Prediction of Harmonic Distortion in ADCs using Dynamic Integral Non-Linearity Model

presented by:

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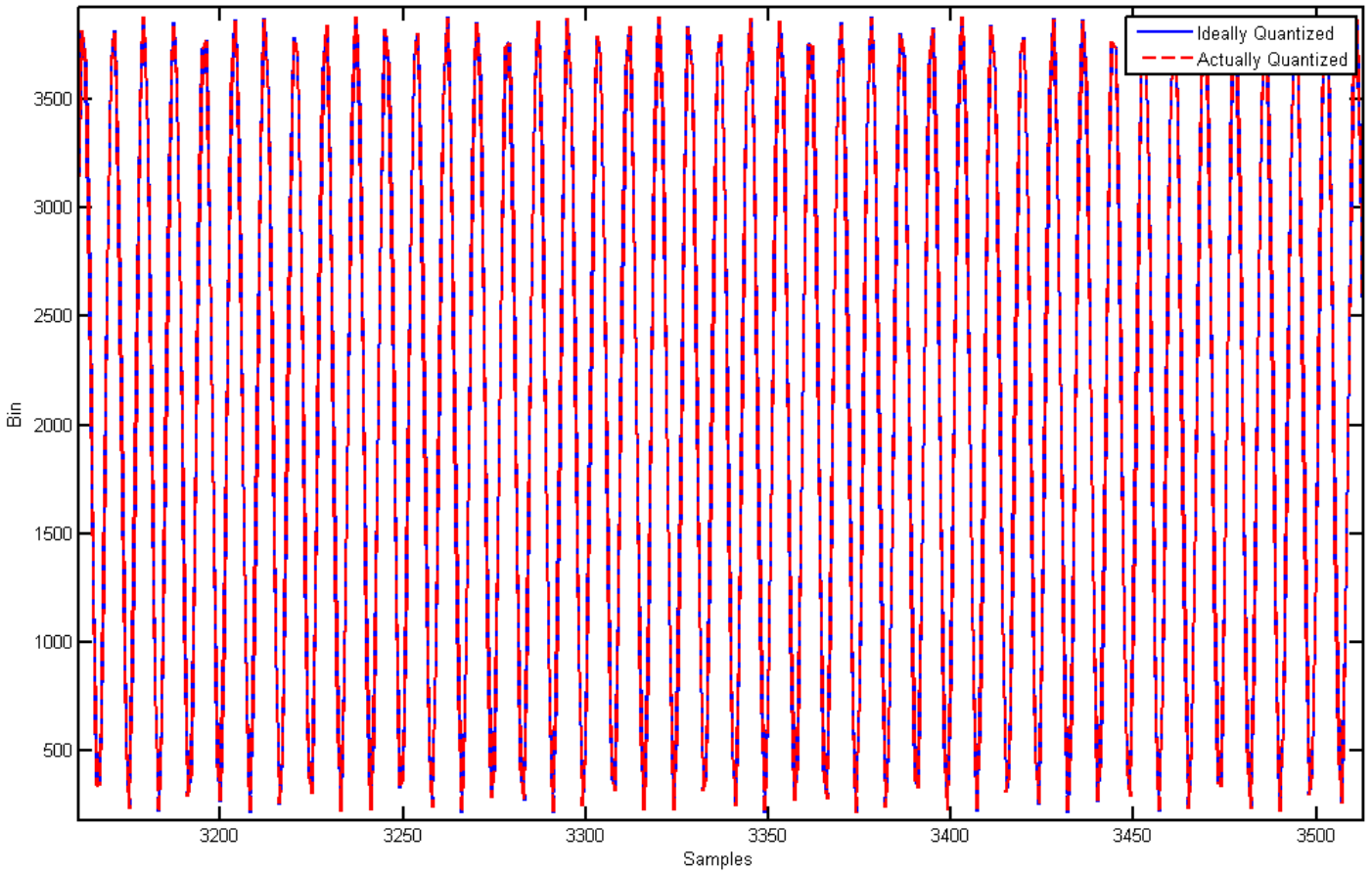
Introduction to Problem

- Analog-to-Digital Converters (ADCs) impair a signal's fidelity
- Two kinds of impairments
  - Noise
    - almost always independent of the input signal
    - places a limit on signal integrity
  - Distortion
    - almost always a function of input signal
    - can be predicted / corrected *if* dynamics causing the distortion are known
- **Goal: *Predict / Correct Distortion!***

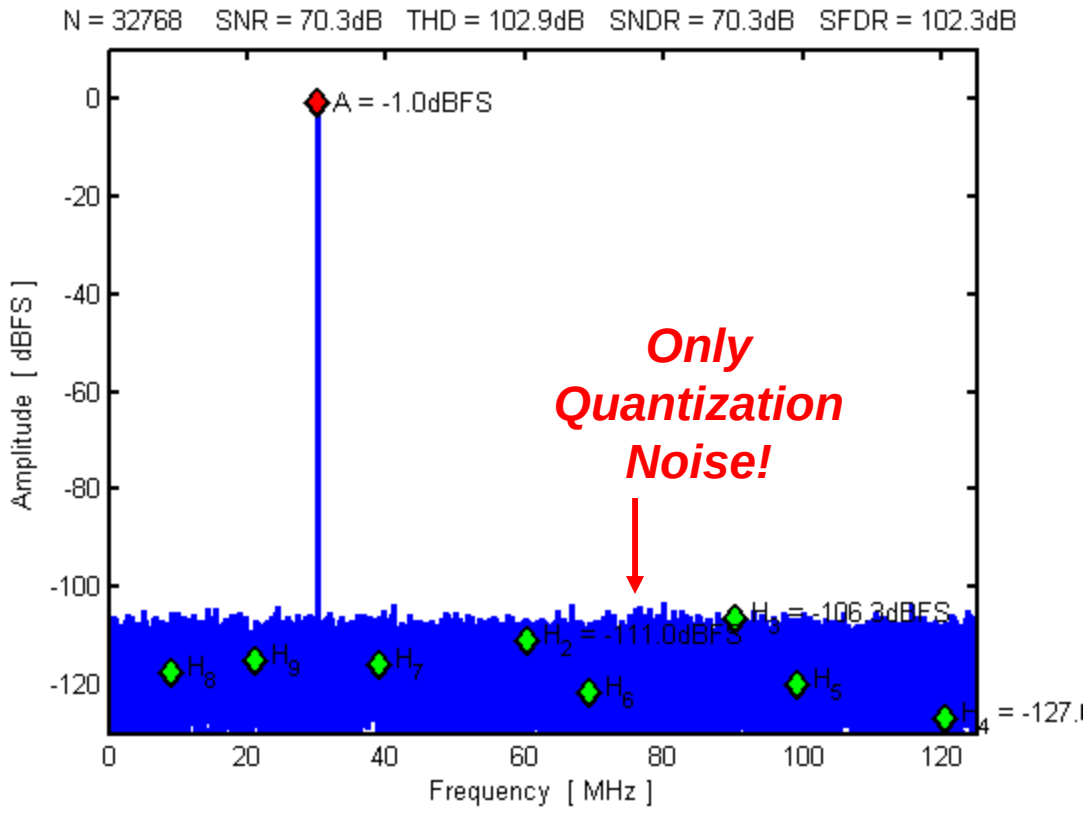
How distortion is measured?

- Frequency Domain
  - Spurious Free Dynamic Range (dBc/dBFS)
  - Total Harmonic Distortion (dBc)
- Time domain
  - Differential Non-linearity (DNL)
  - Intergal Non-linearity (INL)

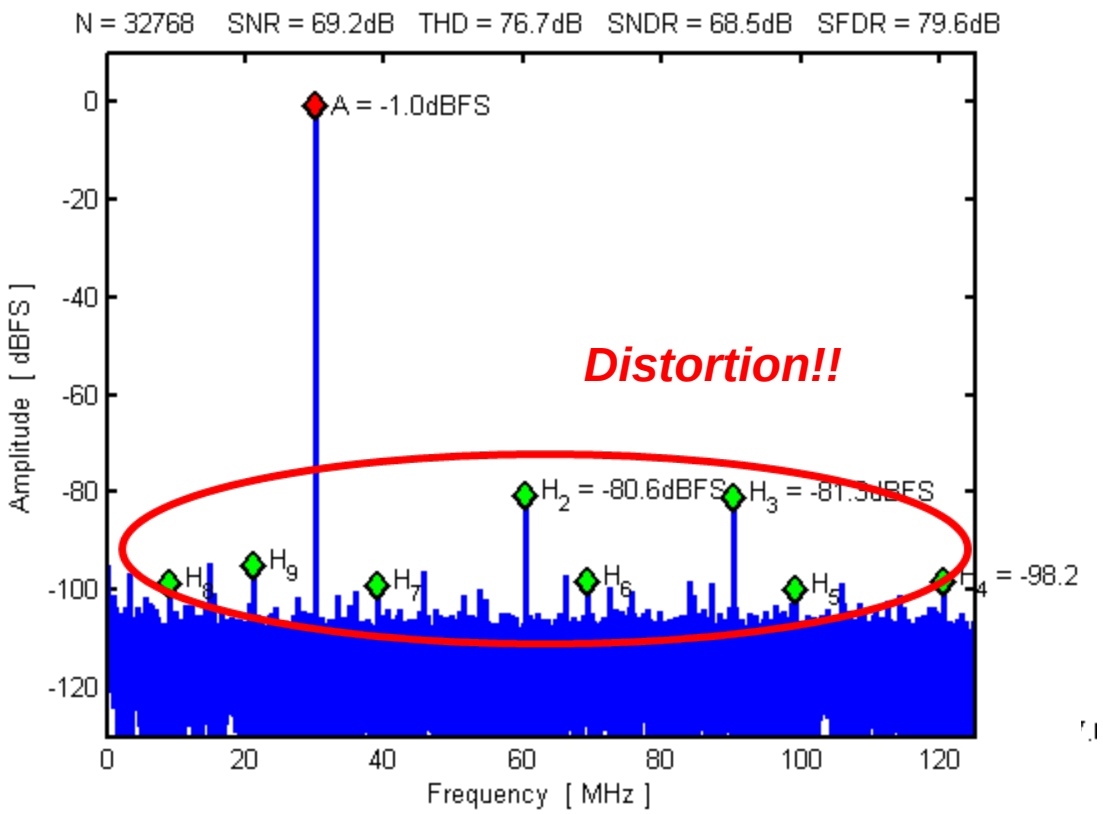
12-bit, 250 MSPS ADC (Time Domain)



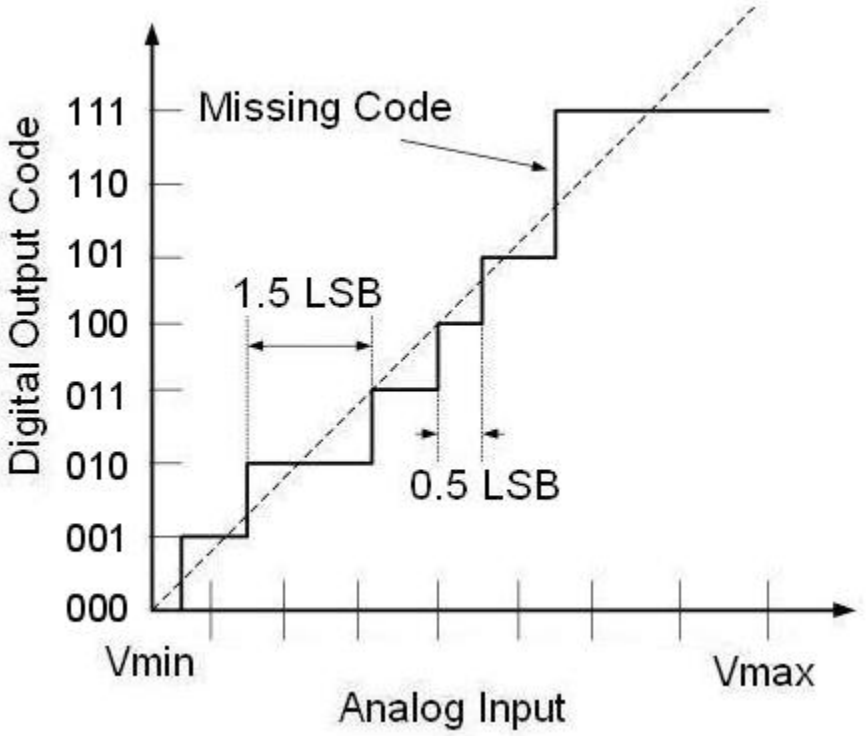
Ideal 12-bit, 250 MSPS ADC (Spectrum)

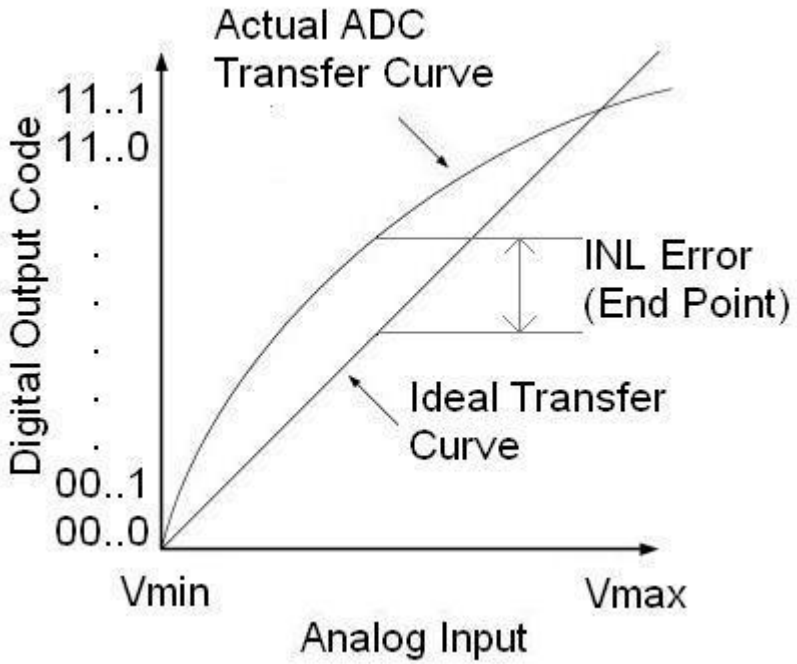


Actual 12-bit, 250 MSPS ADC (Spectrum)

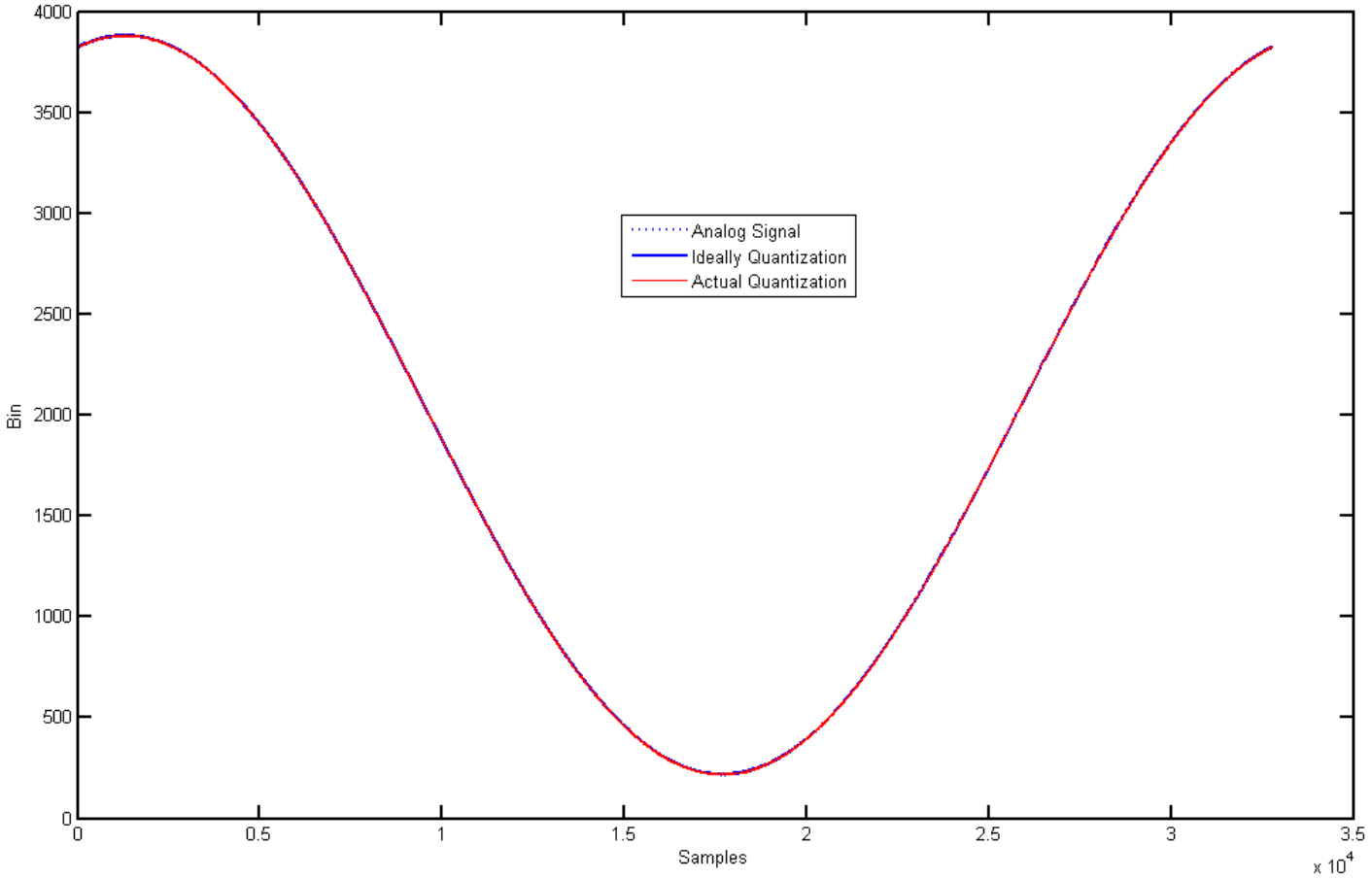


INL/DNL Definition

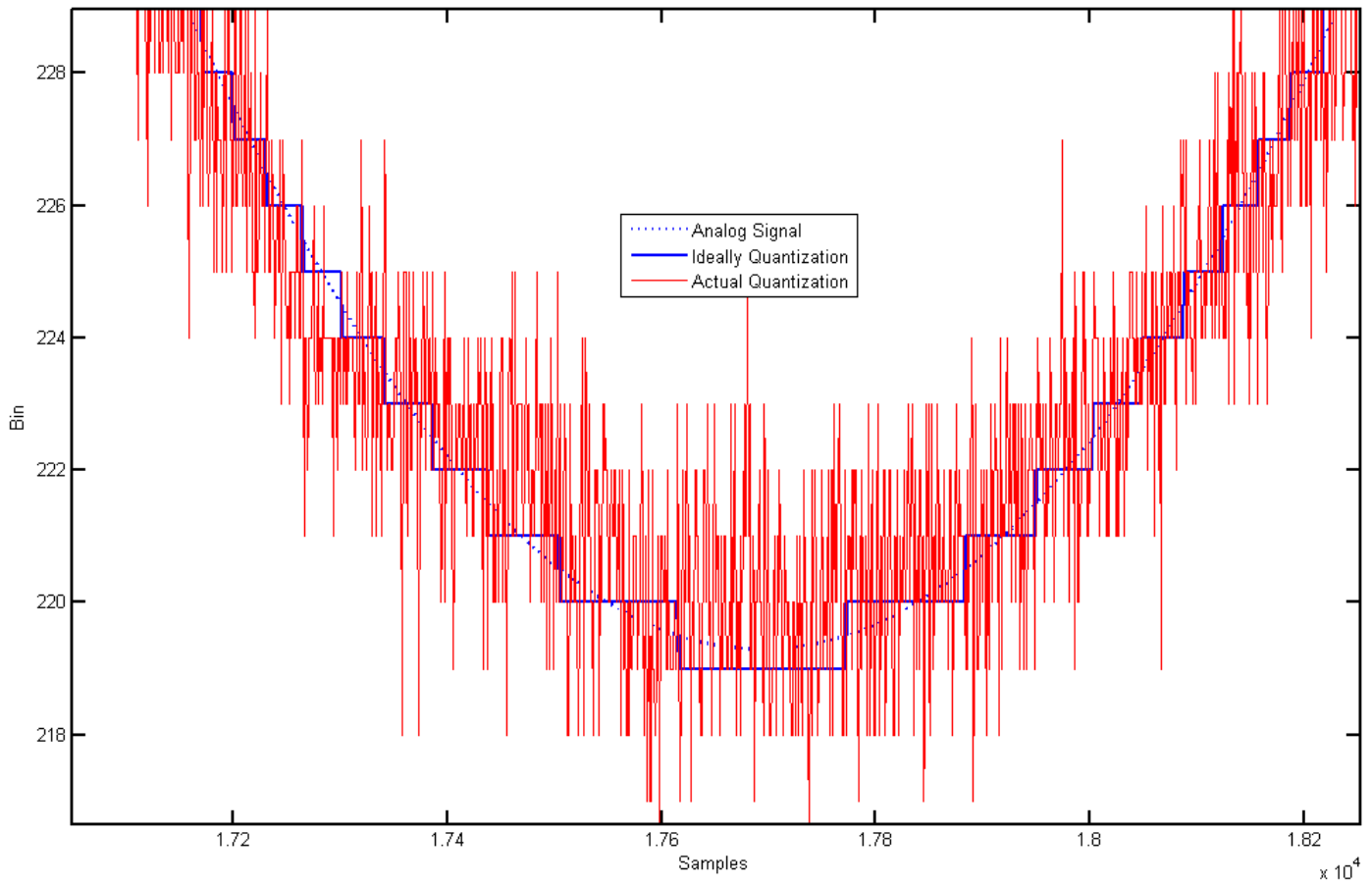




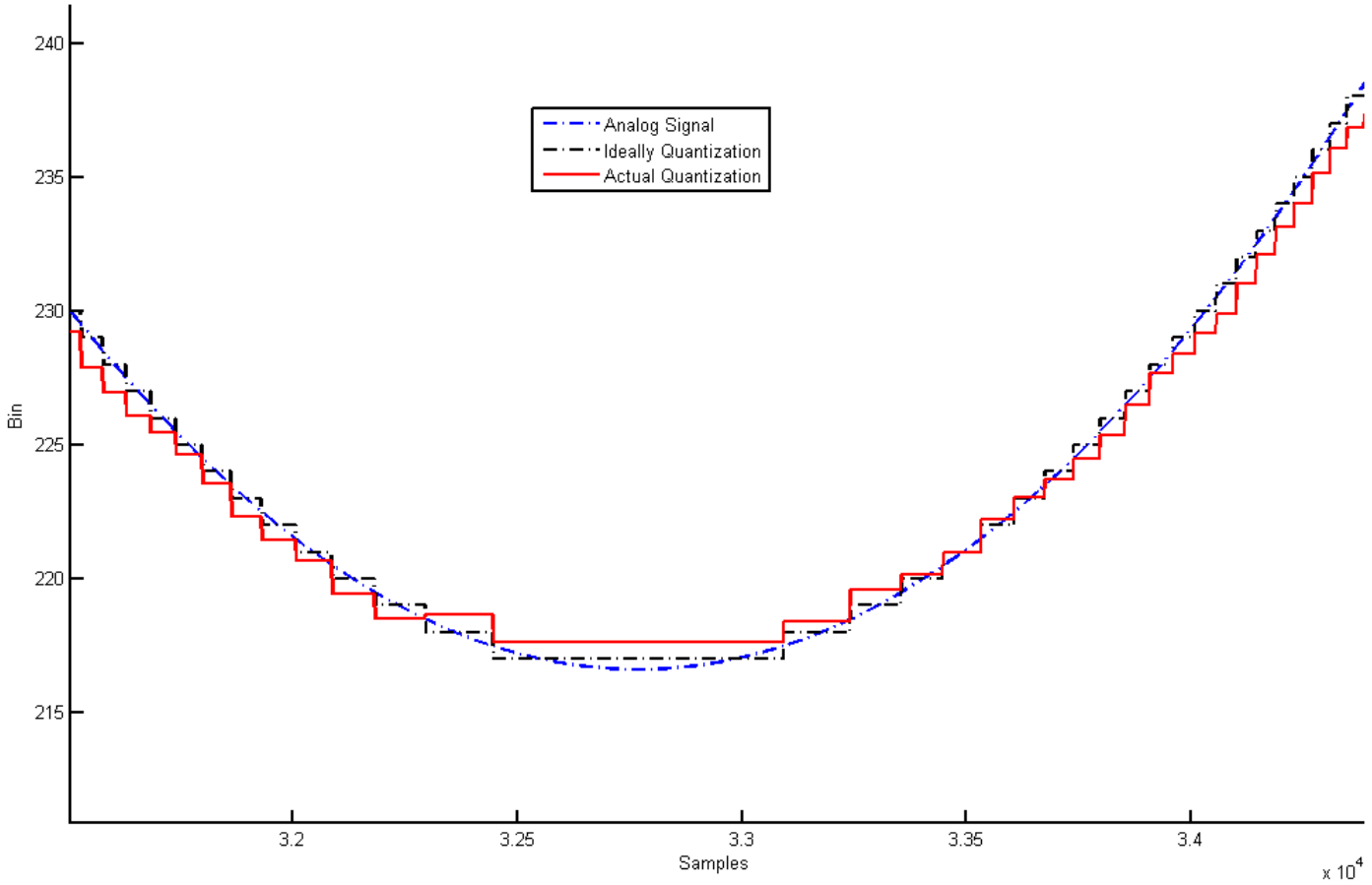
12-bit, 250 MSPS ADC (Time Domain, Unwrapped)



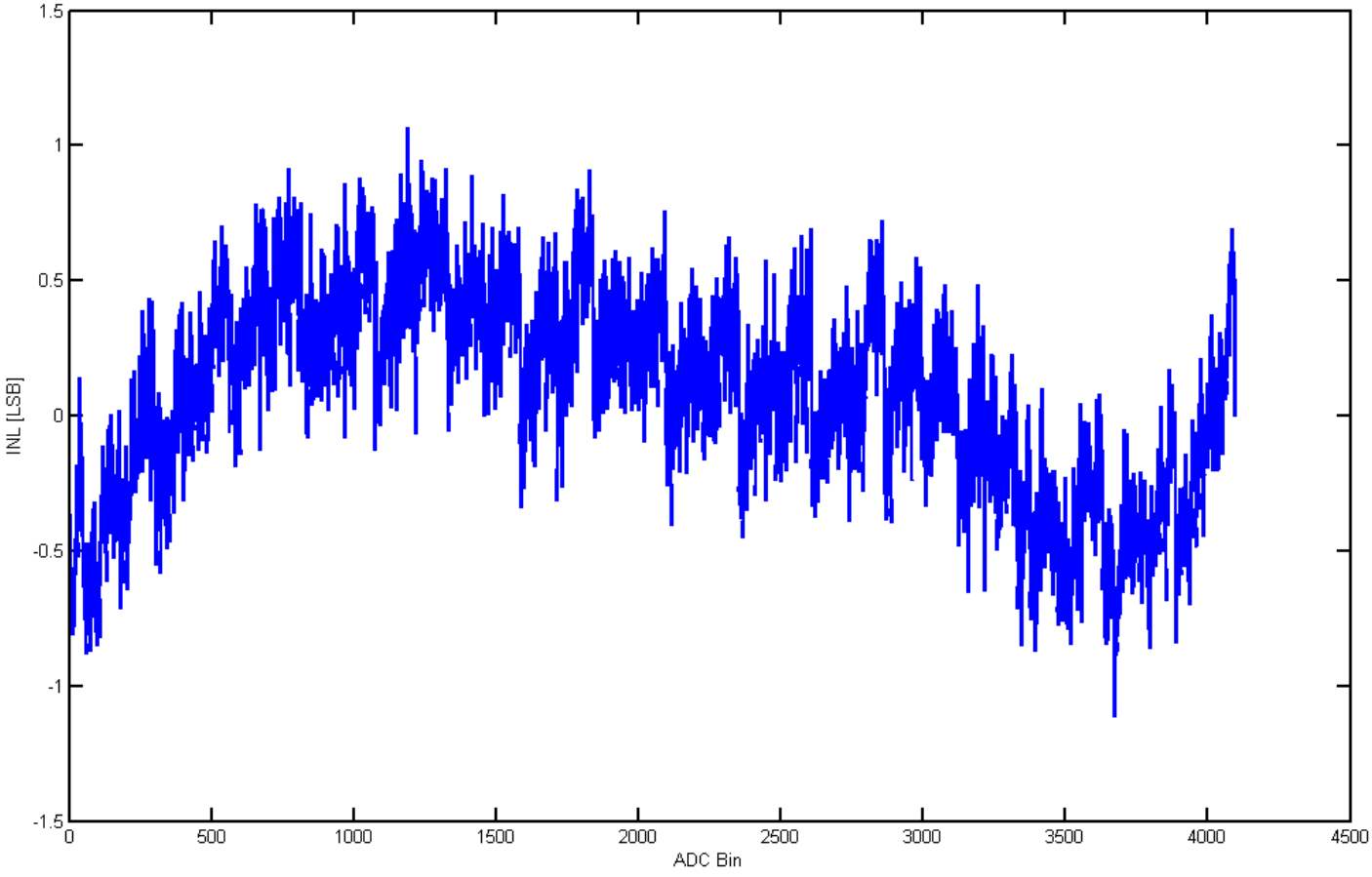
12-bit, 250 MSPS ADC (Time Domain , Unwrapped)



12-bit, 250 MSPS ADC (Time Domain , Unwrapped, Mean)



ADC Transfer Function: INL Curve



This Work

- is about modeling the INL curve, which in turns models the distortion observed in a 12-bit, 250 MSPS ADC from Texas Instruments
- presents an approach that models the INL curve using ‘sum of sines’ (similar to a Fourier Series)
  - compares the results to earlier presented works in which the INL curve has been modeled with piece-wise linear functions

Mathematical Foundation

The INL curve can be seen as the superposition of a smoothly varying function, termed as Low Code Frequency (LCF) INL and a rapidly changing function, termed as High Code Frequency (HCF) INL. For code **k** in a **B**-bit ADC, the INL transfer function can be written as

$$\mathrm{INL}[k] = {}^{\mathrm{HCF}}\,\mathrm{INL}[k] + {}^{\mathrm{LCF}}\,\mathrm{INL}[k] + {}^{\mathrm{Noise}}\,\mathrm{INL}[k]$$

Mathematical Foundation [cont.]

The errors in the ADC are frequency dependent i.e. ADC errors have a memory effect. Therefore,

$$\mathrm{INL}[k,w] = {}^{\mathrm{HCF}}\,\mathrm{INL}[k] + {}^{\mathrm{LCF}}\,\mathrm{INL}[k,w] + {}^{\mathrm{Noise}}\,\mathrm{INL}[k,w]$$

For simplicity, HCF INL is assumed to be static.

Mathematical Foundation [cont.]

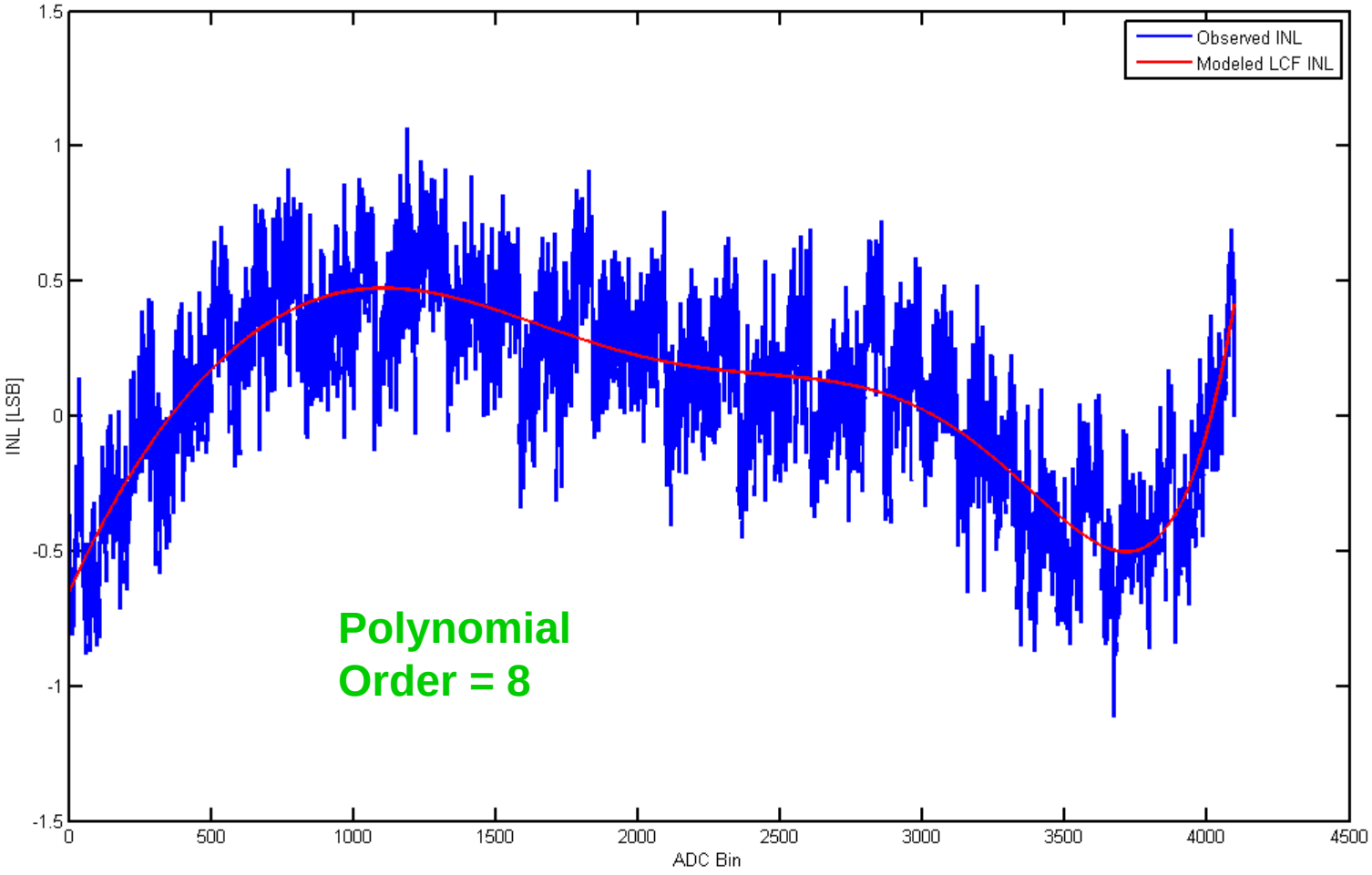
The LCF component of INL is modeled by a polynomial non-linearity with frequency dependent coefficients

$$^{\mathrm{LCF}}\mathrm{INL}[k,w] = h_0(w) + h_1(w)k + h_2(w)k^2 + ... + h_L(w)k^L$$

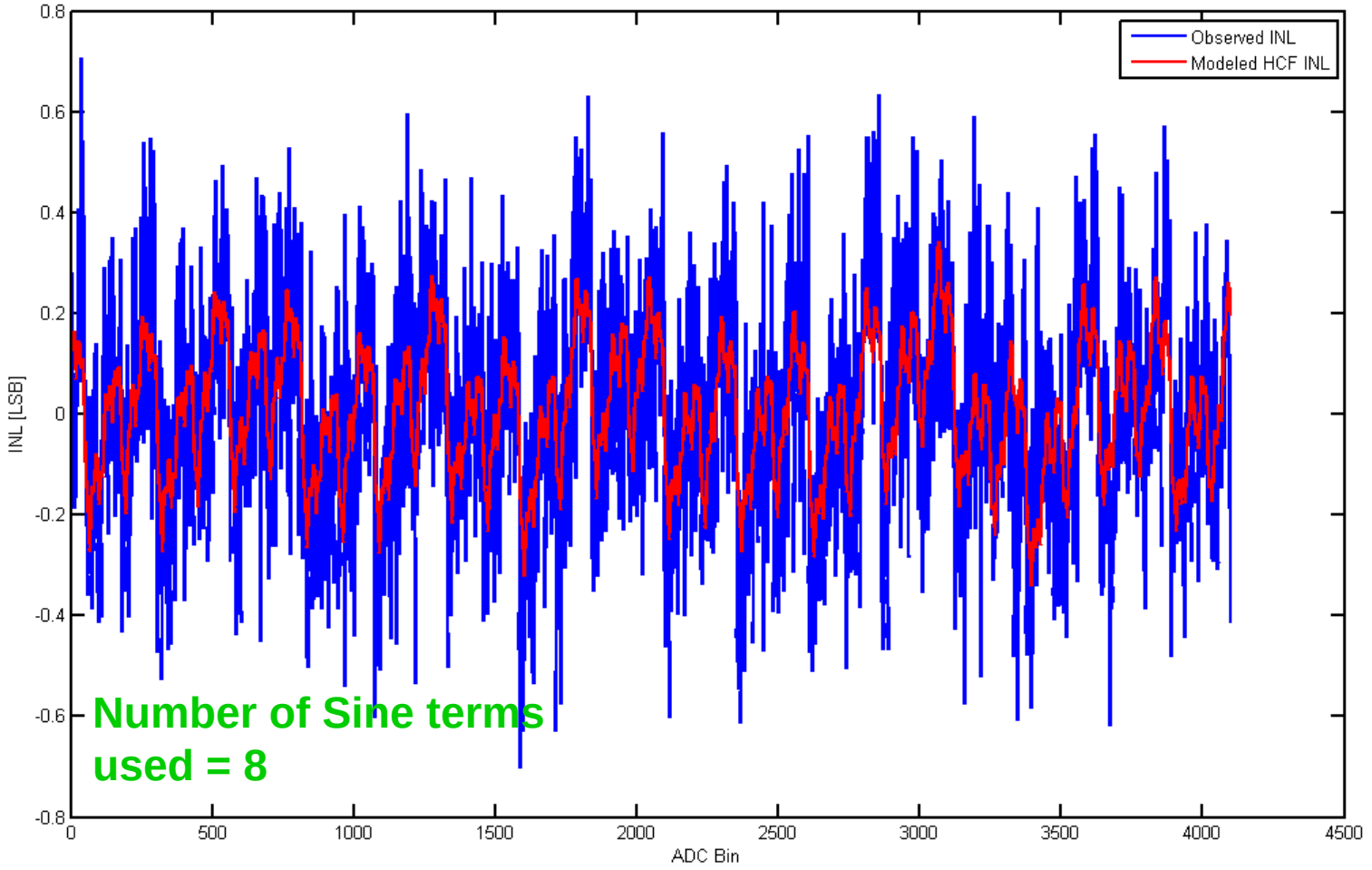
The HCF component of INL is modeled by a a finite summation of sine waves with independent parameters

$$^{\mathrm{HCF}}\mathrm{INL}[k] = a_1 sin(b_1 x + c_1) + ... + a_8 sin(b_8 x + c_8)$$

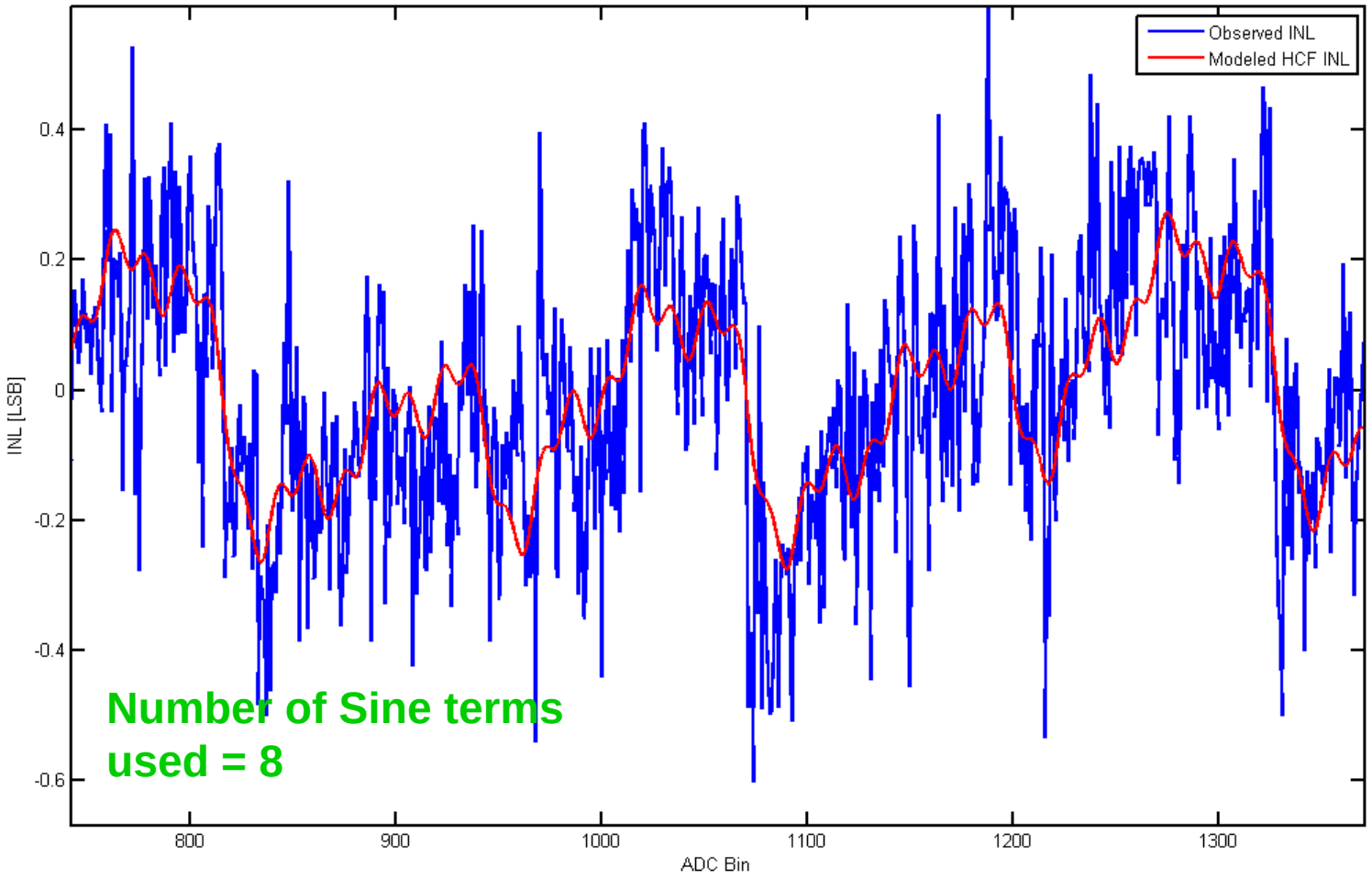
LCF INL Model Illustration



HCF INL Model Illustration on Residue left by LCF



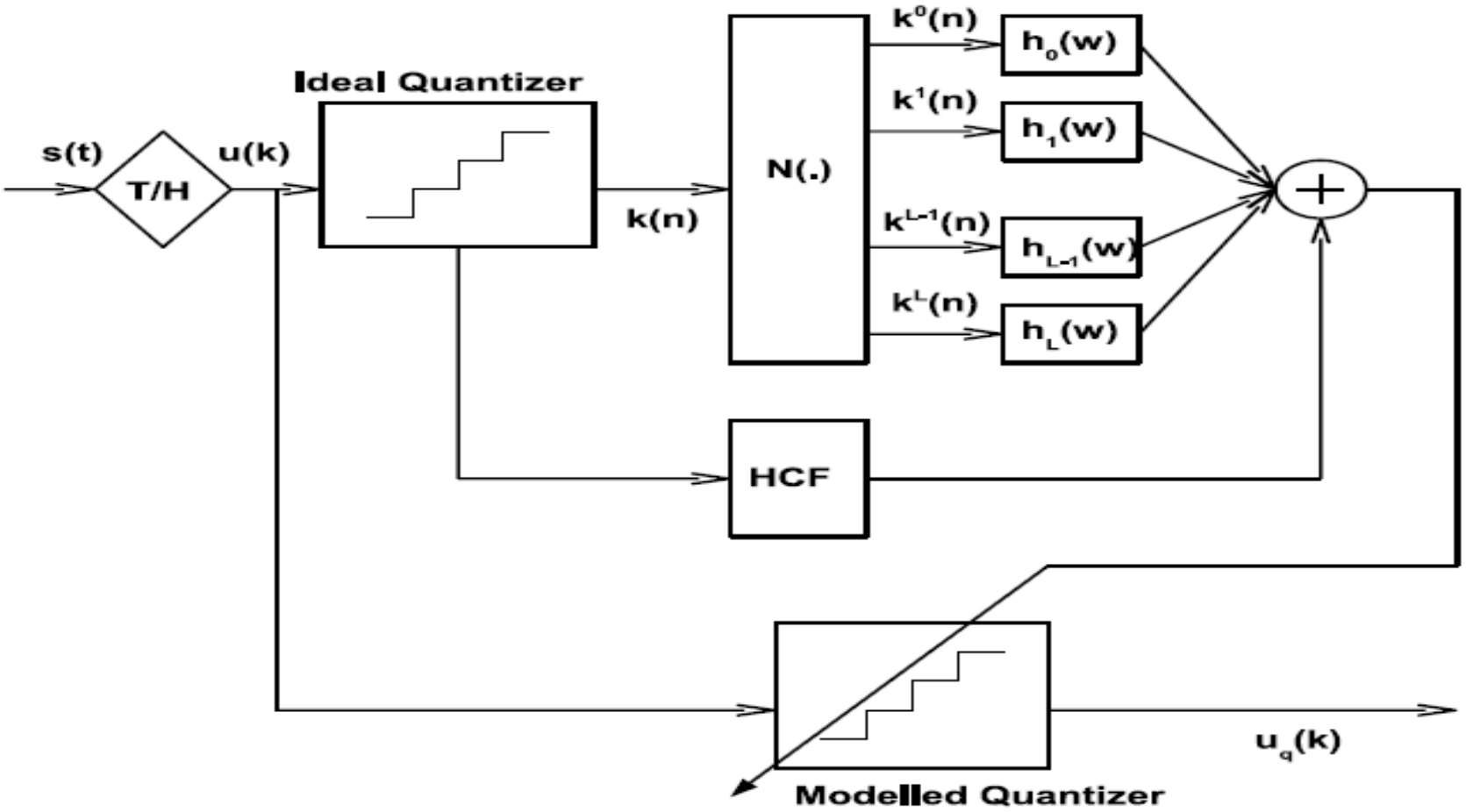
HCF INL Model Illustration on Residue left by LCF



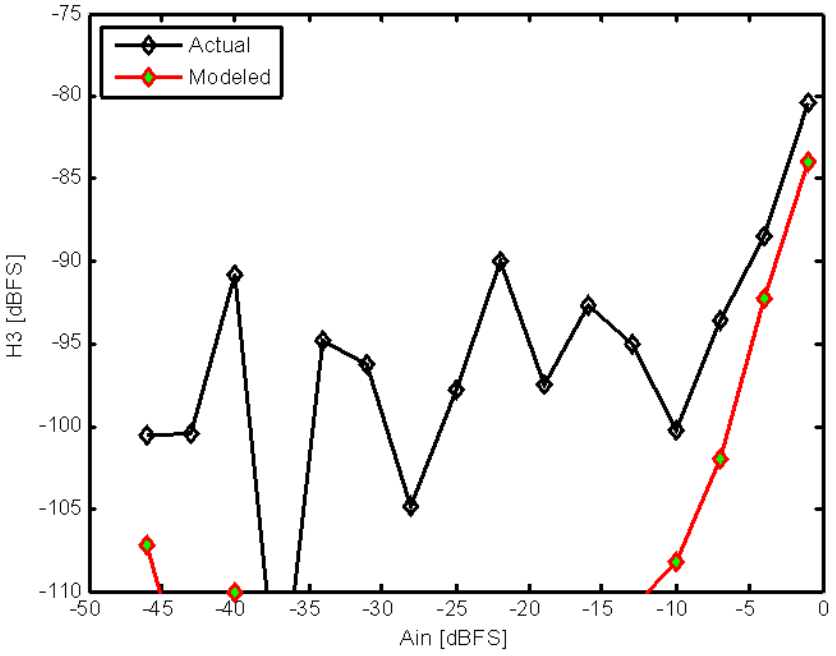
Modeling Strategy

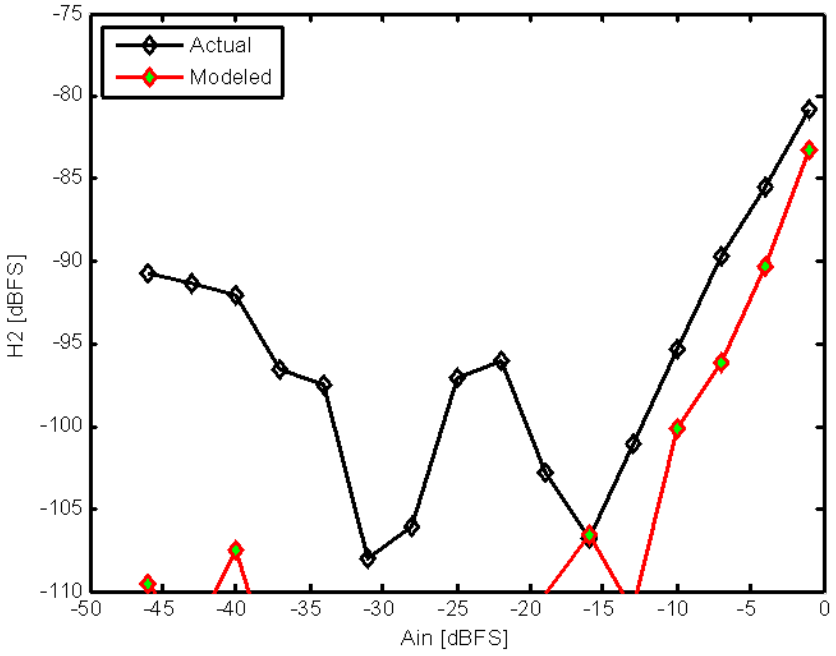
- Capture INL curves of an ADC over a Nyquist Zone, using a set of single tones
- Calculate LCF parameters (a set of polynomial coefficients) for each frequency
- Calculate the residue not modeled by LCF
- Average out the residue for all frequencies
- Use '**sum of sines**' to model the HCF

Model Block Diagram



Model Results for 2nd and 3rd Harmonics (LCF Only)

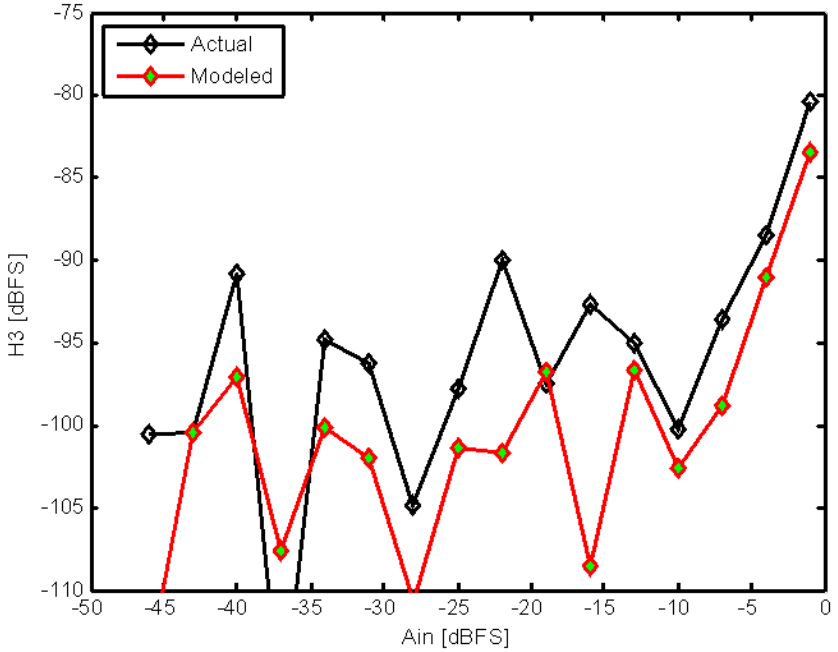


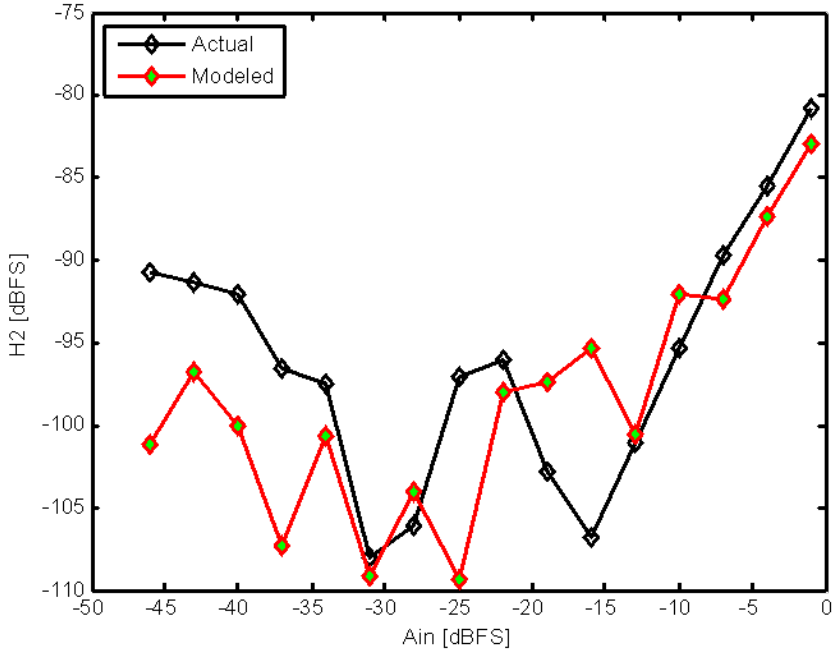


fin = 60 MHz

fs = 250 MSPS

Model Results for 2nd and 3rd Harmonics (LCF+HCF)

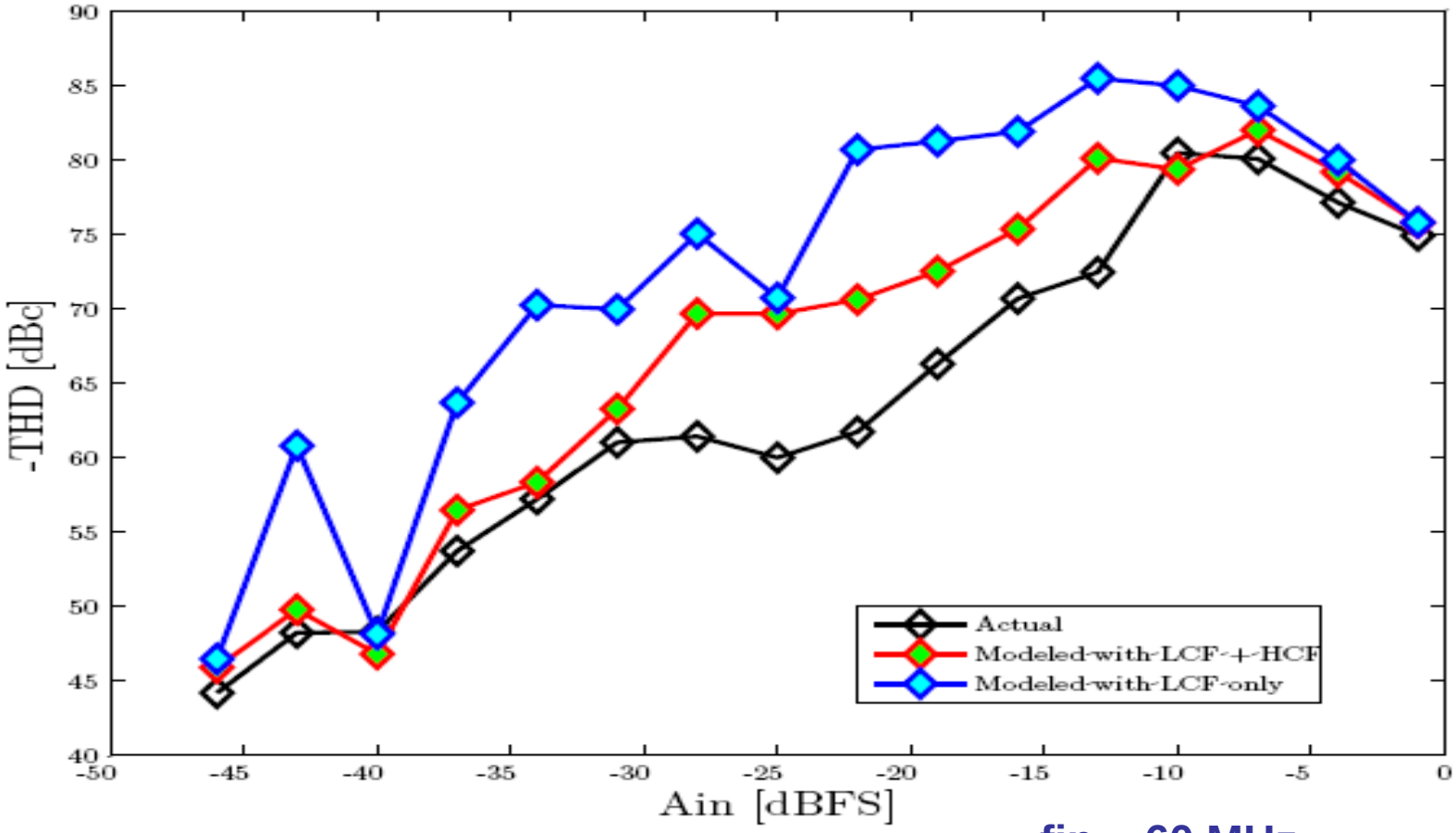




fin = 60 MHz

fs = 250 MSPS

Modeling Results [THD]



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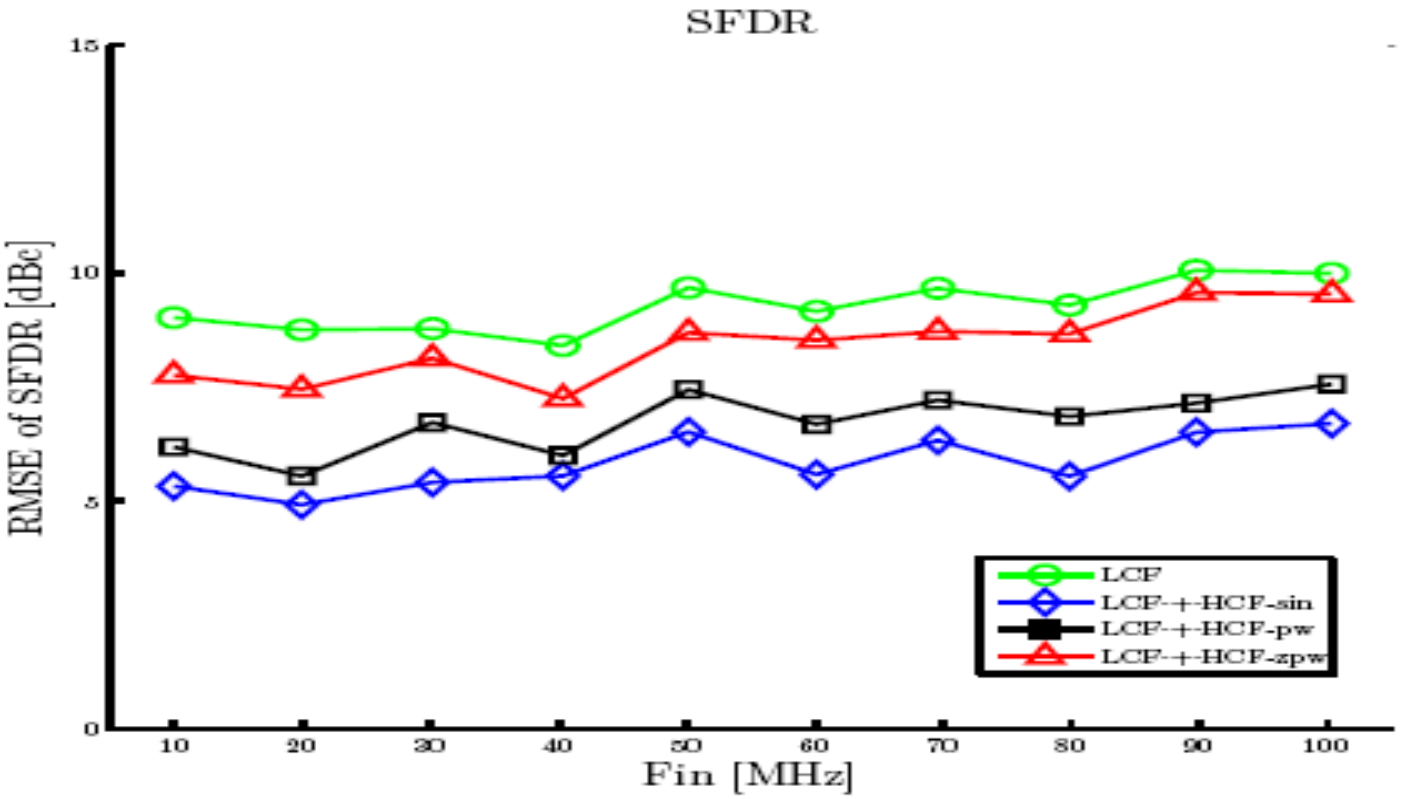
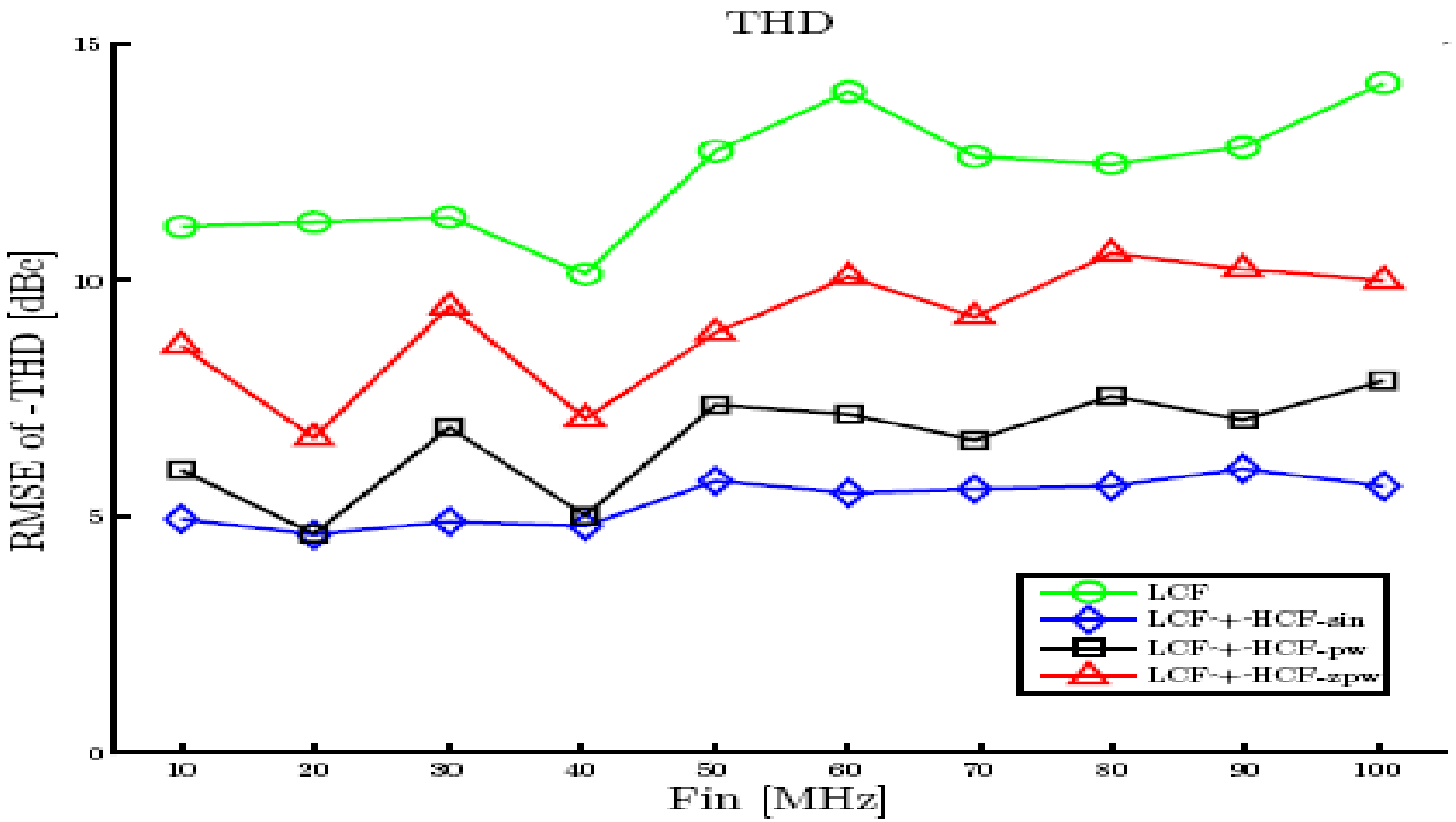
fs = 250 MSPS

SFDR prediction



THD prediction



Future Work

- Error in each bin of ADC has a memory
- INL calculation averages out error in each bin, which implies *lost information!*
- Need to define a model structure that remembers the '*path*' taken to each bin to predict the error correctly for that bin
- Use the model for correction

Thank you!