Early Results From an Analysis of the P2's ADC AC Performance (First draft only)

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The literature on this topic (references attached) discusses two possible approaches. In both of these, a pure sine wave is fed to the ADC and the waveform is recorded into a buffer memory.

In the first method, an FFT power spectrum is then computed and from this, various measures are obtained. Of considerable interest is SINAD, the ratio of the power in the signal (at the frequency of interest) to the power at all other frequencies (which includes distortion from harmonics plus all noise sources) up to the Nyquist limit ($f_{samp}/2$ Hz). An effective number of bits (ENOB) can be calculated from SINAD using the formula for an ideal n-bit ADC, which states that

$$\text{SINAD (dB)} = 6.02N + 1.76 \text{ dB} \qquad \text{(Eqn. 1)}$$

For a non-ideal (i.e. real) ADC, the above formula is simply re-arranged to compute N (which now becomes the ENOB for the real ADC) from the measured SINAD.

Another measure of interest is the THD, or the total harmonic distortion, which measures the power in all the harmonics of the input frequency. This can be expressed in fractional terms or as a percentage. For an ideal sine wave this will be zero. Familiar repeating waveforms such as triangular or square waves can each be represented by an infinite Fourier series and by summing the coefficients in these series, theoretical expressions can be derived for the THD – in the case of triangular waves we find 12.1% and for square waves, 48.3%.

There are a number of other measures of AC performance besides these which are discussed in an excellent Analog Devices tutorial (MT-003.pdf).

The second method of characterizing an ADC's AC performance uses a curve fitting approach. This is described in several of the references and just a brief summary is given here. A least squares fit is performed of the recorded waveform to a sine wave – A Sin[Bt+C]+ D. The RMS error ε_r (expressed in ADC counts) of the residuals (measuring the point-wise differences, measured-fit) is then used to calculate an ENOB.

The RMS error for an ideal ADC ε_i is 1 ADC count (the LSB) divided by the square root of 12 – 1/Sqrt[12] – this result is derived in a number of the references. By dividing the larger of these errors (for the real ADC) by the smaller one (for the ideal ADC) and taking the log2() we find out how many bits we have lost when using the real ADC compared to what the ideal ADC would have yielded.

Therefore to determine the ENOB using the curve fitting method, we use the following formula

$$\text{ENOB} = N_{ideal} - \log_2[\, \varepsilon_r / \varepsilon_i] = N_{ideal} - \log_2[\, \text{Sqrt}(12) * \varepsilon_r] \qquad \text{(Eqn. 2)}$$

Here, N_{ideal} is the resolution (in number of bits) for the ideal ADC. For an ADC yielding a count ADC_L for a ground measurement and ADC_H for a measurement of V_{CC} the ADC span is ADC_H-ADC_L and so the possible number of bits realized is $\log_2(ADC_H\text{-}ADC_L)$. In the case of the P2 we therefore make a slight adjustment to the above formula and use

$$ENOB = \log_2(ADC_H\text{-}ADC_L) - \log_2[\,Sqrt(12) * \varepsilon_r] \qquad \text{(Eqn. 3)}$$

Currently I am just obtaining the difference ADC_H-ADC_L from the maximum and minimum values in the recorded waveform. My (el-cheapo) function generator is based on an AD9834 and its output (depending on the frequency being generated) has some offset from the two power rails which slightly short-changes the final ENOB that is calculated (but I will correct this later by actually measuring V_{gnd} and V_{cc}).

Fig. 1 below shows a National Instruments LabVIEW vi that implements the above two methods. The user chooses an ADC method (bit summing, SINC2, or SINC3), an ADC pin # and a number of ADC_cycles for the measurement as well as a number of points (I delete the first few points after recording the waveform so here the latter was set to 8198 – which minus 6 skipped points yields an 8192 word sample buffer.

The data shown here has ADC pin = 16, ADC_cycles = 64 and with SINC3 acquisitions selected. The trace at the top shows the result of measuring a 204.4 kHz sine wave with the signal in yellow and the fit in red (note - this is an expansion of the full 8192 point waveform). The histogram plot in green shows the residuals. Here the span ADC_H-ADC_L is 2307 and the RMS error ε_r plot is 4.17 ADC counts. Using equation (3) this gives an ENOB of 7.32.

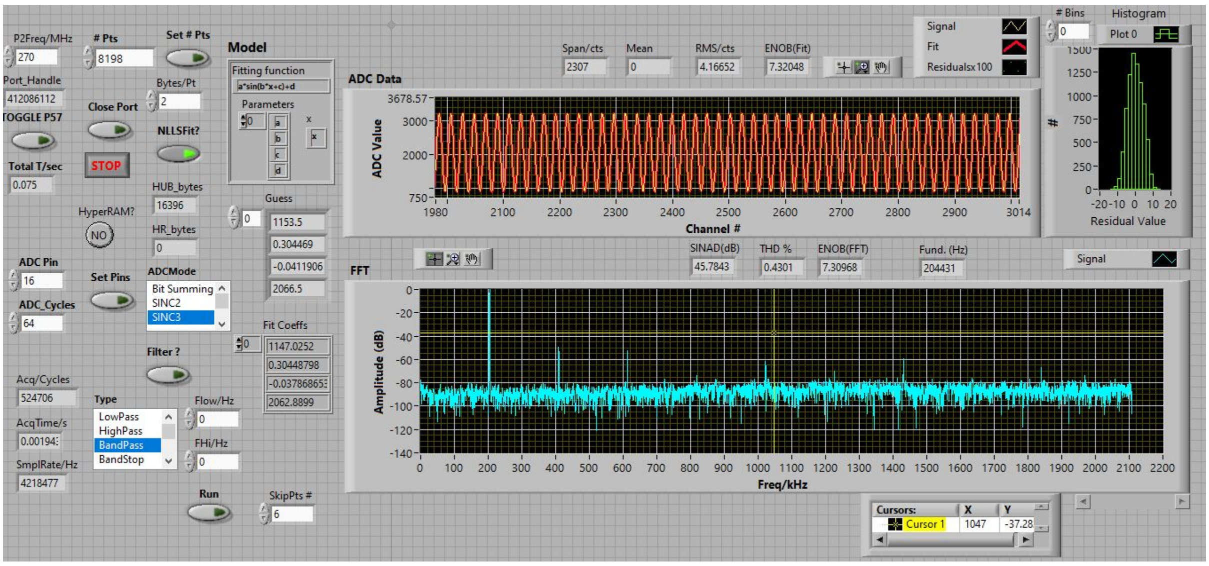

Fig. 1 A LabVIEW vi that implements the FFT and curve fitting methods to obtain an ENOB for a SINC3 ADC acquisition on ADC pin 16 (see text for details).

The lower (light blue) trace in Fig. 1 shows the power spectrum of the acquired waveform. LabVIEW's in-built FFT analysis vi was used to generate this data. Before doing the FFT I removed the DC component from the signal by subtracting its mean value. In this run the

P2's sampling rate is 4.218 MHz and so the Nyquist limit here is half of this – 2.1 MHz – the upper limit of the frequency axis. Several of the performance measures mentioned above have also been calculated in LabVIEW – the SINAD, here 45.8 dB and the THD, here 0.43%. Taking the measured SINAD, the ENOB calculated via equation 1 is 7.31, pleasingly close to the value obtained by the curve fitting method.

Incidentally, I also did some further measurements feeding in triangular and square waves and my measurement system gave THD values very close to the values expected as discussed earlier.