SYSTEM GAIN AND NOISE FIGURE CALCULATIONS FOR DIGITAL COMMUNICATIONS SYSTEMS

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FFT SIGNAL ANALYSIS METHODS

ABSOLUTE AMPLITUDE CALCULATION

Given N, complex, time domain samples from an ADC, execute the following steps to correctly measure the absolute amplitude of a continuous-wave input signal.

1. Normalize time domain samples by the resolution of the ADC. Normally, the time samples represent a peak voltage.

$$\text{Normalization Factor} = \frac{2^{\text{ADC Resolution}}}{2}$$

2. Multiple these samples by the full-scale peak voltage of the ADC.
3. Normalize all samples by N in order to correctly represent the amplitude spectrum after the DFT is performed (see DFT equation).
4. Multiply time domain samples with a Flattop window, correct for coherent power gain. A periodic (not symmetric) window should be used for spectral representation.

$$\text{Windowed Samples} = \text{Samples} * \text{Flattop Window} * \frac{1}{a_0};\ \text{where } a_0 = 0.215578948$$

5. Convert the time domain samples to frequency domain samples by applying the Discrete Fourier Transform.
6. Calculate the FFT power spectrum by taking the square of the magnitude of each complex frequency sample.

$$\text{FFT Power Spectrum} = |X[n]|^2$$

7. Normalize the power spectrum per the input impedance, mW to present the result in dBm units.

$$\text{FFT Power Spectrum (dBm)} = 10 * \log\left(\frac{\text{FFT Power Spectrum}}{\text{R} * \text{1mW}}\right)$$

SYSTEM NOISE FIGURE

Given N, linear, power spectrum samples, execute the following steps to correctly measure the system noise figure.

1. Windowing causes the effective noise bandwidth within a bin to expand by a factor called Equivalent noise bandwidth (ENBW). When the power in a frequency bin is assumed to be a tone, the concept of noise bandwidth does not apply, and no compensation for ENBW should be applied. When the power in a frequency bin is assumed to be from AWGN source, the concept of noise bandwidth does apply and compensation for ENBW should be applied. Correction is performed by dividing the frequency domain samples by the ENBW factor for the window chosen.

$$\text{ENBW Corrected Samples} = \frac{\text{Frequency Samples}}{\text{ENBW Factor}}$$
$$\text{where ENBW Factor} = 3.77 \text{ for the Flattop window}$$

2. Compute the total noise power in an arbitrary window by integrating the noise frequency bins over the window and convert to dBm.

$$\text{Total Window Noise Power at the Output (dBm)} = 10 * \log_{10} \sum_{\text{start bin}}^{\text{stop bin}} \text{Linear Power Spectrum Samples}$$

3. Subtract the previously measured system gain to arrive at the Total Window Noise Power at the System Input (dBm).
4. Compute the FFT bin, unit bandwidth (Hz), sometimes also called the FFT resolution bandwidth (RBW) by dividing the sample rate by the size of the FFT.
5. Calculate the bandwidth of the noise window by multiplying the total number of noise window bins by the FFT resolution bandwidth.
6. Convert the noise window bandwidth to dBHz.

$$\text{Noise Bandwidth (dBHz)} = 10 * \log_{10} \text{Noise Bandwidth}$$

7. Subtract the noise bandwidth (dBHz) from the Total Window Noise Power at the System Input (dBm) to get the Average Noise Power Spectral Density at the Input (dBm/Hz)

$$\text{Average NSD}\left(\frac{\text{dBm}}{\text{Hz}}\right) = \text{Total Window Noise Power} - \text{Noise Bandwidth}$$

8. Calculate the Approximate System Noise Figure by taking the difference between the Average Noise Spectral Density and the kTB Thermal Noise Spectral Density.

$$Noise\ Figure\ (dB) = Average\ NSD\left(\frac{dBm}{Hz}\right) - 174\ \left(\frac{dBm}{Hz}\right)$$

PLOTS

The following data captures were taken with a PRODUCT X., utilizing direct conversion receive mode, tuned to 900 MHz (internal local oscillator) with the baseband 1 path, and 68 dB gain setting.

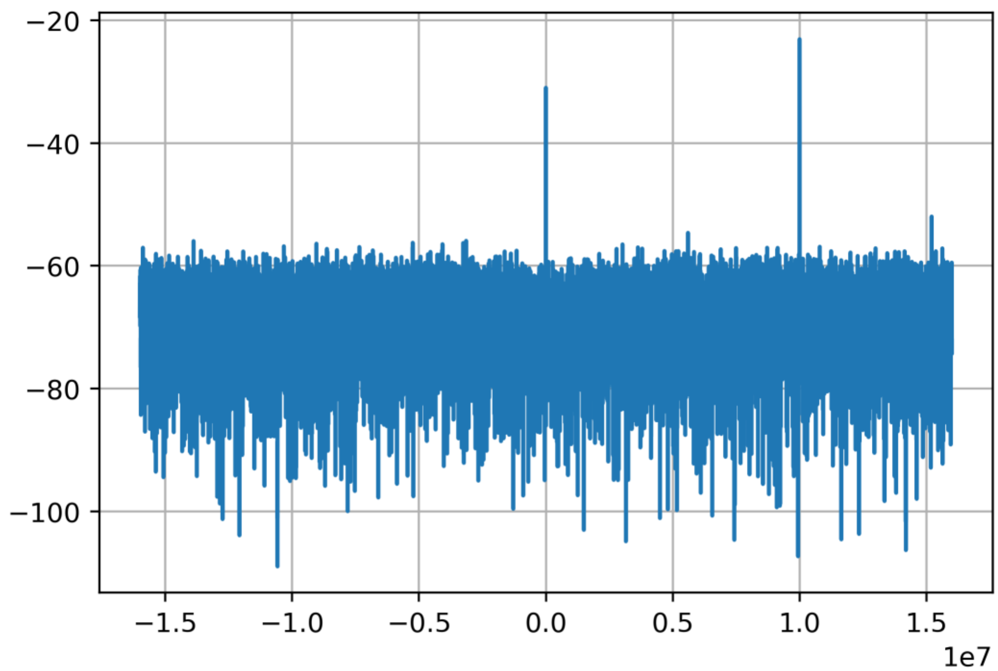

Figure 1: -80 dBm input signal @ 10 MHz, 32 MSPS, N=2*15, no averaging

<u>Reported Statistics:</u>

System Gain: 56.94 dB

System Noise Figure: 15.31 dB

ADC Full Scale Input: 0.97 dBm

Peak of: -23.06 dBm, occurred at index: 26621

Signal Level of: -24.03 dBFS

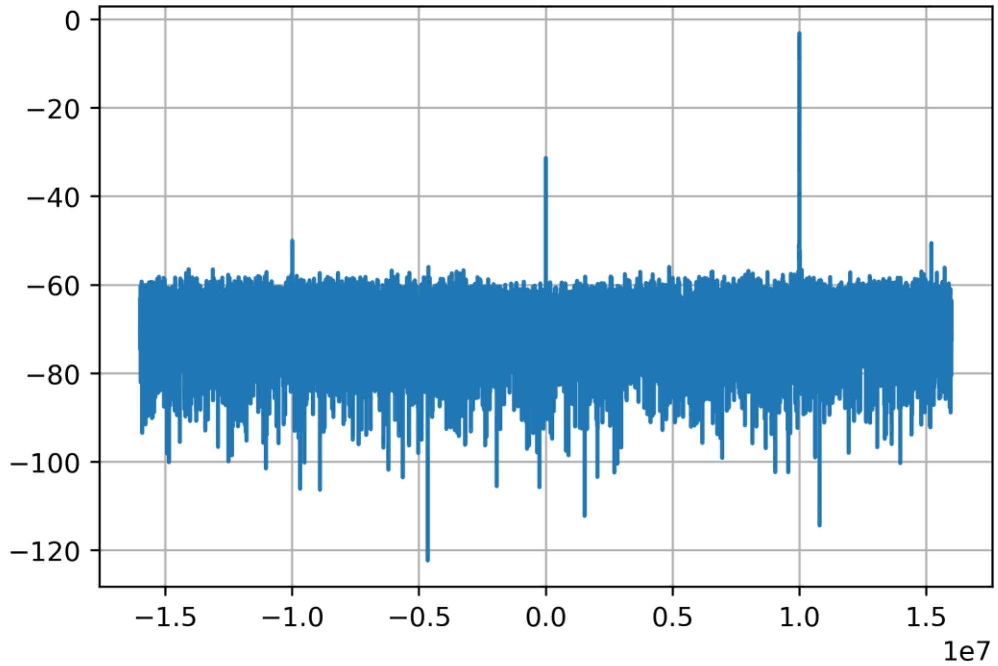

Figure 2: -60 dBm input signal @ 10 MHz, 32 MSPS, N=2*15, no averaging

<u>Reported Statistics:</u>

System Gain: 56.92 dB

System Noise Figure: 15.65 dB

ADC Full Scale Input: 0.97 dBm

Peak of: -3.08 dBm, occurred at index: 26621

Signal Level of: -4.05 dBFS

SPECTRAL FLATNESS FOR OFDM WAVEFORMS

Spectral Flatness provides insight into transmitter waveform integrity, specifically analyzing subcarrier performance across the waveform's channel bandwidth.

1. For most common OFDM waveforms, such as in a 3GPP compliant LTE system, analysis should be performed on the pilot symbols. This is due to the fact that these are the symbols the reciever will use for channel estimation and synchronization.

2. Custom OFDM waveforms which use a large number of pilot symbols or static pilot symbols that are not rotated around the constellation, can alternatively perform the Spectral Flatness analysis on the data carriers since this data is known to be changing.
3. Capture 1 OFDM frame and apply the FFT to obtain the complex frequency spectrum, $X[n]$.
4. Calculate the Power Spectrum by squaring $X[n]$.
5. Calculate the, per carrier RMS power, over N measurements.

$$\text{Carrier RMS Power} = \sqrt{\frac{\text{FFT}(\text{x}[\text{n}])^2}{\text{N}}}$$

6. Calculate the mean and variance of the carrier's RMS power.
7. Take the ratio of the carrier RMS power variance divided by the RMS power mean. This value indicates the carrier's variance normalized w.r.t the mean carrier power – overall resulting in a good indicator of the subcarrier's spectral flatness.
8. In addition to looking at the per carrier spectral flatness it may also be useful to look at the overall waveform flatness as the mean of the normalized carrier power variance. This metric, combined with the per carrier metric, provide substantial information about waveform integrity from both the individual subcarrier and waveform bandwidth perspectives.

REFERENCES

[1] Stefan Scholl, "Exact Signal Measurements using FFT Analysis", Microelectronic Systems Design Research Group, TU Kaiserslautern, Germany