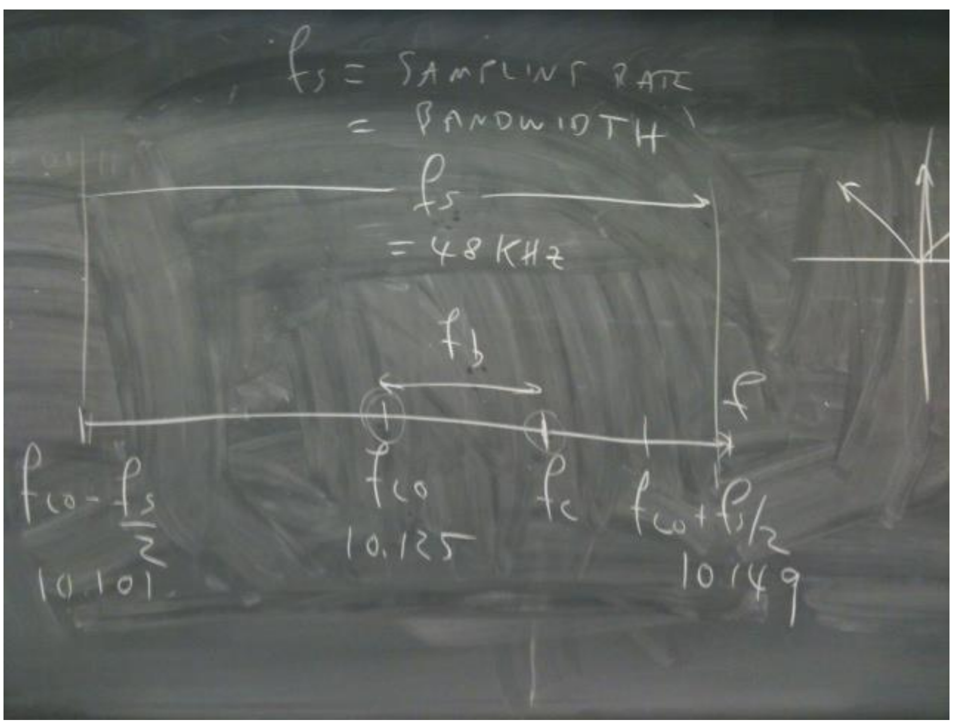
Radio tuning, selecting a particular signal with software using USRP HF 0-30 MHz receiver.
Note: this document has been edited from the radio tuning for Softrock document with minor changes. The same diagram is used for both Softrock and USRP tuning to emphasize that the ideas are the same.

The USRP 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 a digital local oscillator (LO) frequency that has been set to 710 KHz and f_s is the sampling rate. Here $f_s = 256$ KHz (selected in GNURadio), so the span is 256 KHz (± 128 KHz) centered at 710 Hz. Selecting a signal at a desired frequency f_c (e.g. 790 KHz) is called “tuning” .

The USRP receiver operates in the digital domain by generating a complex LO signal at f_{LO} =710 KHz and mixing (multiplying) it with a desired RF signal at 790 KHz $\hat{r}(t) = e^{j2\pi f_c t}$ at f_c to yield a complex baseband signal $\tilde{r}(t) = I(t) + jQ(t)$ at the difference frequency $f_b = f_c - f_{LO} =$ 790-710=80KHz , where

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

$I(t)$ and $Q(t)$ can be observed 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 710, 10.125 should be 710-48, 10.149 should be 710+48
It should be redrawn with $f_s = 256$ KHz instead of 48 KHz.

The USRP receiver shifts a 256 KHz wide slice of spectrum centered at $f_{LO} = 710$ (i.e. 582- 838 KHz) down to -128 KHz to +128 KHz (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 $| f_b |< 128$ KHz.. The 256 KHz slice of spectrum may contain many different signals at various frequencies within the 256 KHz range (recall waterfall plot in lab 0).

The desired signal we want to "tune in" is the complex baseband signal
$\tilde{r}(t) = e^{j2\pi f_b t}$
and we want to receive only this signal In the above, we assumed the RF signal
$\hat{r}(t) = e^{j2\pi f_c t}$
is a carrier wave with constant amplitude.

Since for AM broadcast signals, the RF signal contains information encoded in its amplitude, i.e
$a(t) = A_c[1 + k_a m(t)], A_c = 1, \phi(t) = \text{constant} = 0,$
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 centered at $f_b = f_c - f_{LO}$

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

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 $\tilde{r}_2(t) = \tilde{r}(t)e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}$ 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} and a second time by f_b to receive the desired signal information $a(t)$

Table of frequencies used in the above.

f_s sampling rate set in GNURadio

f_{LO} local oscillator frequency (fixed frequency crystal analog oscillator at 710 KHz)

f_c carrier frequency of desired signal at radio frequency 790 KHz (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

$\hat{r}(t)e^{-j2\pi f_{LO}t} = e^{j2\pi f_c t}e^{-j2\pi f_{LO}t} = e^{j2\pi f_b t} = \cos 2\pi f_b t + jsin2\pi f_b t = I(t) + jQ(t)$

f_E desired frequency for decoder (zero in this case and for many cases)

$f_d = f_b$ 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

$\tilde{r}_2(t) = e^{j2\pi f_b t}e^{-2\pi f_d t} = e^{j2\pi(f_b - f_d)t} = e^{2\pi f_E t} = 1$ since $f_d = f_b$

For case of amplitude modulation

$\tilde{r}_2(t) = \tilde{r}(t)e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}e^{-j2\pi f_b t} = a(t)e^{j\phi(t)}$