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

SDR Receiver

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
3rd order measurement block diagram

Generator 1
10.0000 MHz

Generator 2
10.0025 MHz

Resistive combiner

Step Attenuator

SDR Under Test
IP3 measurement: Open HPSDR Hermes
2.5 KHz spacing

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

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: samp_rate
Values: 122.88M

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

hermesWB
Rx Preamp Off/On: 0
Ethernet Interface: enp1s0
HPSDR Clock Sources: 0xF8
Alex TxAntenna: TxA1
Alex RxAntenna: TxAnt via TR Relay
Alex Rx HPP: Bypass
Alex TxA LPF: 6m LPF
MAC Address or IP

FFT
FFT Size: 16384
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: 10
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.

- DC Component (ADC offset voltage)
- Spurious Component
- Input Rx Leakage
- Spurious Components
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.

FFT Scalloping and Windowing Variations

• FFT bin response is \( \frac{\sin(x)}{x} \) – 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>Method</th>
<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>
<td>-3.96</td>
</tr>
<tr>
<td>Blackman-Harris</td>
<td>-9.76</td>
<td>-9.00</td>
<td>-9.76</td>
</tr>
<tr>
<td>Kaiser</td>
<td>-7.88</td>
<td>-6.57</td>
<td>-7.88</td>
</tr>
</tbody>
</table>
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.