Noise Power Ratio for the GSPS ADC

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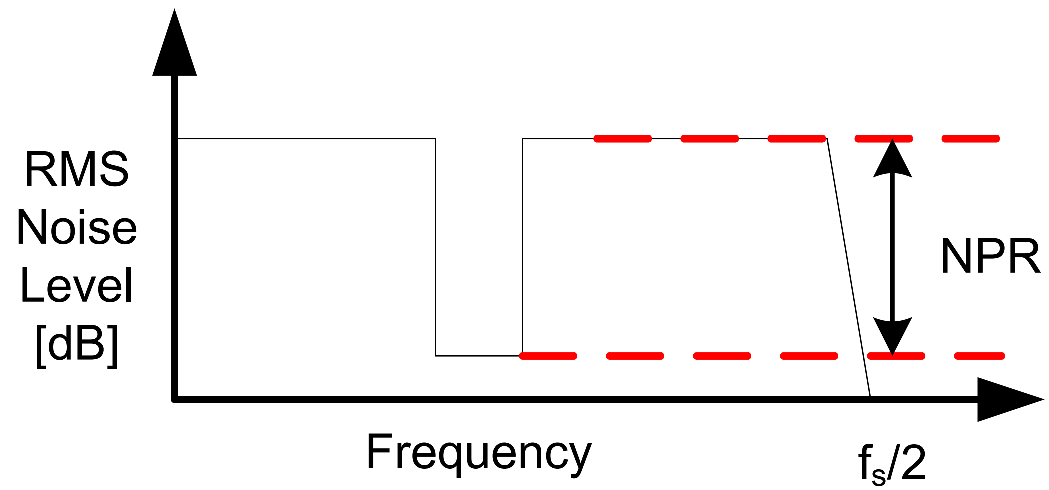
Noise Power Ratio (NPR) Overview

- Concept
- History
- Definition
- Method of Measurement
- Notch Considerations
- Theoretical Values
- RMS Noise Loading Level

NPR Overview: Concept

- Noise Power Ratio (NPR) is how quiet one unused channel in a wideband system remains when the other channels cause noise in it due to inter-modulation. In a wideband system, it is more appropriate than a simple IMD test as a measurement of system performance. [1]



NPR Overview: History

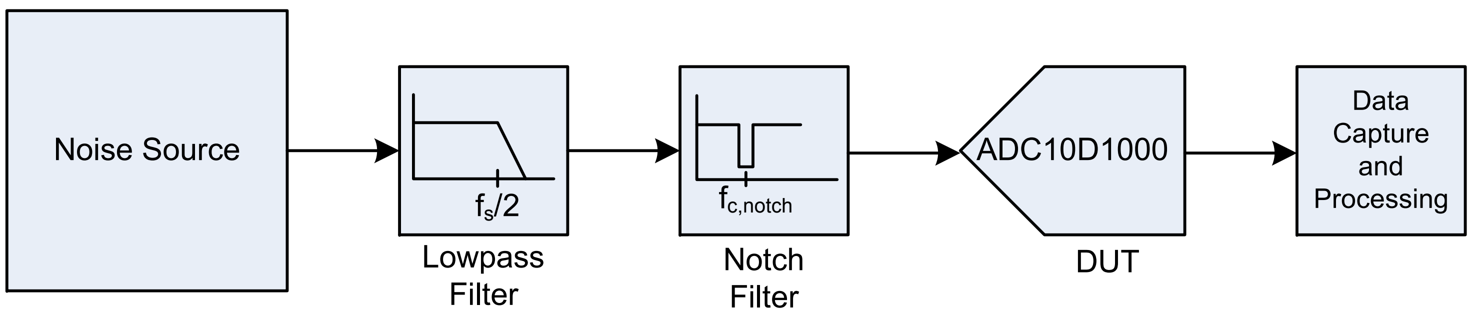
- NPR testing was historically developed to evaluate Frequency Division Multiplexed (FDM) communication systems. A typical system might consist of 4 kHz wide voice channels, stacked up for transmission into one higher bandwidth signal. At the receiving end, the FDM data was de-multiplexed and converted back to 4 kHz voice channels. Noise and distortion was added to the signal after passing through amplifiers, repeaters, channel banks, etc. [2]
- Because ADCs also process broadband signals and because their specific applications are varied, this figure of merit finds a modern-day application in evaluating ADC performance. [3]

NPR Overview: Definition

NPR is the ratio of the sum of the power inside the notched bins (P_{Ni}) to the sum of the power in an equal number of bins outside the notch (P_{No}).

$$NPR = 10 * \log_{10} \frac{P_{Ni}}{P_{No}}$$

NPR Overview: Method of Measurement

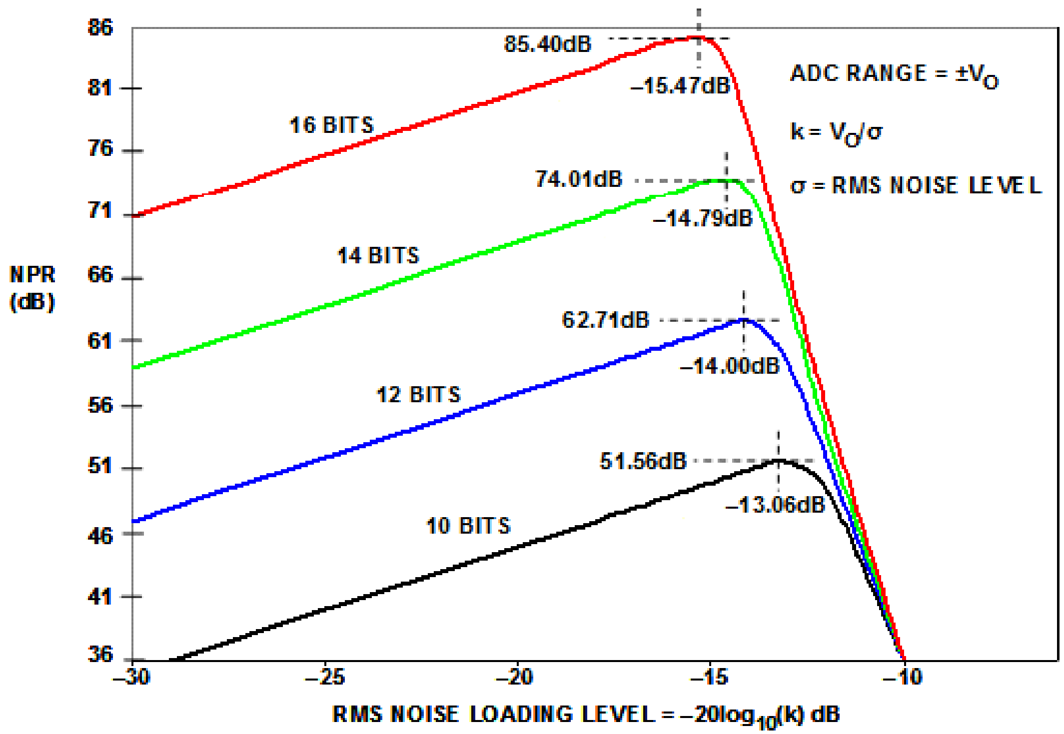


- Either a Gaussian or uniformly distributed signal may be used for the noise source, but for ADCs, the Gaussian source is more relevant. [2]
- A lowpass filter is used to prevent noise aliasing, which would lead to a higher, inaccurate NPR measurement.

NPR Overview: Notch Considerations

- *Width* – A tradeoff exists for the notch width; if the notch is too narrow, there will not be enough samples within the notch for a statistically meaningful result, but if the notch is too wide, then the test results may not be valid.
  - Recommendation: The notch width should include more than 100 bins, but it should be less than 10% of the signal bandwidth.
- *Depth* – "To obtain a meaningful measurement, the depth of the notch must be at least 10dB greater than the NPR value being measured." [3]
- *Frequency* – The NPR vs. noise input level may be measured at a mid-band notch frequency, for example, $f_s/4$. To characterize the ADC fully, the NPR should also be measured over frequency at the noise input level for which the NPR is maximized.

NPR Overview: Theoretical Values



- The theoretical NPR curve is shown for a 10, 12, 14 and 16-bit ADC vs. the RMS noise loading level. [2]
- These curves are based on an ideal ADC where the only noise is from quantization and clipping.
- For a 10-bit converter, such as the ADC10D1000, the maximum NPR should occur at an RMS noise loading level of -13.06dB.

NPR Overview: RMS Noise Loading Level

- NPR is typically plotted as a function of RMS noise loading level.
- Historically, the goal was to find the optimum channel loading level which would yield the maximum NPR.
- For low noise loading levels, the undesired noise is primarily thermal noise, so that a 1dB increase in RMS input level leads to a 1dB increase in NPR.
- As the RMS noise loading level is increased, components in the system begin to overload (clipping for an ADC) and inter-modulation products are created, which cause the notch noise floor to increase. [2]

<u>RMS Noise Loading Terms:</u>

- ADC Range = $\pm V_o$; full-scale is $2V_o$ peak-to-peak
- Input RMS noise level is σ
- Crest factor is $k = V_o/\sigma$; peak-signal-to-rms-noise-ratio
- RMS-noise-to-peak-signal-ratio is 1/k; expressed in dB, this becomes:

$$-20 * \log_{10}(k)$$

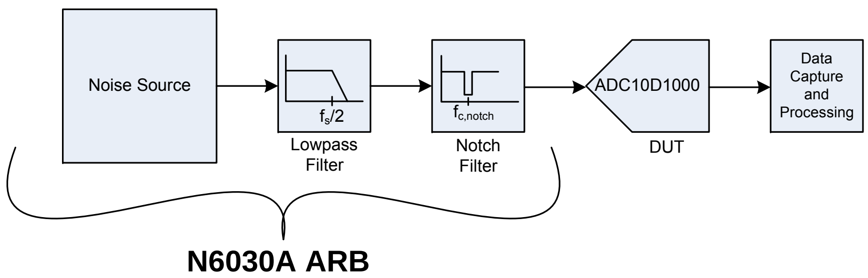
Test Setup

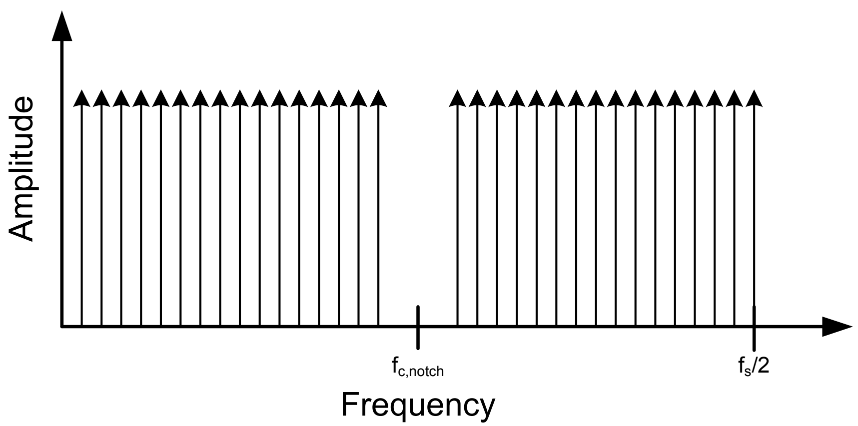
- Overview
- ARB Setting and Waveforms
- Method of Measurement

Test Setup: Overview

- *Noise Source* – A Gaussian noise source, lowpass filter, and notch filter are all integrated into one piece of equipment: an Arbitrary Waveform Generator (ARB).
- *Hardware* – The major equipment required for this measurement were an ARB, spectrum analyzer, logic analyzer, and scope.
- *Data capture and processing*
  - Logic analyzer – The data was captured (32k/capture) three times at each setting and averaged afterwards.
  - Matlab – This program was used to window the data to calculate power spectral density inside and outside the notch, and calculate NPR.

Test Setup: Arbitrary Waveform Generator (ARB) Setting





- The N6030A ARB (15-bit internal DAC) is used to generate approximately 1000 sinusoids from 0 to 500MHz (DC to fs/2), spaced at 500kHz apart.
- It can generate a differential noise signal with a Gaussian distribution and has an internal 500MHz filter.
- To create a "notch filter", the sinusoids at that frequency are simply not generated. In this way, it is quite easy to vary the notch location and width.
- The notch for NPR measurements was centered at f_c=320MHz with a width of 25MHz (5%).

Test Setup: ARB Waveforms

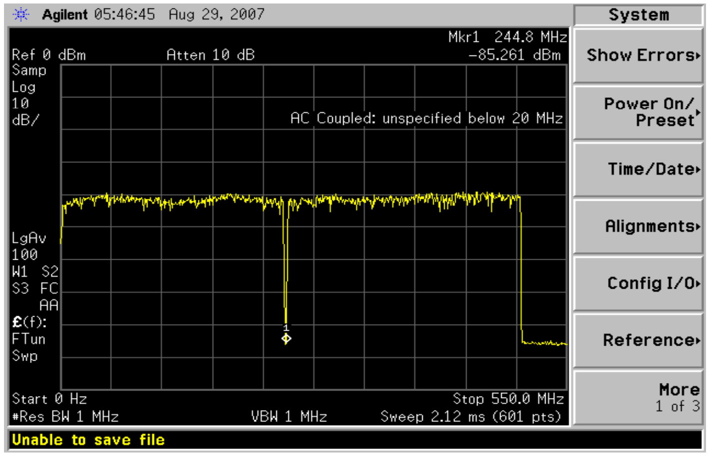


Figure 1. ARB output DC to fs/2

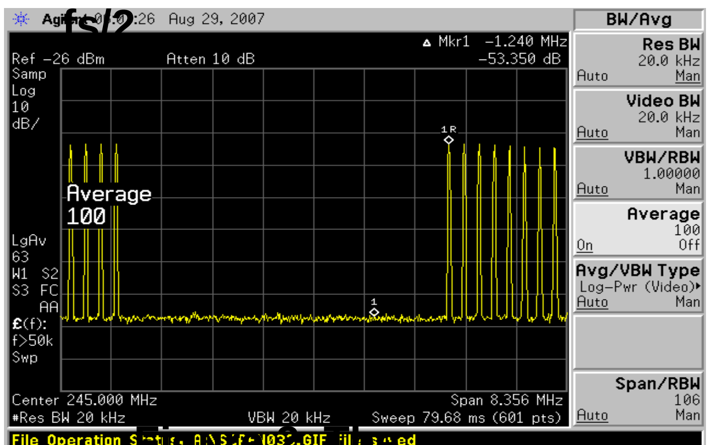


Figure 2. The Notch

- Fig.1 shows the ARB output from DC to $f_s/2$. At this scale, it appears that the input signal is simply white noise with a notch in the center.
- Fig. 2 shows the notch at a higher resolution. Here, it is apparent that the "white noise" is simply evenly spaced sinusoids with a section left out to create the notch.

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Test Setup:
Method of Measurement

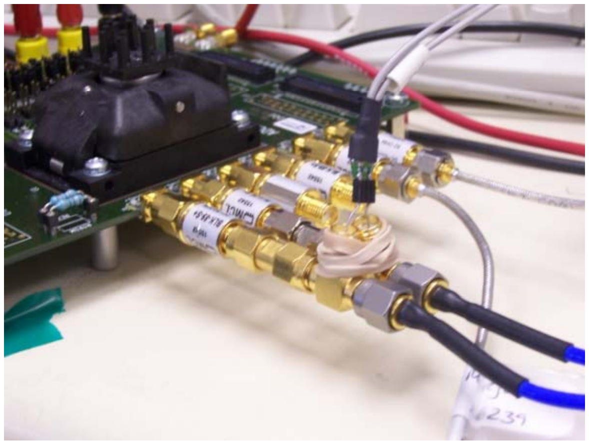

Figure 1. Probe setup

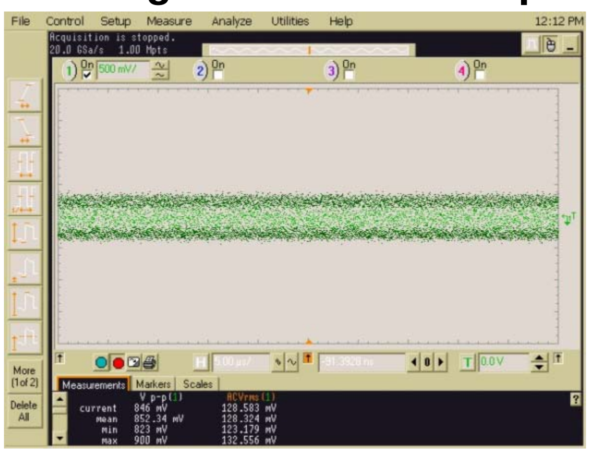

Figure 2. RMS Noise

- At each data point, the RMS noise loading (x-axis) and NPR (y-axis) are measured independently.
- The NPR is measured from the data capture, which is post-processed in Matlab.
- The RMS noise loading level is measured starting with V_{rms} from the scope.
- If the probes were directly connected to the ADC input or the ARB output, they loaded the signal a few dB, so they were placed after the amp/attenuator and before the DC blocks, and left on during the data capture.

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Reference Documents

[1] Fred H. Irons, “The Noise Power Ratio – Theory and ADC Testing,” IEEE Transactions on Instrumentation and Measurement, Vol. 49, No. 3, June 2000, pp. 659-665.

[2] W. Kester and R. Reeder, “MT-005: Noise Power Ratio (NPR) – A 65-Year Old Telephone System Specification Finds New Life in Modern Wireless Applications,” Oct., 2005; http://www.analog.com/en/content/0,2886,771%255F854%255F91252,00.html.

[3] IEEE Std. 1241-2000, IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters, IEEE, 2001, ISBN 0-7381-2724-8.