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.
      \[ NF = 10 \times \log_{10} \left( \frac{10^{(\text{ENR}/10)}}{10^{(Y/10)}-1} \right) \]
  • 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.
3\textsuperscript{rd} 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 3\textsuperscript{rd} 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

SDR Receiver

Legend:
- Legacy receiver
- Direct sampling SDR

- IM3 product increases 3 dB per dB of input power
- IM3 product is nearly independent of input power
(0 dBFS = ADC clipping level)

Ref. Adam Farson VA7OJ
Generator Combiner Types

- Resistive combiner - poor
  - + Impedance matching.
  - + very broadband
  - + Inexpensive, junk box parts.
  - - Does not isolate generators from each other

- Wilkinson combiner - better
  - + Provides some generator-generator isolation
  - +/- Moderate cost
  - - Frequency-dependent:
    - Coaxial cable delay lines or LC quarter wave sections
  - +/- Somewhat broadband:
    - Transformers. Cost: higher

- Active buffer amplifier for each generator
  - - Expensive, Active. Need amplifiers with good reverse isolation.
  - + Good generator-generator isolation.
  - + More broadband.
Quick and Dirty approach:
Poor generator isolation
IP3 measurement: Open HPSDR Hermes
2.5 KHz spacing

SDR IP3 Measurement

Input level of carriers
Generator induced spurious (crosstalk)
Measured 3rd order IP3 level
Average residential noise Level (at 10 MHz)

Output DB vs Input DBfs

S9+90
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

Options
- Title: hermes WB spectrum
- Output Language: Python
- Generate Options: QT GUI

Variable
- Id: sample_rate
- Values: 122.88M

QT GUI Range
- Id: alpha
- Label: IIR Filter alpha
- Default Value: 1
- Start: 0
- Stop: 1
- Step: 100u

hermesWB
- RX Preamp Off/On: 0
- Ethernet Interface: 0
- HPSDR Clock Sources: 0xF
- Alex Tx Antenna: Tx 1
- Alex Rx Antenna: Rx Ant via TR Relay
- Alex Rx HPP: Bypass
- Alex Tx LPF: 6m LPF
- MAC Address or IP

FFT
- FFT Size: 16,384
- Forward/Reverse: Forward
- Window: window.blackmanharris
- Shift No
- Num. Threads: 1

Vector to Streams
- Vec Length: 8,192k

Single Pole IIR Filter
- Alpha: 1
- Vec Length: 8,192k

Complex to Mag
- Vec Length: 8,192k

Log10
- n: 20
- k: 0
- Vec Length: 8,192k

Null Sink
- Vec Length: 8,192k

Mirror-image samples
Array of IIR filters
OpenHPSDR Rx with 50 ohm source resistor.
SNR $\neq$ Dynamic Range

- This 16 bit ADC specified as 12.6 effective number of bits (ENOB).
  - $\text{SNR} = 1.76 + 6.02 \times 12.6 = 77.6 \text{ dB}$

- $\text{SNR} =$ 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.

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

Amplitude vs. FFT Bin Position
1024 point FFT

<table>
<thead>
<tr>
<th>Lower FFT Bin Edge</th>
<th>FFT Bin Center</th>
<th>Upper FFT Bin Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>-3.96</td>
<td>0.00</td>
</tr>
<tr>
<td>Blackman-Harris</td>
<td>-9.76</td>
<td>-9.00</td>
</tr>
<tr>
<td>Kaiser</td>
<td>-7.88</td>
<td>-6.57</td>
</tr>
</tbody>
</table>

dB (source is 0.00 dB)