Digital Waveform Recorders

Error Models & Performance Measures

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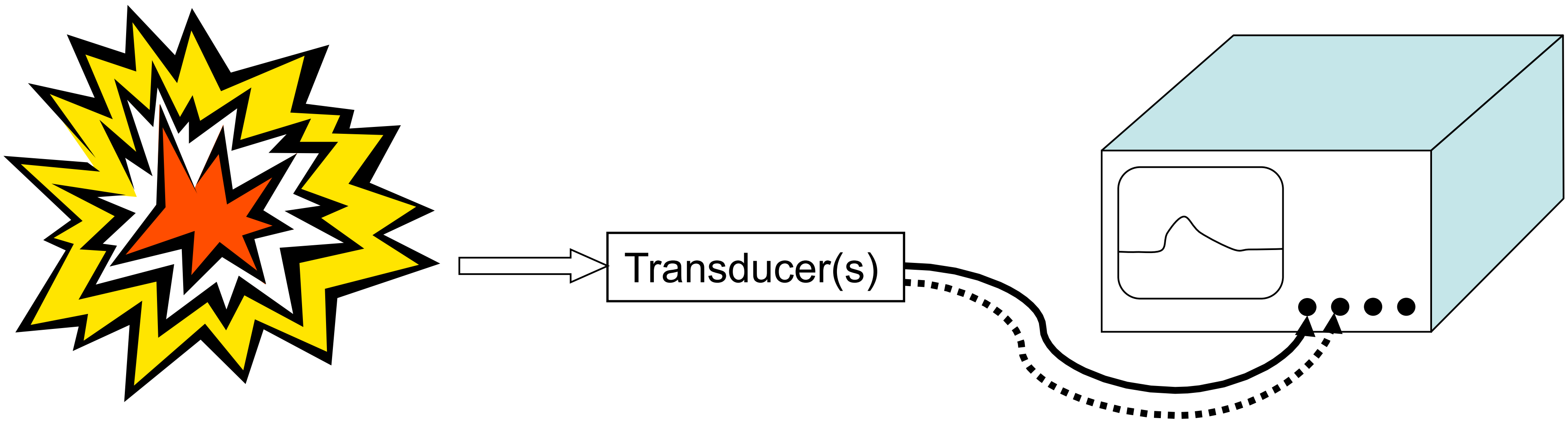
Experimental Set-up for high-speed phenomena

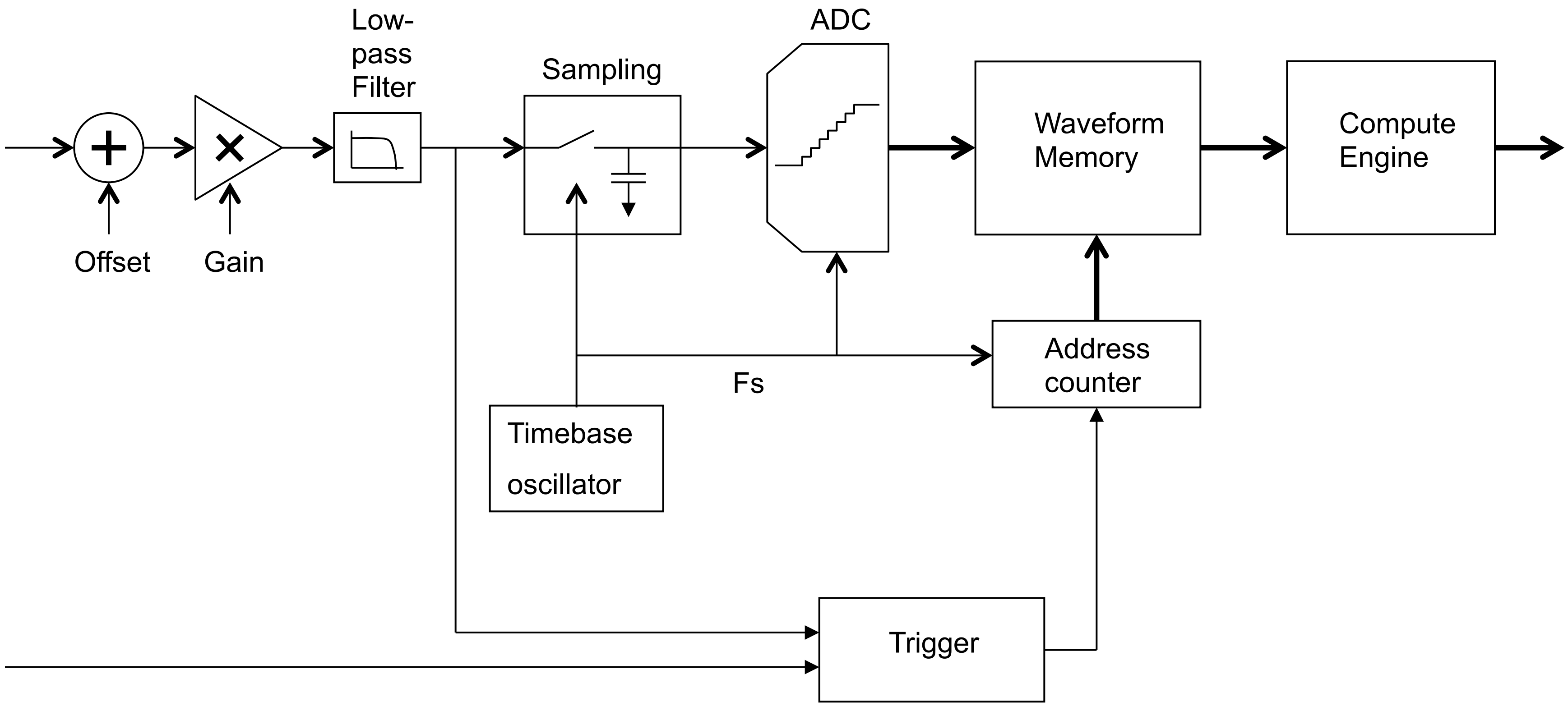


high-speed physical phenomenon under study

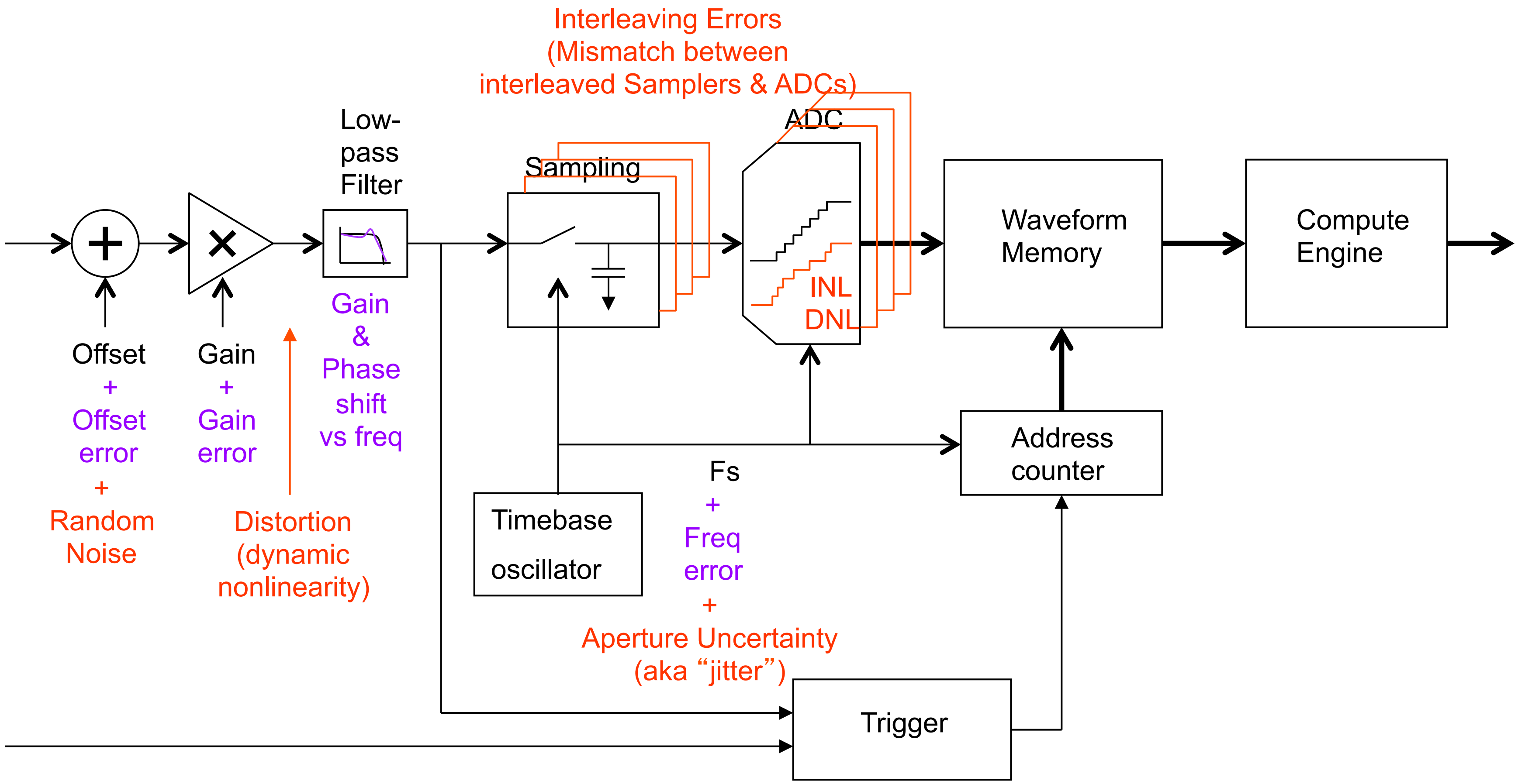
physical properties converted to electrical signal(s)

electrical signals captured by digital waveform recorder for computer analysis

An ideal model of a digital waveform recorder



A real model of a digital waveform recorder



Errors in DC offset, gain, phase, and frequency are relatively straightforward to measure & model, and sometimes to correct using Digital Signal Processing.

Other errors are generally more difficult to model and/or correct using Digital Signal Processing.

IEEE Standard for Digitizing Waveform Recorders

Read IEEE Std 1057-1994. The abstract begins:

- Terminology and test methods for describing the performance of waveform recorders . . . .

The standard includes definitions of and measurement techniques for:

- Gain & Offset (Input signal ranges)
- Bandwidth, Frequency Response & Settling Time
- Sample Rate & Long-term Timebase Stability

These measures are often referred to as "Banner Specifications" and are generally the first performance parameters to check for sufficiency in a given application.

- Random Noise
- Harmonic Distortion
- Differential & Integral Nonlinearity
- Spurious Response (interleaving errors)
- Aperture Uncertainty
- and many other detailed error sources

The effects of these errors are more complicated to evaluate or compare, but are included in the "Effective Bits" parameter, a broad measure of most dynamic errors in a digital waveform recorder.

After checking that the "Banner Specs" are sufficient, look at Effective Bits! If the results are poor, dive deeper to find the particular cause of lost bits and determine the effect on your measurement application.

Effective Bits (aka ENOB, E-bits, Effective Resolution)

Basic Test Method

- Apply a pure sine wave to the digitizer under test & acquire a record of data

- Least-Squares fit an ideal sine wave to the data, varying: amplitude, offset, phase, & frequency

- Calculate the number of bits of an **ideal** digitizer that would produce the same mean-square-error when digitizing the same input signal. This is the number of "effective" bits.

$$E = \log_4 [\ \text{fullscale}^2 / (12 * \text{mean-square-error})\ ]$$

- When quoting Effective Bits, specify all test conditions (input range, input amplitude & frequency, sample rate, bandwidth selection & method, etc.), as these may impact the measurement.

Practical Matters

- Use a synthesized signal generator with output filters for the sine wave source.

- Test using a large (90% fullscale) input signal to exercise the entire input range.

- Test at many input frequencies, as most dynamic errors are a strong function of frequency

    - Generally, Effective Bits is displayed graphically as a function of input frequency

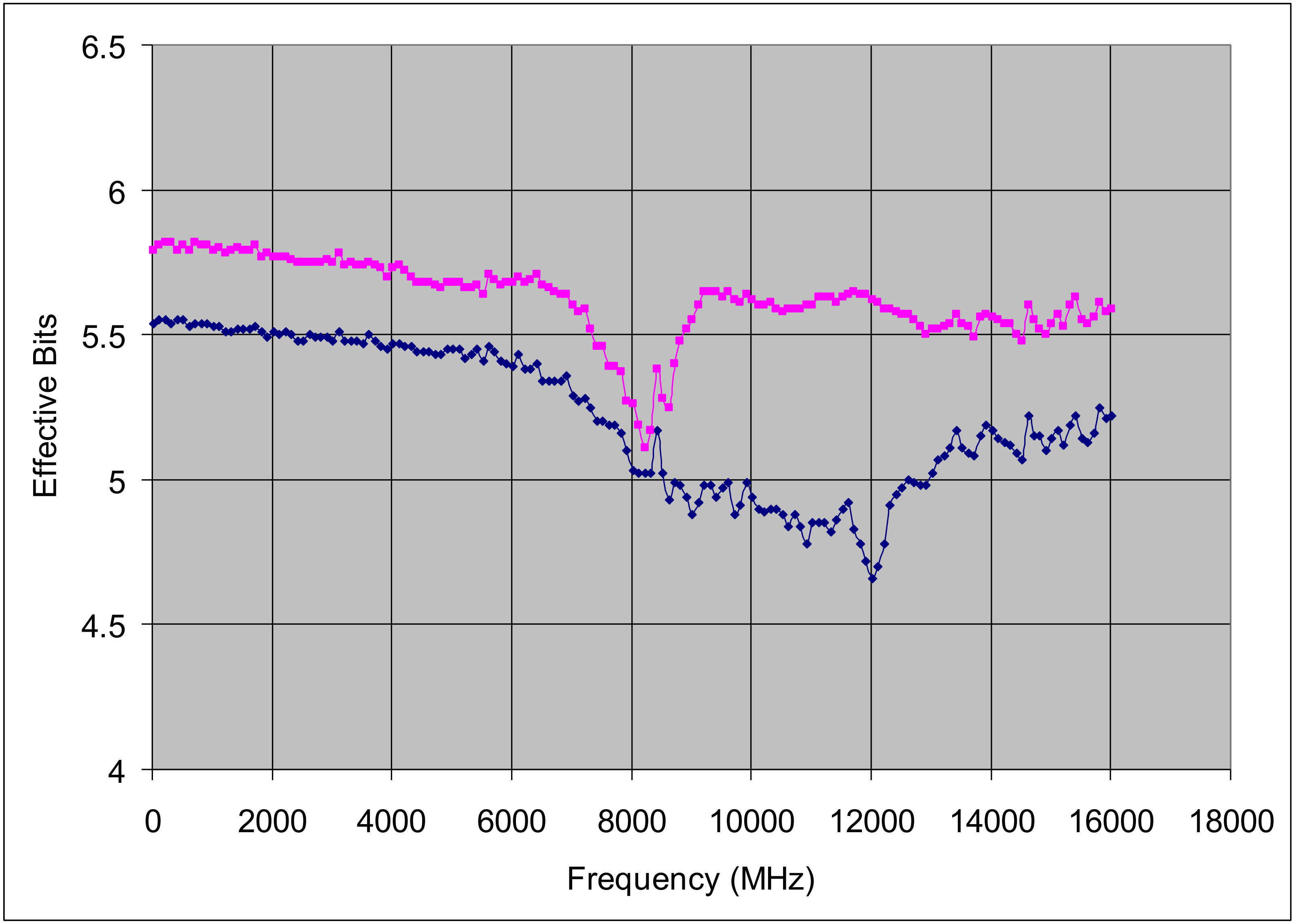
- When comparing Effective Bits graphs, insure comparable instrument settings

- Expect Effective Bits to drop with increasing input frequency, but rise again near bandwidth

    - Harmonics will exceed bandwidth and be filtered out, but other distortion products may not be.

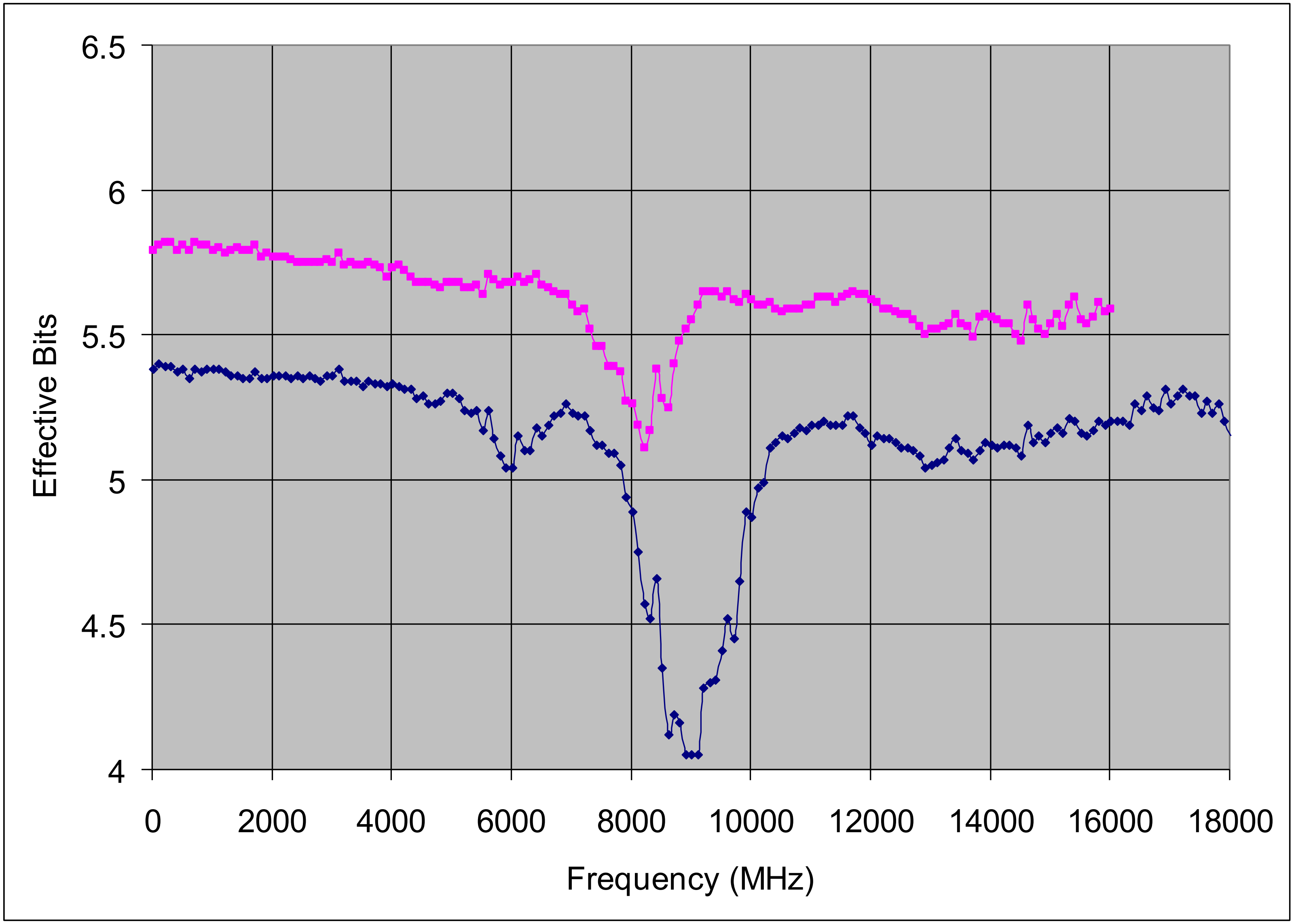
Effective Bits: Comparing Bandwidth Modes (DSP vs Raw)

Max sample rate, 16 GHz bandwidth, 200 mV fullscale range



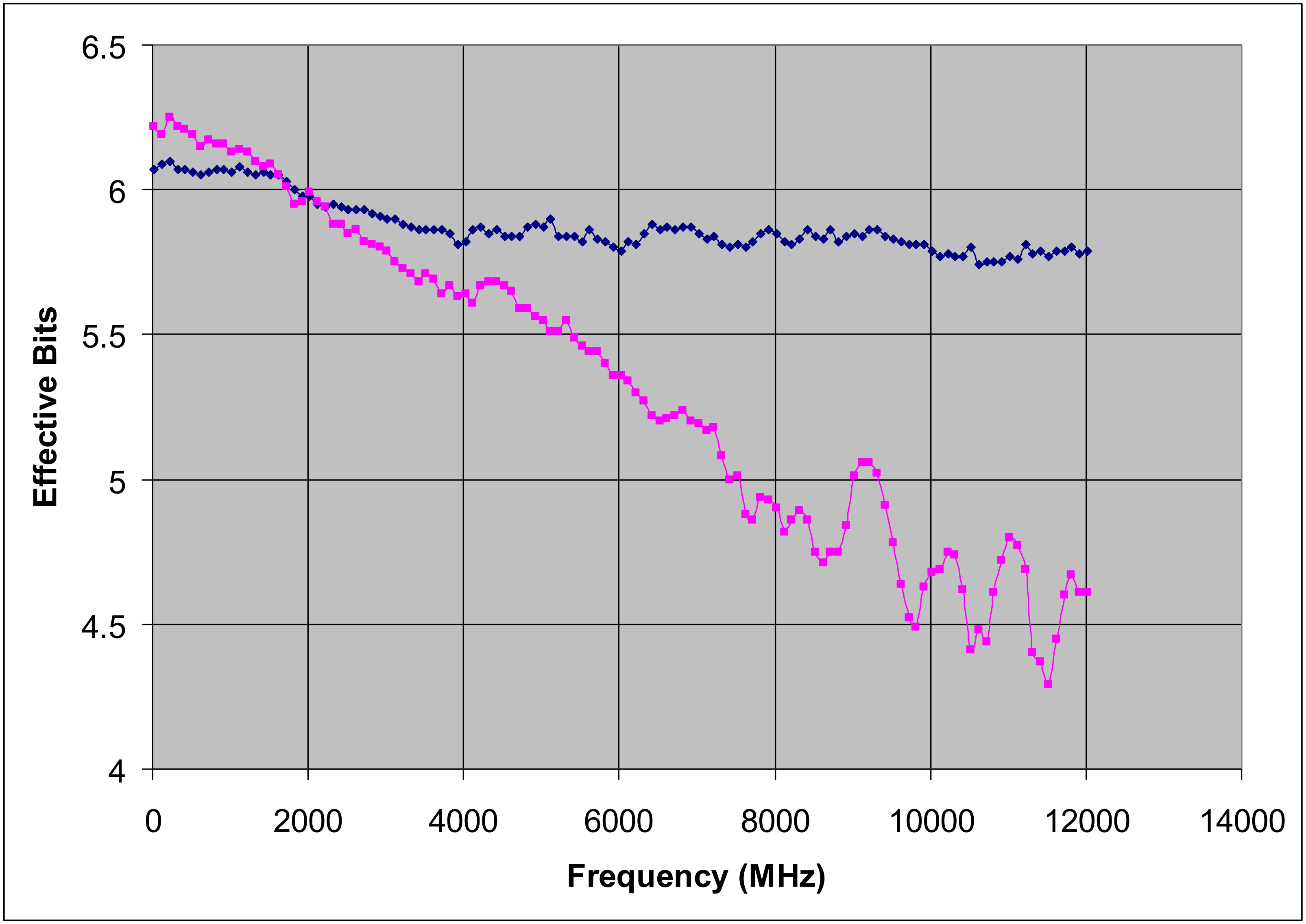
Effective Bits: Comparing Bandwidth Settings (16 vs 18 GHz)

Max sample rate, DSP bandwidth, 200 mV fullscale range



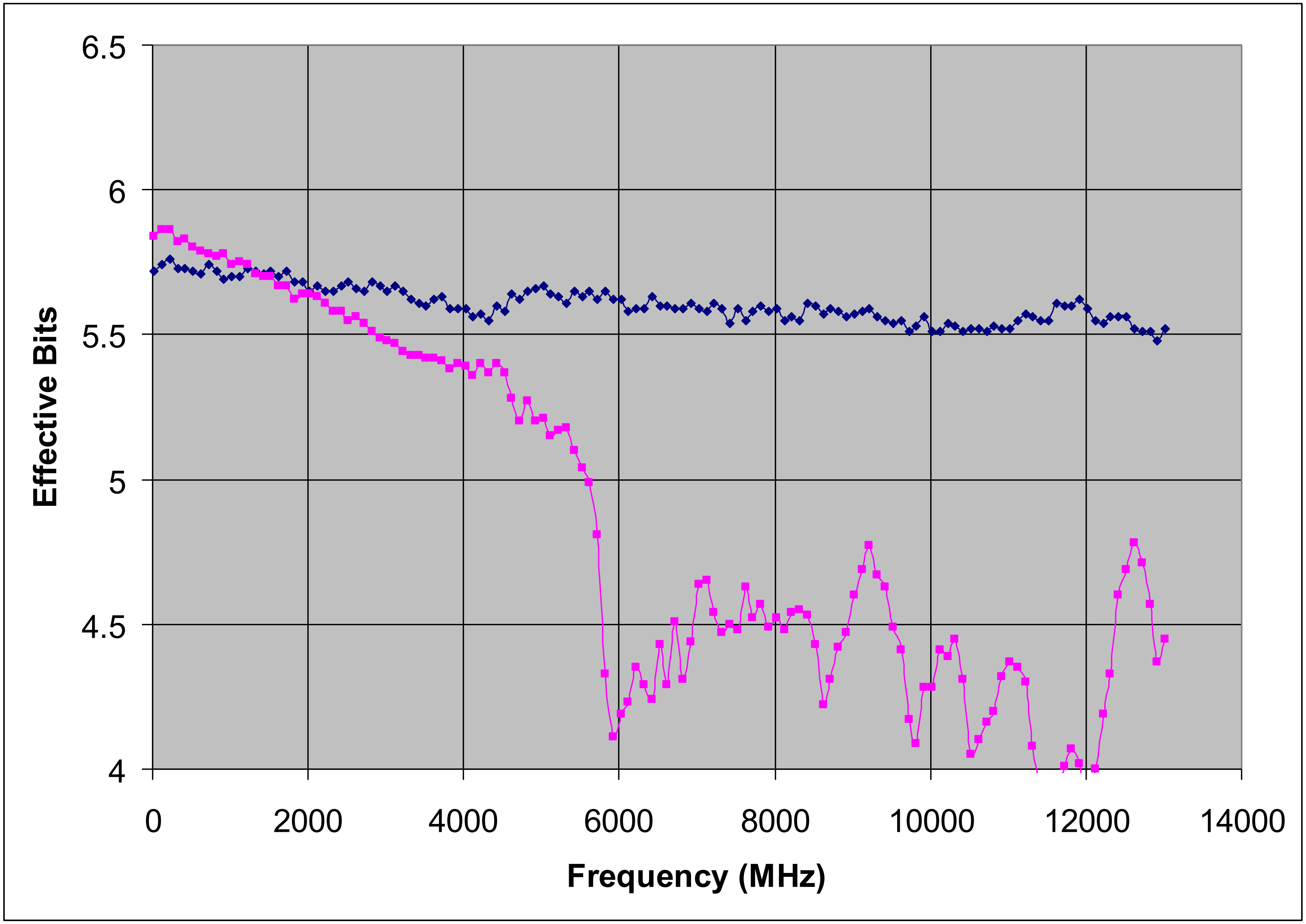
Effective Bits: Comparing different units

Max sample rate, 12 GHz DSP bandwidth, 400 mV fullscale range



Effective Bits: Comparing different units

Max sample rate, 13 GHz DSP bandwidth, 160 mV fullscale range



Diving Deeper – Causes of Effective Bits losses

Study the nature of the sine fit "residual" error

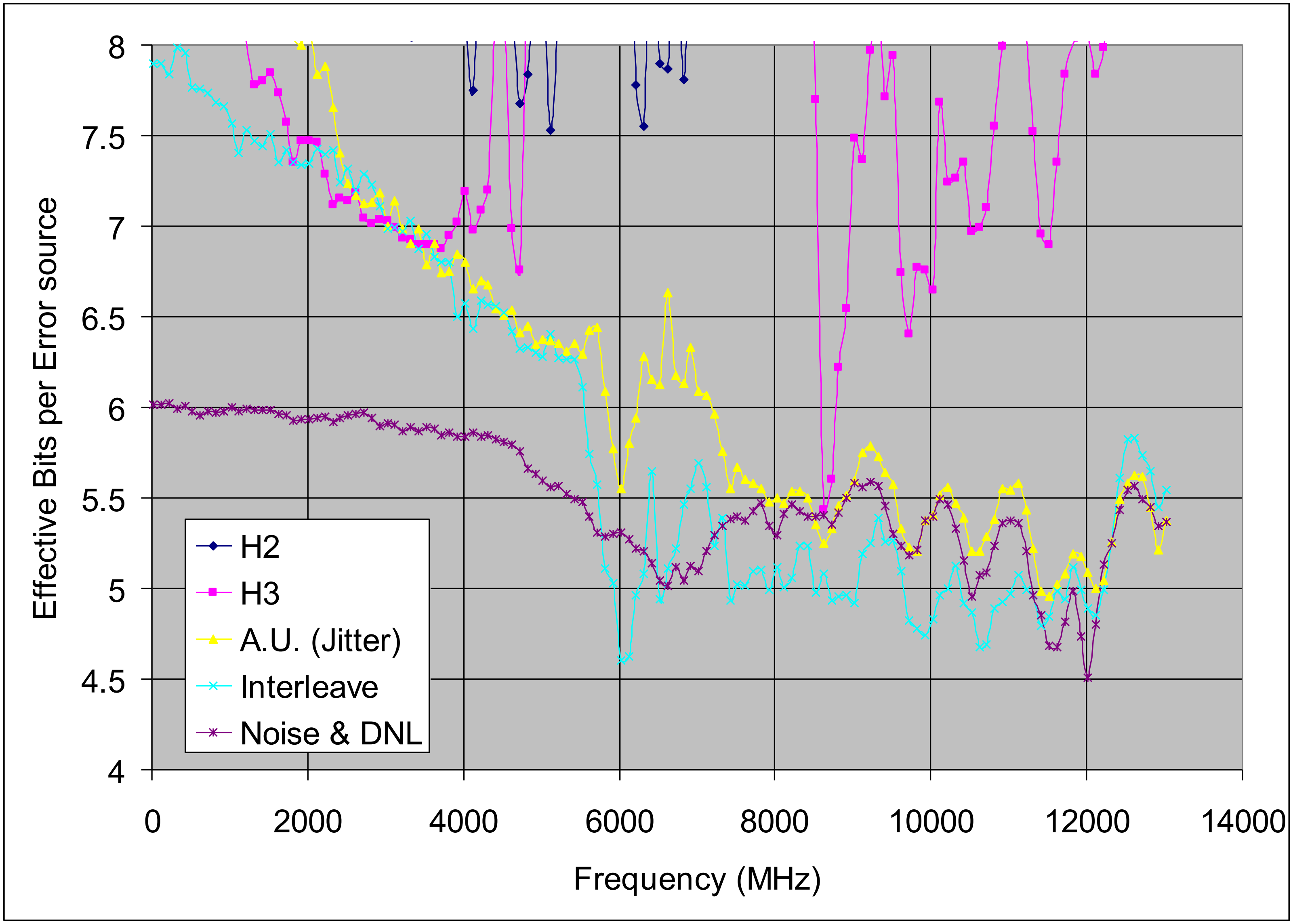
- Fitting a sine wave of 2x, 3x, …. the fundamental to the residual error identifies harmonic distortion
- Fitting separate sine waves to every "N' th" sample in the record can identify interleave mismatch
- Observing increased error at the high-slewrate sections of the sine indicates aperture uncertainty
  - Fit a sine wave of 2x fundamental to the square of the residual error
- Similar techniques can be used for other error sources with known models
- Remaining error that does not fit any pattern above is likely random noise and/or DNL

If you don't have a sine-fit algorithm handy . . . .

- The Fast Fourier Transform (FFT) **is** a sine-fit algorithm for integer cycles-per-record
- Many digital waveform recorders have FFT algorithms available for use
- Many of these same error sources can be recognized by their signature in an FFT:
  - Harmonics are spurs at integer multiples of the fundamental
  - Interleave gain & phase errors are spurs at $F_{IN} \pm k * F_S / N$
  - Interleave offset errors are spurs at k * FS / N

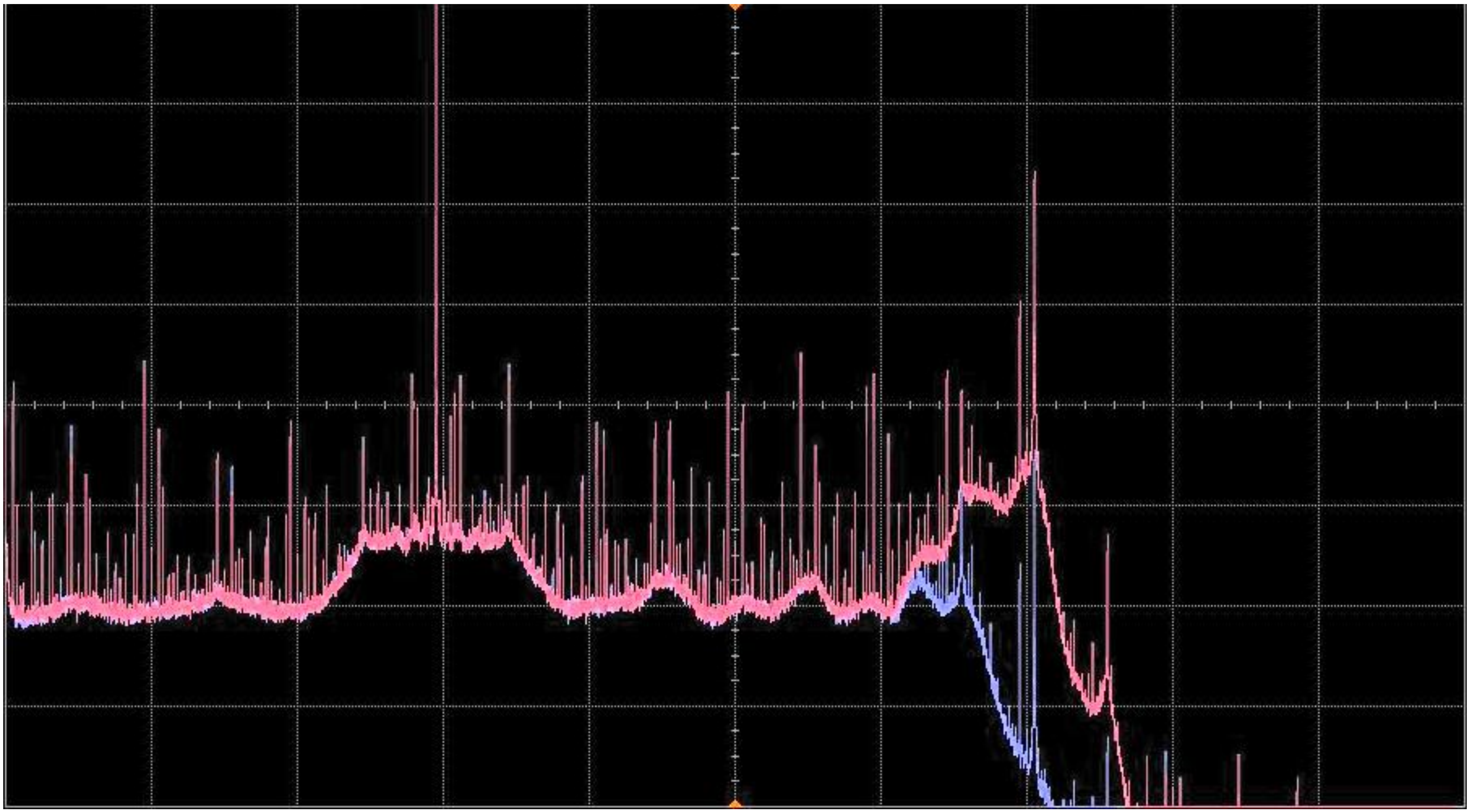
Diving Deeper – analyzing Sine-fit residual error

Max sample rate, 13 GHz DSP bandwidth, 400 mV fullscale range



Diving Deeper – analyzing an FFT

Max sample rate, 12 & 13 GHz DSP BWs, 5.9 GHz F_{IN}, 400 mV FSR



Conclusions

To determine if a digital waveform recorder is sufficiently accurate:

- Start by looking at the "Banner Specs"
  - Gain & Offset (Input signal ranges)
  - Bandwidth (Raw and/or DSP), Frequency Response & Settling Time
  - Sample Rate & Long-term Timebase Stability
- Then take a look at Effective Bits
- If the Effective Bits are questionable, dive deeper to find the particular dominant error(s)
  - Random Noise
  - Harmonic Distortion
  - Differential & Integral Nonlinearity
  - Interleaving Errors
  - Aperture Uncertainty
- Determine the impact of the dominant error(s) on the system accuracy