Dynamic Range

Analog-to-Digital Converter specifications include sampling rate and number of bits per sample.

device	Samples per second	Bits per sample	Dynamic Range (DR) 6 dB per bit
Audio CD	44.1 K	16	96
USRP	100 M	14	84
RTL-SDR	3.2 M	8	48

The dynamic range is the dB difference of the strong signal level at which all bits are on and the ADC clips, and the weakest signal that can be easily detected (least significant bit).

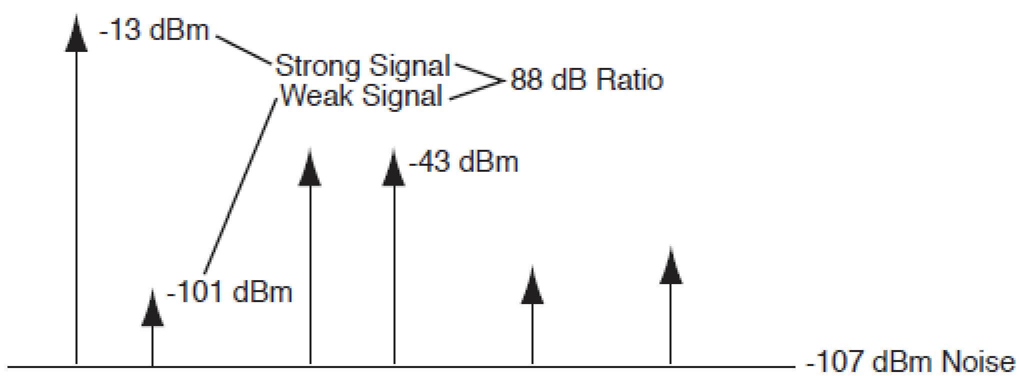

Figure 5.27: Weak Signals Must Be Detectable in the Presence of Strong Signals

Dynamic range with FM signals

For the USRP FM receiver, the noise level in a 256 KHz bandwidth is around -107 dBm. If the receiver gain is set to be low so that the thermal noise activates only the least significant bit, then the strongest signal that can be received at the ADC input without clipping the ADC is Smax= -107 + DR. For the USRP, from the table above, DR = 84 dB and Smax = -107 + 84 = -23 dBm.

Now assume there is a signal present at -13 dBm. This signal will clip the ADC. If we reduce the gain so that noise (or signals) at -101 dBm activate only the least significant but, then the strongest signal we can receive is -101 + 84 = -17 dBm, and the -13 dBm signal will still clip the ADC. One way to allow the stronger signal to be received without clipping is to reduce the receiver gain even more, but then the weak signal at -101 dBm would be lost in the noise.

For the case considered in the lab, the strong signal (UVic radio CFUV 101.9 MHz) is about -30 dBm, so that there is no clipping and both the weak Seattle station (KING-FM 98.1 MHz) and CFUV can be received. However, if the receiver RF gain is increased, then CFUV will clip.

Dynamic range with IQ signals

ADC clipping has an effect on IQ signals as follows.

Consider a general IQ signal $s(t) = a(t)\cos 2\pi f_c t + \phi(t) = i(t)\cos 2\pi f_c t - q(t)\sin 2\pi f_c t$ with complex envelope $\tilde{s}(t) = a(t)e^{j\phi(t)}$ so that $i(t) = a(t)\sin\phi(t)$ and $q(t) = a(t)\sin\phi(t)$

Assume this signal has a constant envelope, so that $a(t) = A$ is constant., and $\phi(t) = 2\pi f_b t$

Now increase the system gain so that both $i(t)$ and $q(t)$ are clipped by the ADC and have values $i(t) = \pm 1$ and $q(t) = \pm 1$ for all values of *t*. For this case, the only possible values of $\phi(t)$ are $\pm\pi/4, \pm 3\pi/4$

Sketch the waveforms $i(t), q(t), a(t).\phi(t)$ and the XY scope plot of $q(t)$ versus $i(t)$ you would expect to see when the ADC is not clipping and again when the ADC is clipping.

Noise figure

Recall the link budget notes equation (14)

$$P_{r,n} = k + T_0 + (S/N) + W + F$$

where $k = -228.6, T_0 = 10log(290),$
$k + T_0 = -174$ dBm/Hz

and all quantities are in dB.

The noise figure can be estimated if all other quantities are known. The observed noise level is $P_r = -174 + W + F$ in dBm assuming *S/N=0* dB and the bandwidth *W* is expressed in dB relative to 1 Hz.