Gnuradio Amateur Radio Meetup

Using Gnuradio for some amateur radio measurements.

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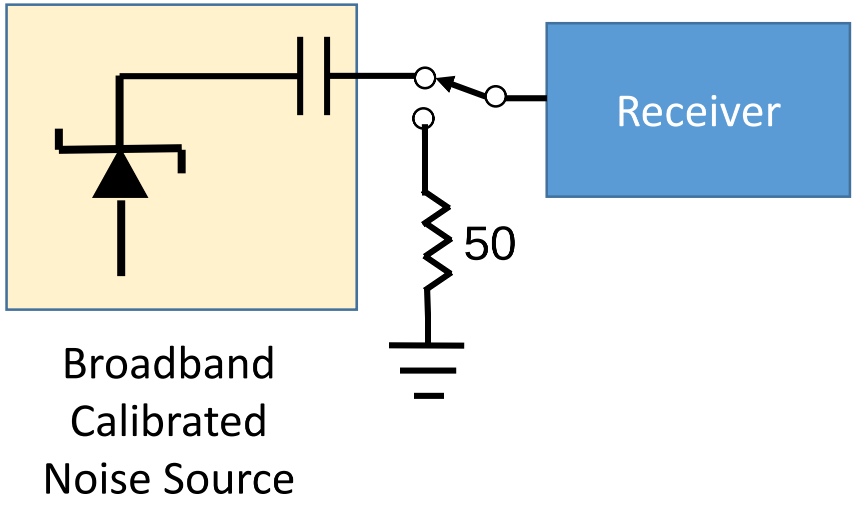
Outline

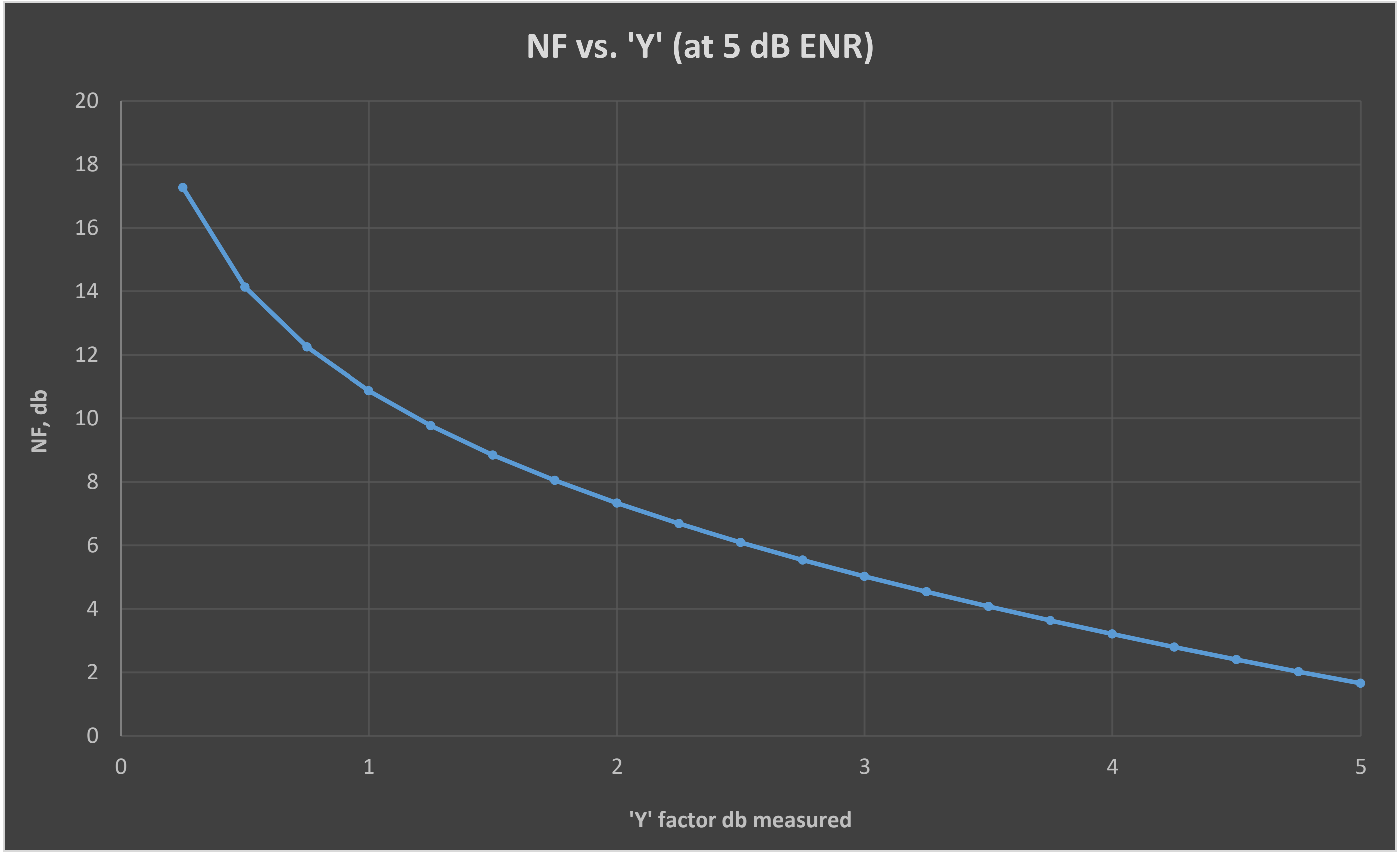
- Measuring Receiver Noise Figure.
- Finding the ADC maximum input signal level and Offset.
- Exploring Receiver Dynamic Range Measurements.
- Identifying Some Spurious Components.
- FFT Scalloping variation considerations.

- Measure the Noise Figure (NF) of a receiver
  - Use Y-factor method.
    - 'Y' is the increase in noise (dB) when the noise source is turned on.

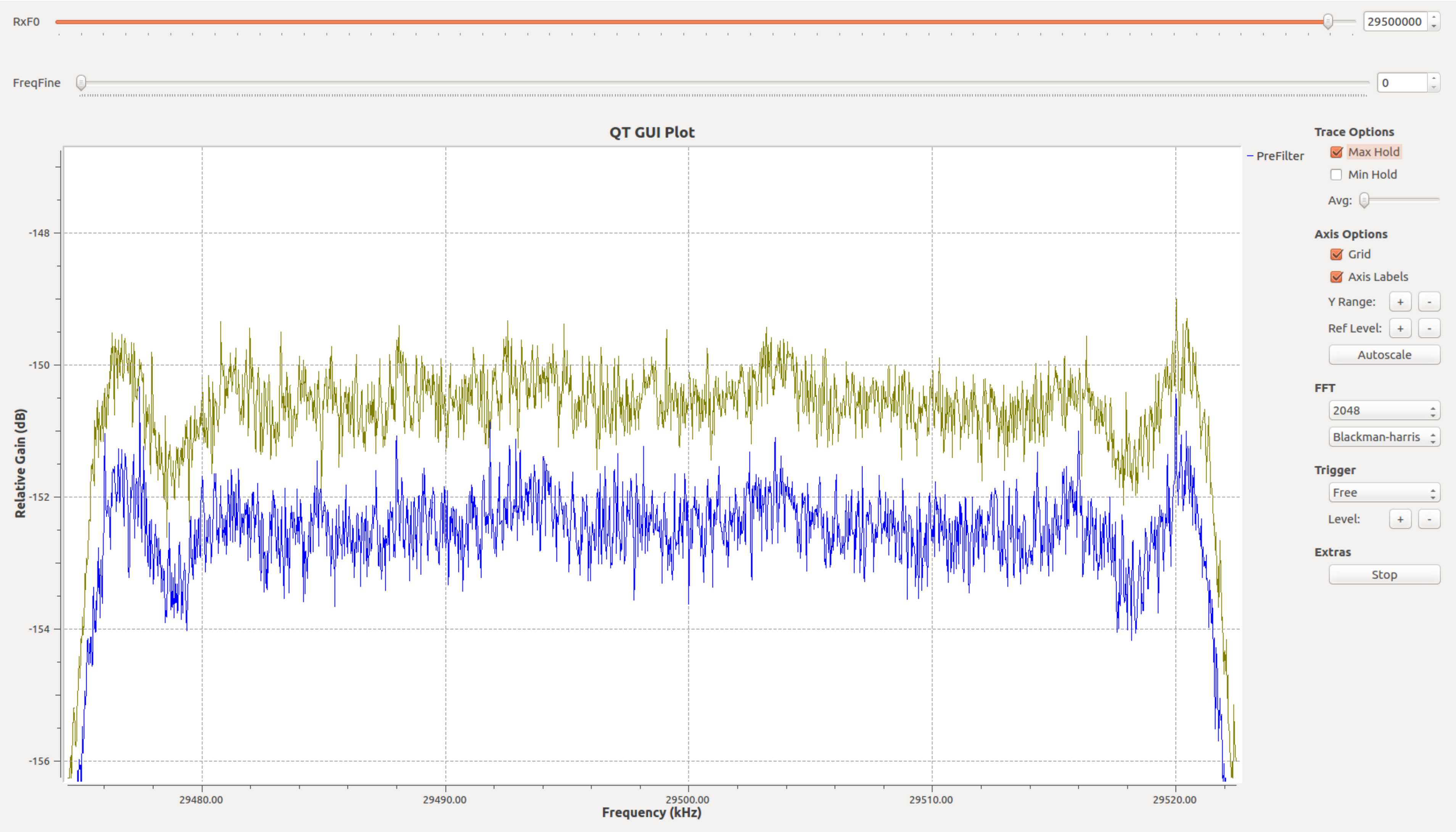
$$NF = 10 * \log_{10} (10^{(ENR/10)} / (10^{(Y/10)}-1))$$

  - Radio: Open HPSDR / TAPR Hermes + Alex (filters & relays).
  - Noise Source: 5 dB Excess Noise Ratio (ENR).





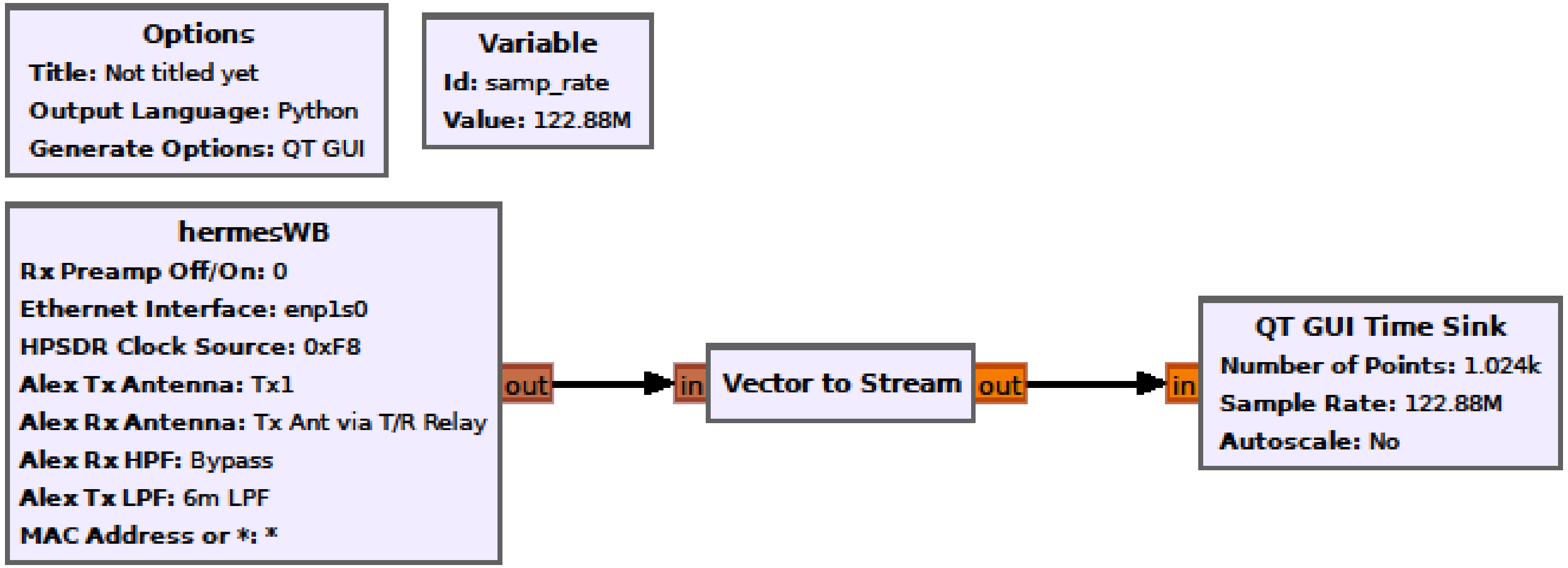
Hermes + Alex NF Measurement (gnuradio)



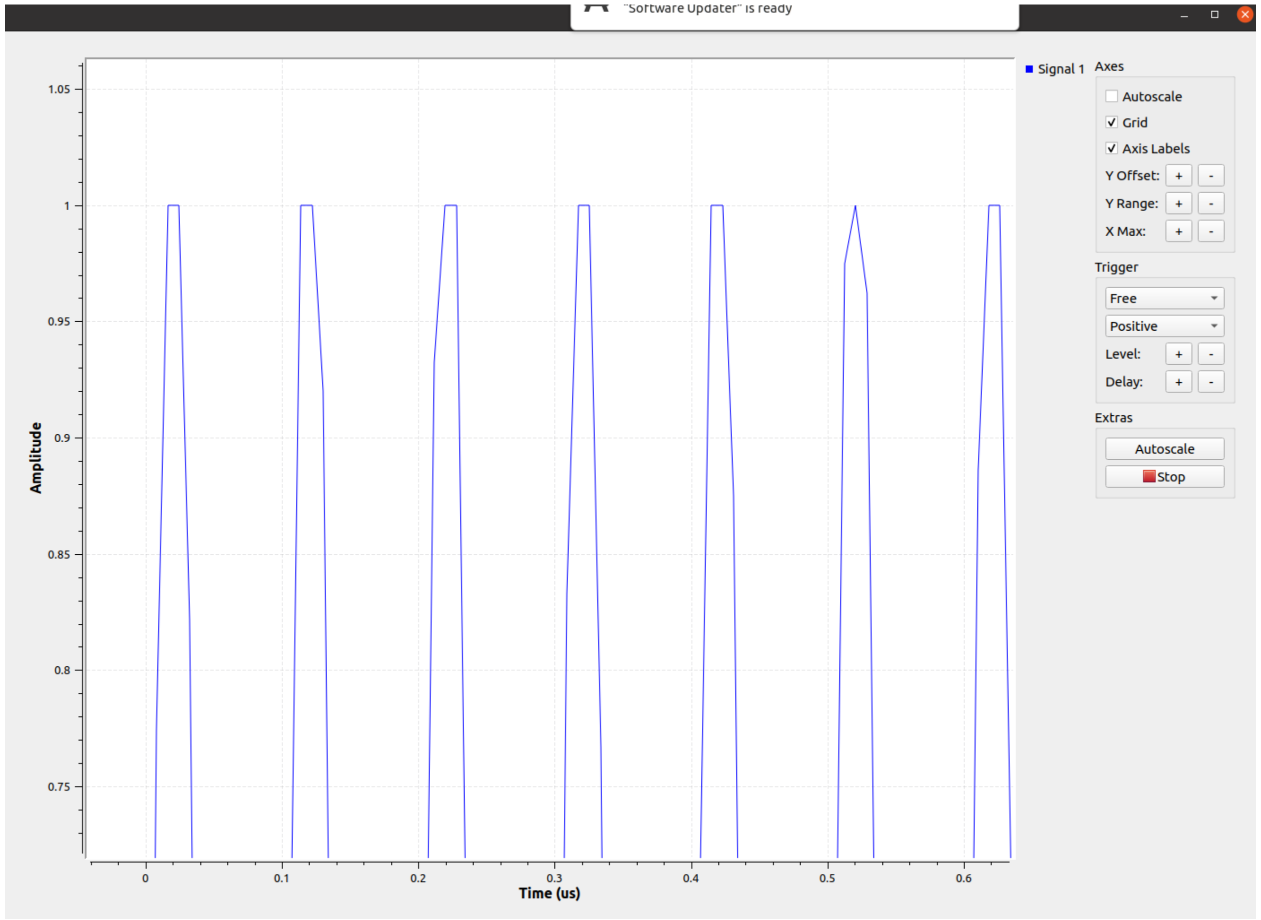
- 5 dB ENR Source ‘ON’ vs. Source ‘OFF’
- 48 Ks/s, 2048 FFT, bin size = 23.4 Hz.
- Exponential Averaging, tau ~ few seconds
- 2 dB / major division

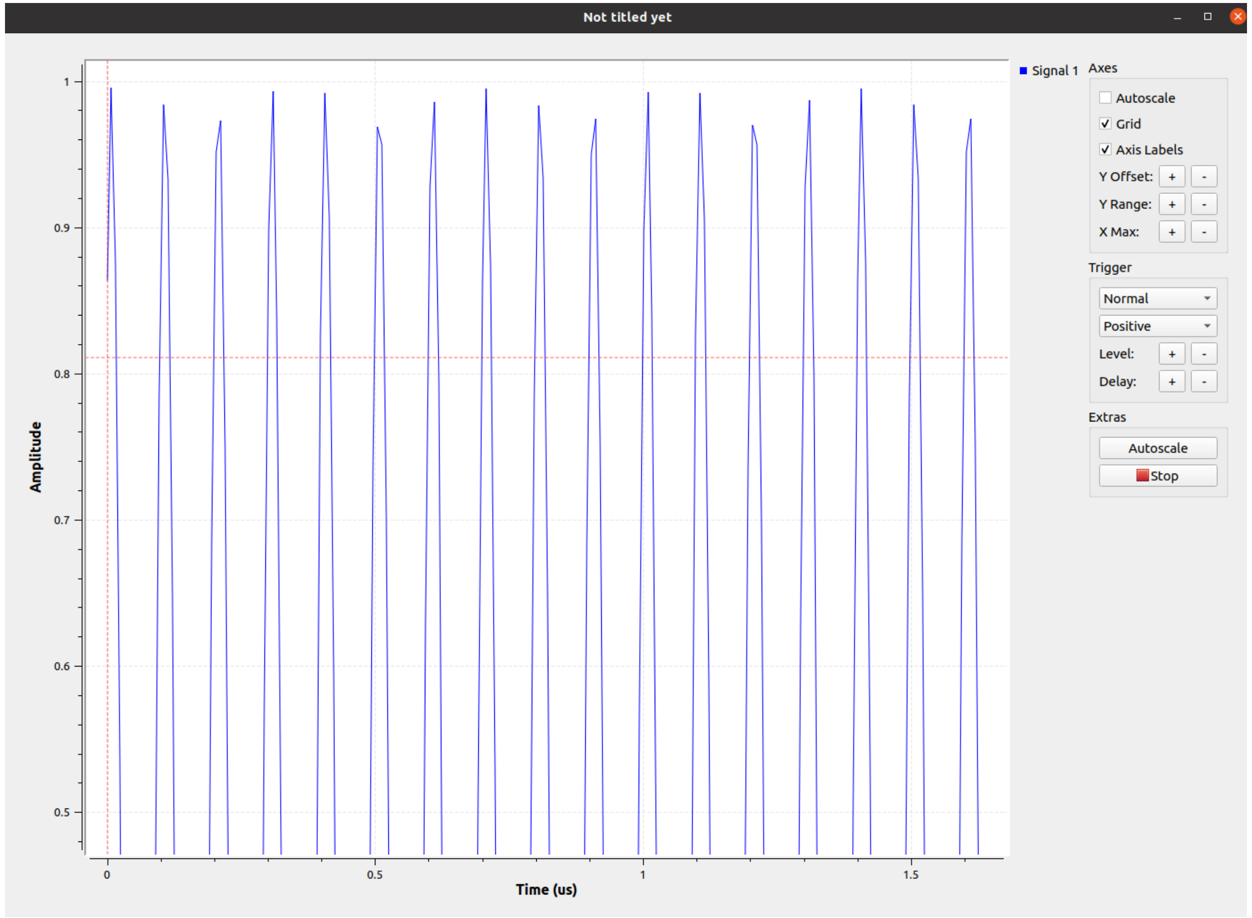
Finding the ADC Maximum Input Level

- Use wideband (WB) receiver (raw ADC samples).
- Adjust step attenuator to just observe clipping. Add one more dB attenuation to eliminate ADC reaching the maximum values.
- Disconnect receiver, Measure voltage across 50-ohm load.
  - This is defined as 0 dBFS (zero dB referenced to Full Scale).
- The receiver has a selectable 20 dB attenuator
  - Preamp=ON means the 20 dB input attenuator turned off).

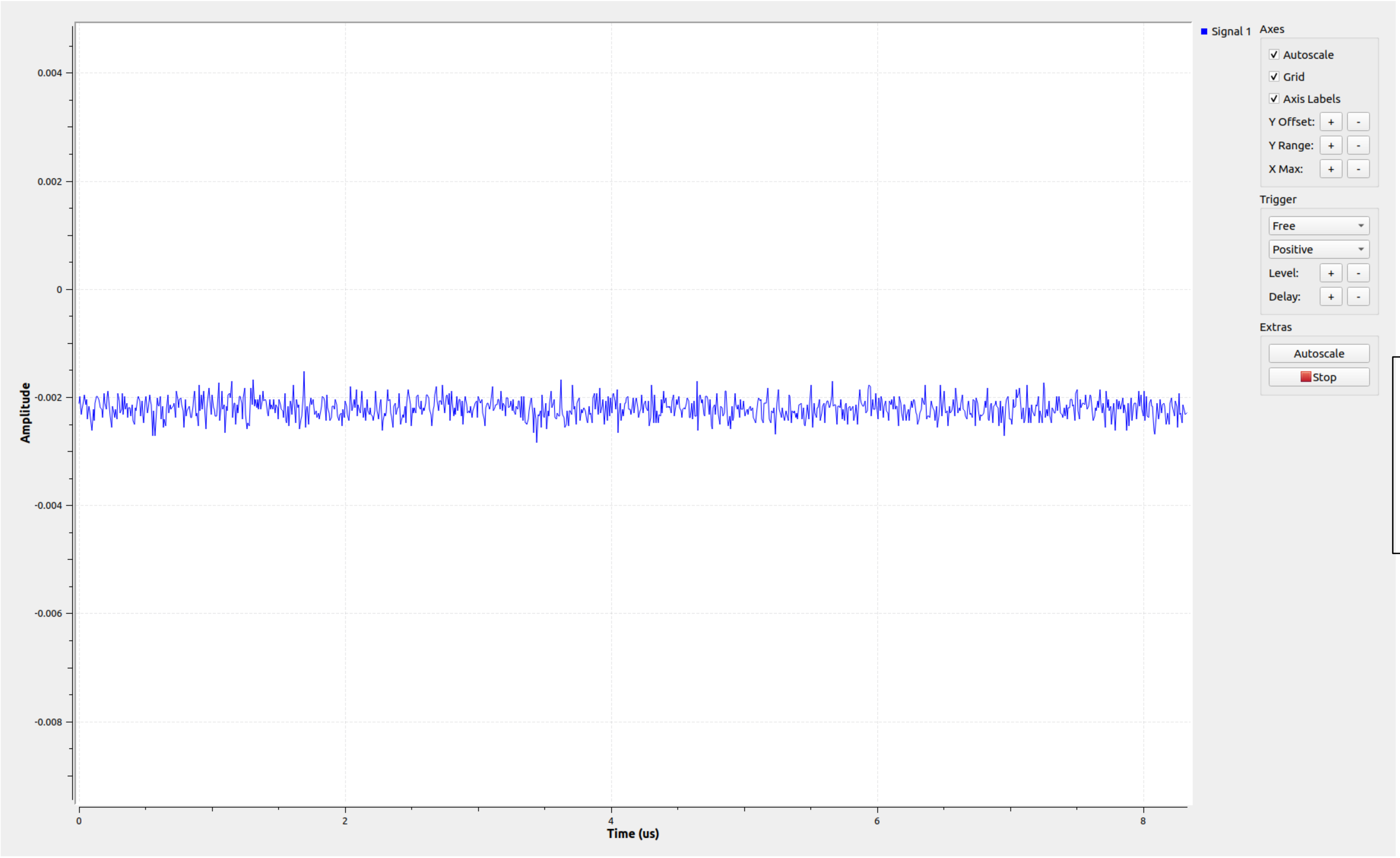


Clipping compared to 1 dB reduction (no clipping)
(hermesWB ADC scale is -1.0 to +1.0)





ADC offset voltage (same flowgraph but no signal, 50 ohm terminated receiver)



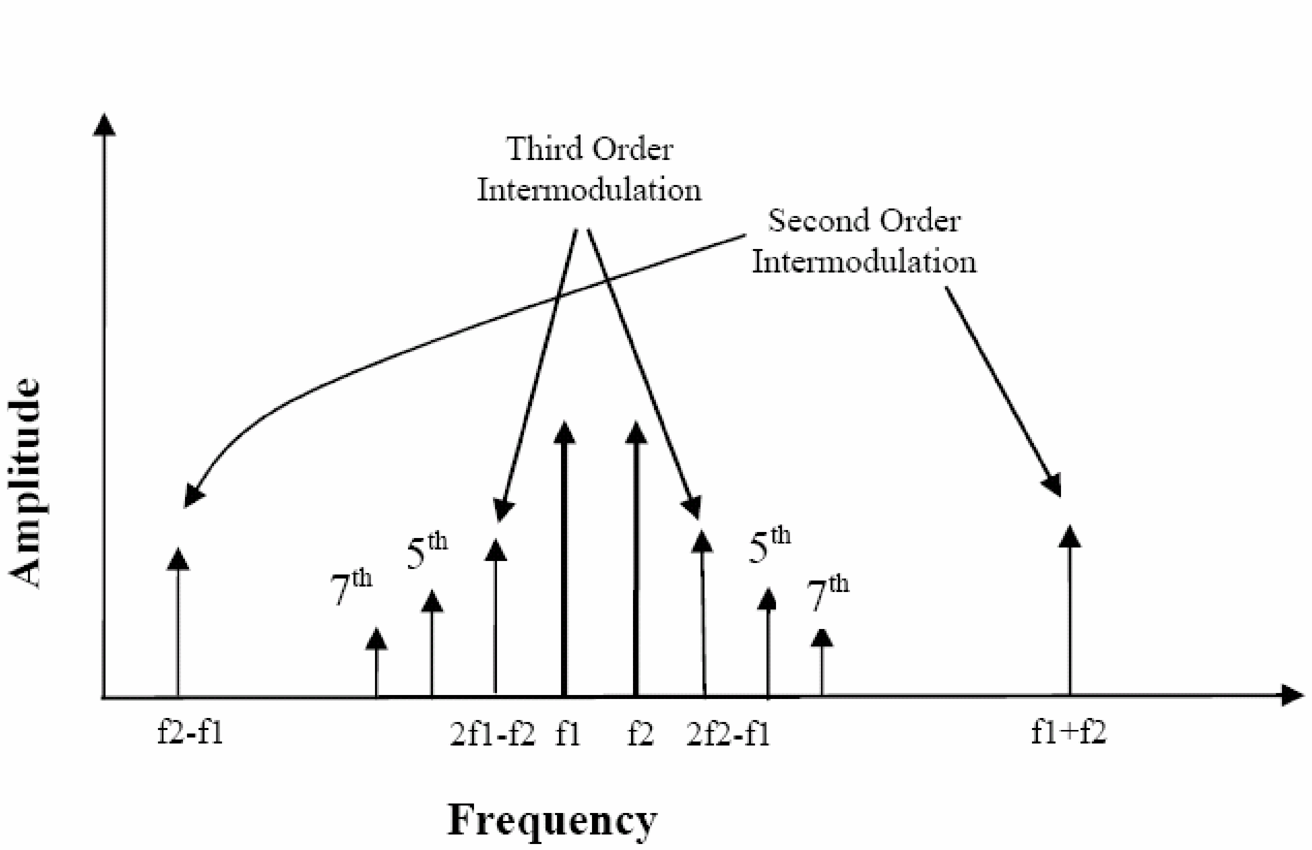
About – 2 mV offset voltage
ADC range:
-1.0 to + 1.0 volts
16 bit ADC:
about -64 counts offset.

3rd Order Dynamic Range in SDR

- SDR receivers do not behave in the same way as analog receivers.
- Intercept-point is not very meaningful for the SDR.
- Measured 3rd order using gnuradio.
- Need to turn receiver pre-amp on and off to achieve sufficient linear measurement range

Dynamic Range

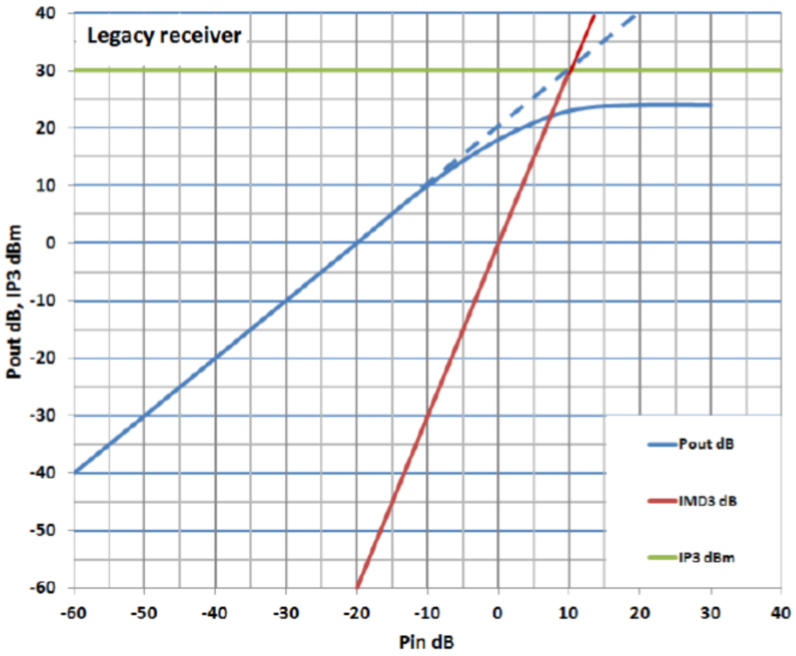
- Multiple carriers + non-linearity in the receiver produces intermodulation distortion products (IMD).



IP3 not well defined for ADC (SDR) receiver

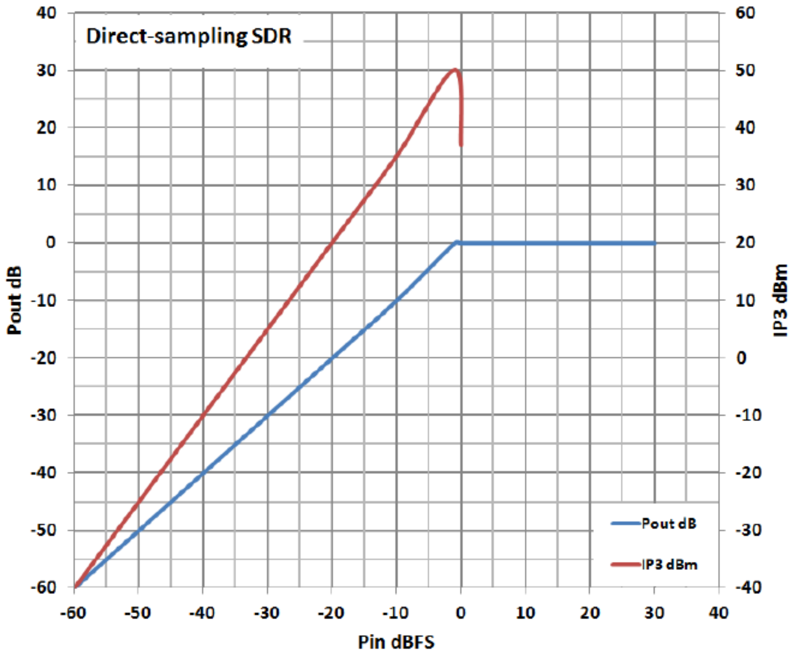
The IP3 Problem in an ADC

Analog Receiver



IM3 product increases 3 dB per dB of input power

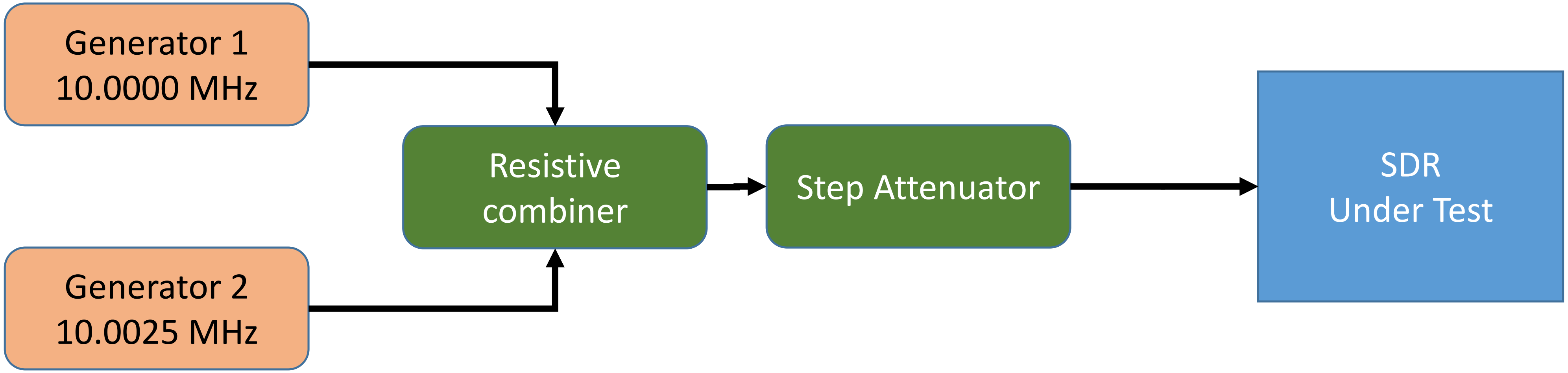
SDR Receiver



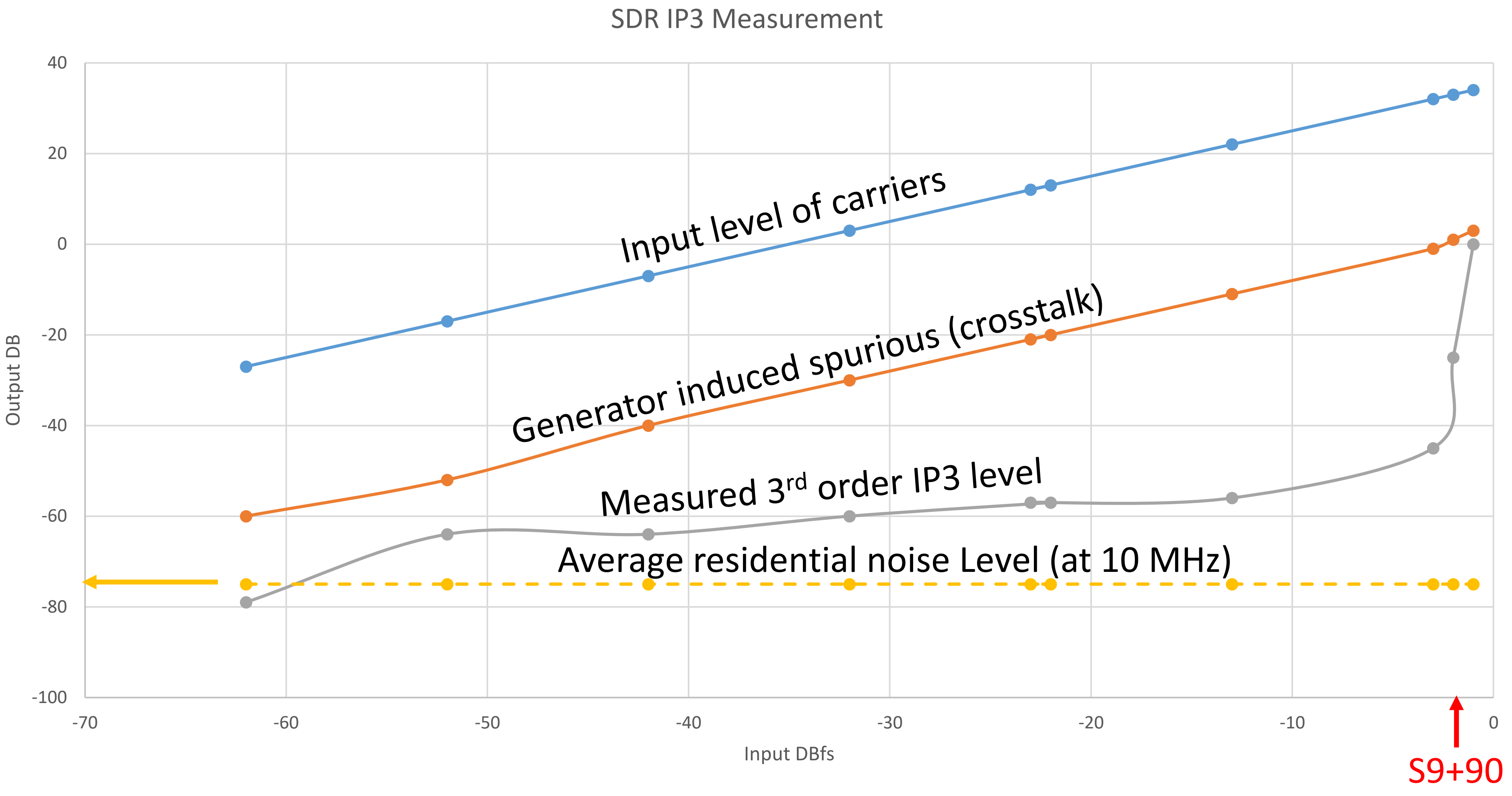
IM3 product is nearly independent of input power (0 dBFS = ADC clipping level)

Ref. Adam Farson VA7OJ

3rd order measurement block diagram



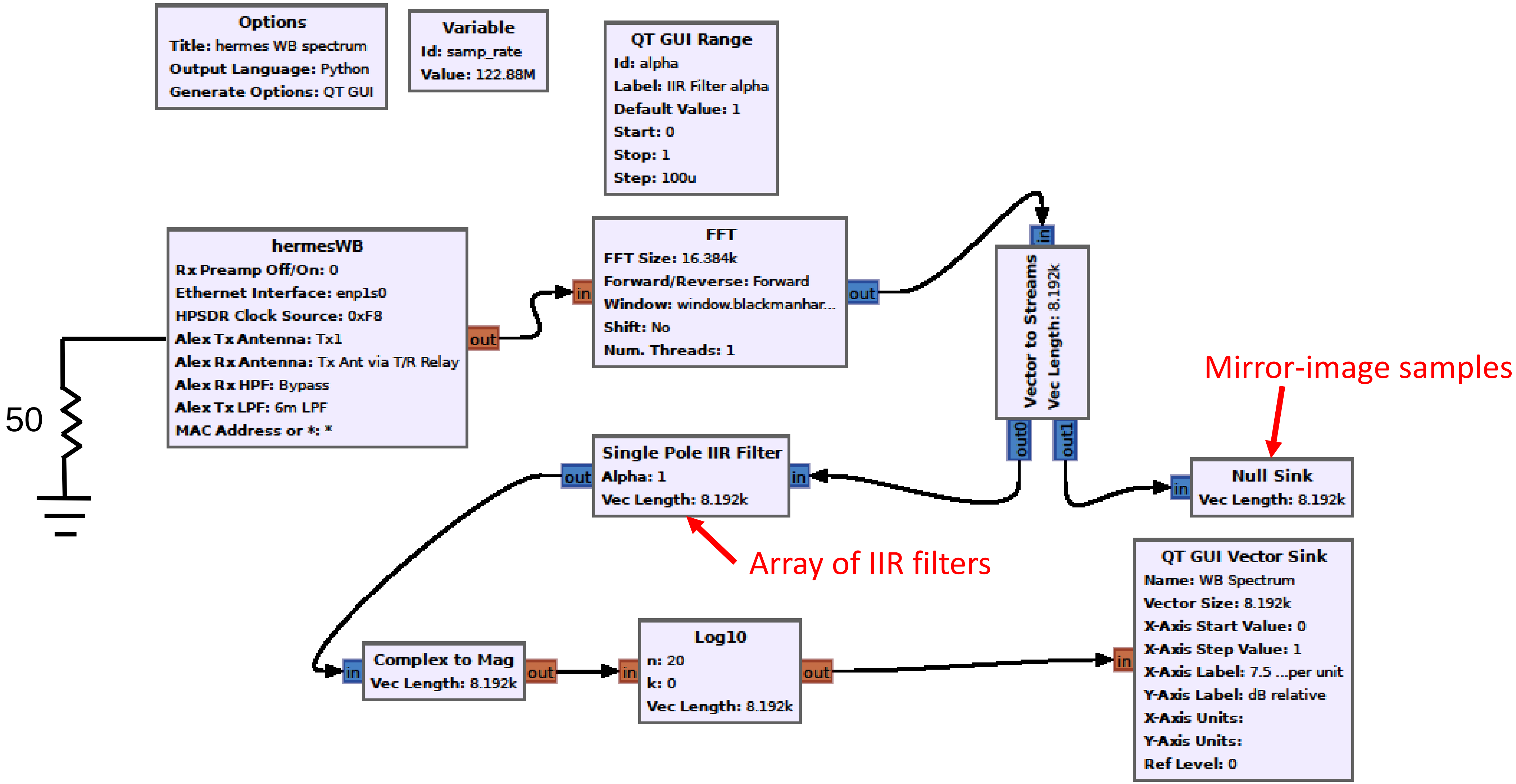
IP3 measurement: Open HPSDR Hermes
2.5 KHz spacing



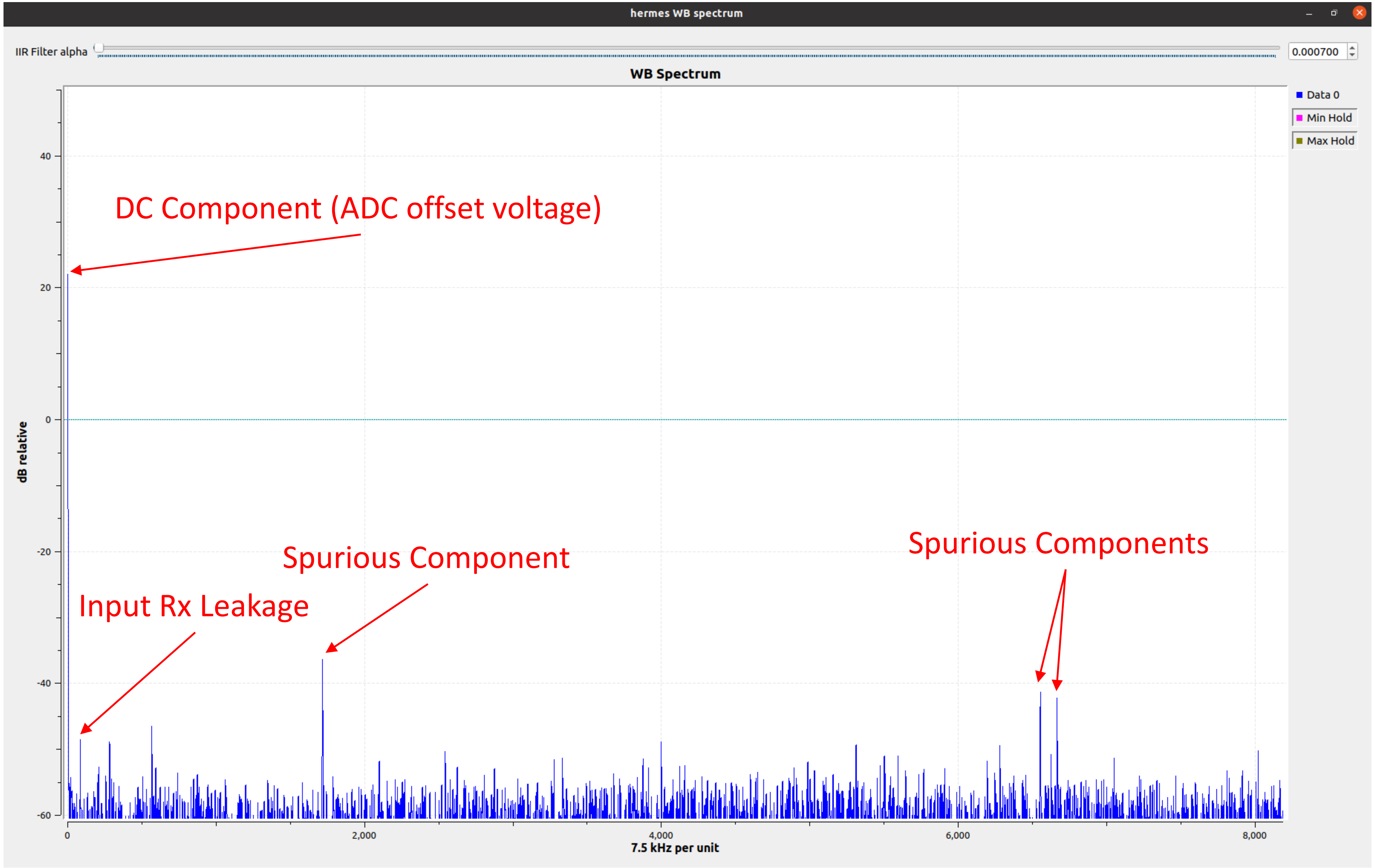
Identifying Spurious Components

- Most SDR receivers generate some internal spurious spectral components.
- Set SDR to wideband sampling mode.
  - OpenHPSDR has unique WB mode: provides 16384-time-contiguous real samples then long dead time. Repeat.
- Perform FFT on WB samples as vector of 16384
  - Then throw away half (because real: FFT output is mirror symmetric.
  - FFT window to reduce impact of sampling discontinuity.
- Filter FFT output bins with 8192 IIR filters.
  - Reduce noise level by integration.
- Display with vector sink.
  - 122,880,000 sample rate / 16384 samples = 7,500 Hz / bin

Measurement Flowgraph



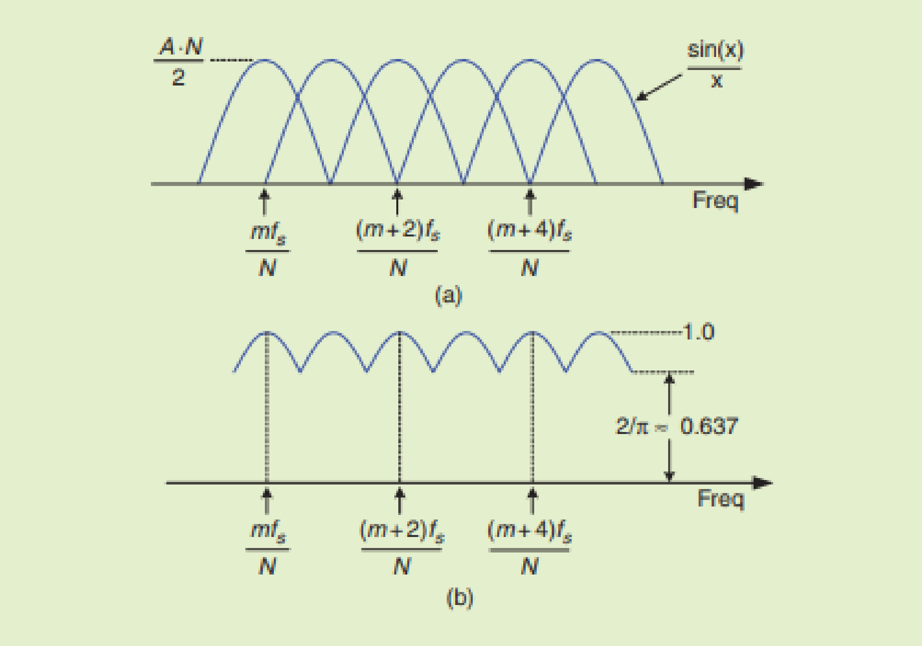
OpenHPSDR Rx with 50 ohm source resistor.



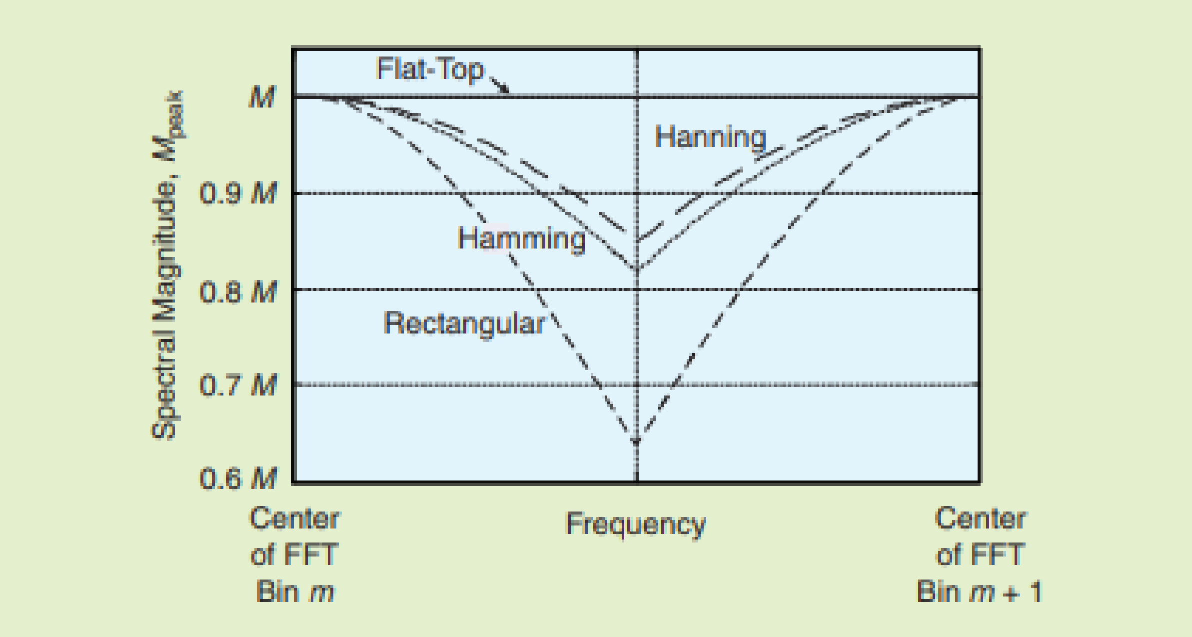
SNR != Dynamic Range

- This 16 bit ADC specified as 12.6 effective number of bits (ENOB).
  - SNR = 1.76 + 6.02 * 12.6 = 77.6 dB
- SNR = Maximum signal compared to quantization noise in the ADC's Nyquist BW (ADC clock / 2).
- Filtering and decimation reduce the noise by integration / limiting of the bandwidth.
  - Spurious components that are periodic do not decrease by integration.
- Max signal divided by invariant (spurious) signals yields the Spurious-Free Dynamic Range (SFDR).
  - ADC SFDR is specified at about 100 dB.
    - The actual receiver implementation degrades this.

FFT Scalloping – Amplitude vs. Frequency Offset from bin center.



[FIG1] FFT frequency magnitude responses: (a) individual FFT bins and (b) overall FFT response.



[FIG2] Windowed-FFT, bin-to-bin, frequency magnitude responses.

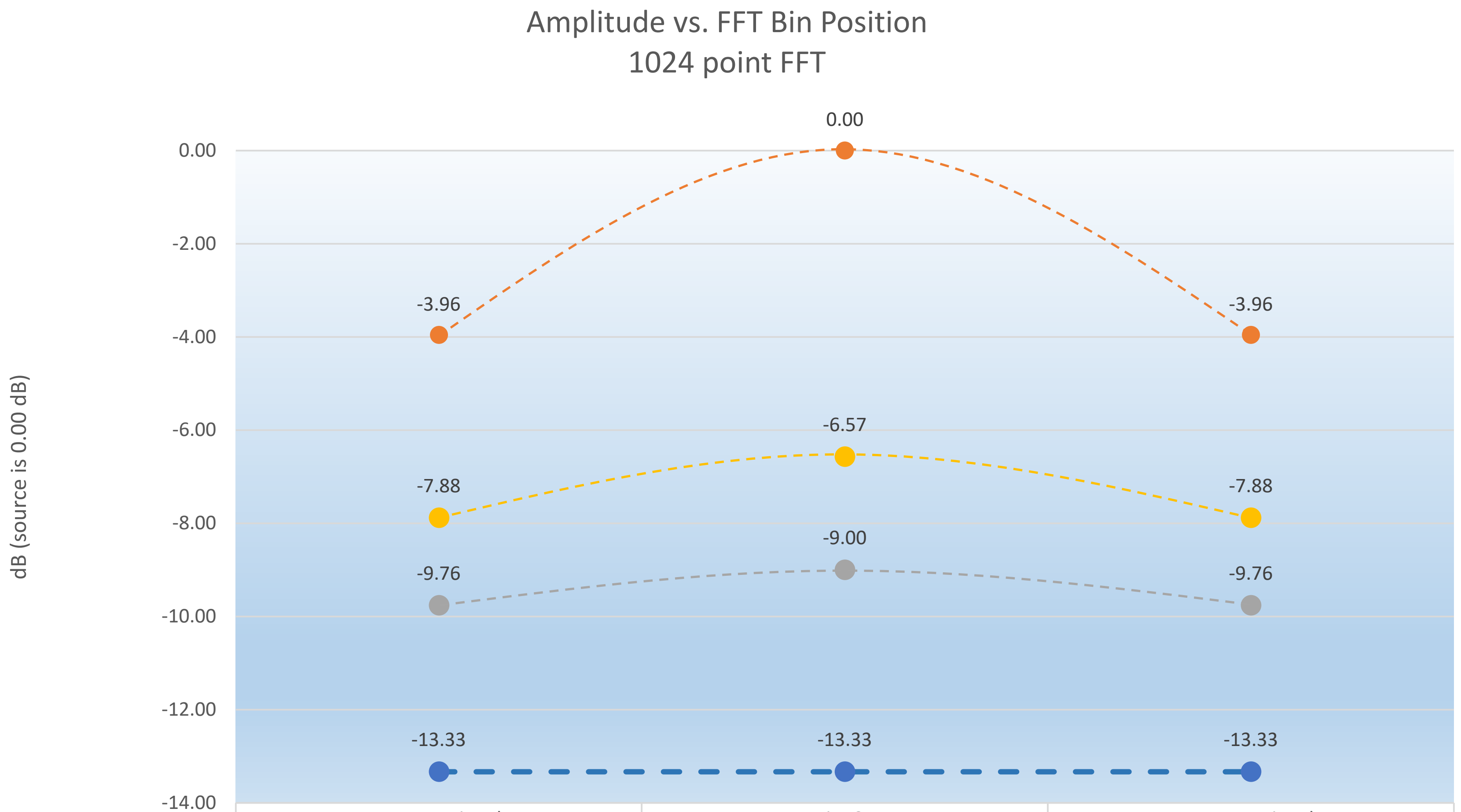
Figures from: R. Lyon – “Reducing FFT Scalloping Loss Errors without Multiplication”, IEEE Signal Processing Magazine, March 2011

FFT Scalloping and Windowing Variations

- FFT bin response is sin(x)/x – resulting in amplitude ‘scalloping’
- FFT assumes that the input signal is periodic.
- Windowing can be applied in the time domain to clean up some FFT spectral leakage.
- Windowing modifies scalloping errors in the FFT output.
  - Windows cause the output of the FFT to vary as the signal deviates from the center frequency of the FFT output bin.
  - Different windows have different errors – referred to as scalloping errors.
- Standard Gnuradio windows do not have the same gain.
  - Leading to additional amplitude variations - about 13.3 dB.
  - Lyon’s approach is for all windows to have the same amplitude at the FFT bin center.

Gnuradio (3.8 and 3.9) Measurements

Amplitude vs. signal frequency relative to bin center and bin edge



	Lower FFT Bin Edge	FFT Bin Center	Upper FFT Bin Edge
Rectangular	-3.96	0.00	-3.96
Blackman-Harris	-9.76	-9.00	-9.76
Kaiser	-7.88	-6.57	-7.88
Flat-top	-13.33	-13.33	-13.33

Rectangular   Blackman-Harris   Kaiser   Flat-top

Numeric Precision

- OpenHPSDR receivers create 24-bit 2’s complement binary values.
  - They are converted to single-precision floating point in the HPSDR gnuradio block.
- The dynamic range of 24 bit numbers is 16,777,215 : 1, or about 144.5 dB.