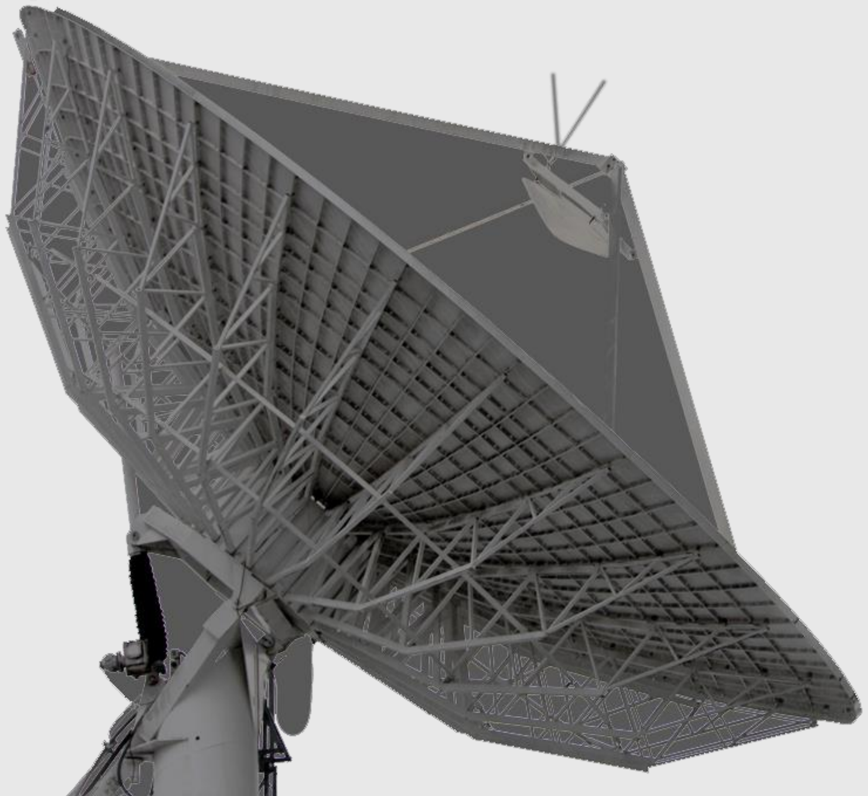
How advances in digitizer technologies improve measurement accuracy



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Impacts of oscilloscope signal integrity

By choosing an oscilloscope with superior signal integrity you get the following benefits:

- **What is displayed on the oscilloscope screen more accurately depicts the actual waveform:**
- **More accurate and repeatable measurements:**
  - Wider eyes
  - Less error in your Rj measurements
  - Less total jitter because you are more accurately depicting Rj

Agenda

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Agenda

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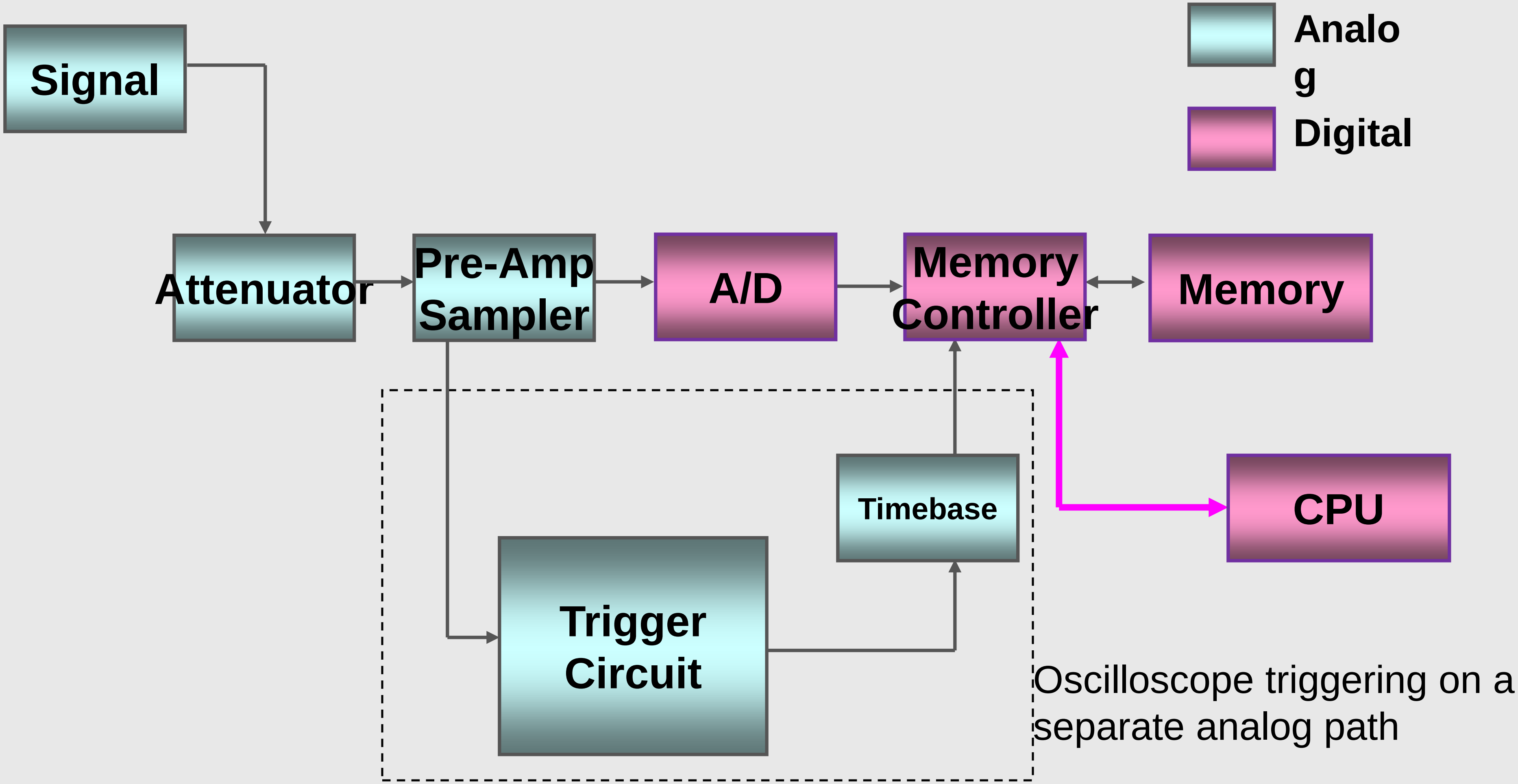
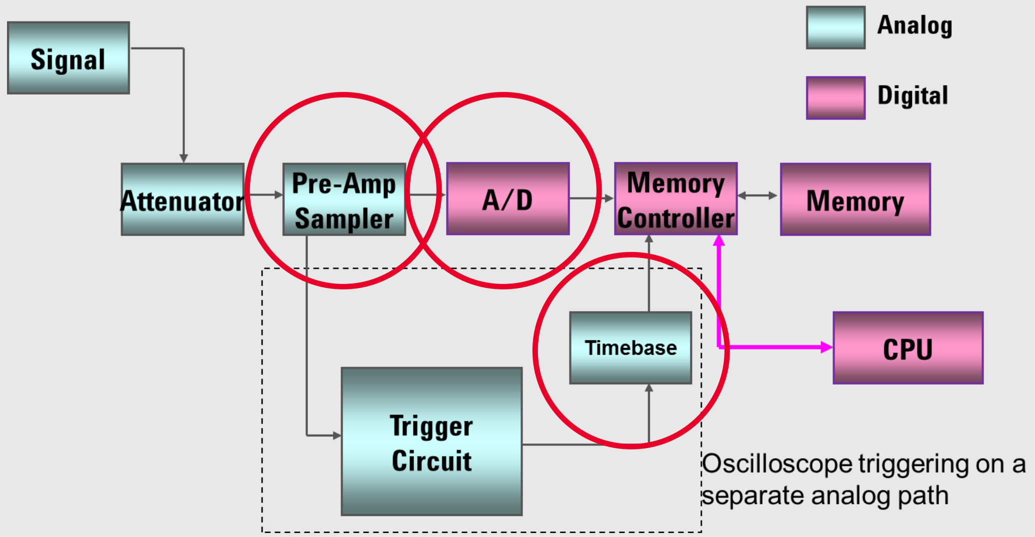
The Oscilloscope – The basic building blocks



Oscilloscope Building Blocks



Oscilloscopes typically consist of three key components that impact your signal integrity:

1. Pre-amplifier
2. ADC
3. Timebase

The Pre-amplifier

Keysight's proprietary multi-chip modules

Is arguably the most important component of an oscilloscope design as it:

1. Presents a DC coupled 50 ohm termination impedance at the scopes inputs to its full bandwidth
2. Provides a mean to offset the dynamic range of the input signal
3. Corrects the response of the oscilloscope
4. Provides anti-aliasing at maximum sample rate
5. Can drive both sampler IC and the trigger IC
6. Isolates the sampler IC from the trigger outputs

ADC (analog to digital converter)

The ADC

1. Is the most recognized component on the oscilloscope.
2. Converts the analog data to digital data.
3. Is the limiting factor in the bits of resolution that an oscilloscope can be.
4. Is defined by its bandwidth (40 GS/s) and its signal to noise ratio
5. Typically have 8 bits of resolution on oscilloscopes, although recently oscilloscopes have added 10 and 12 bit ADCs

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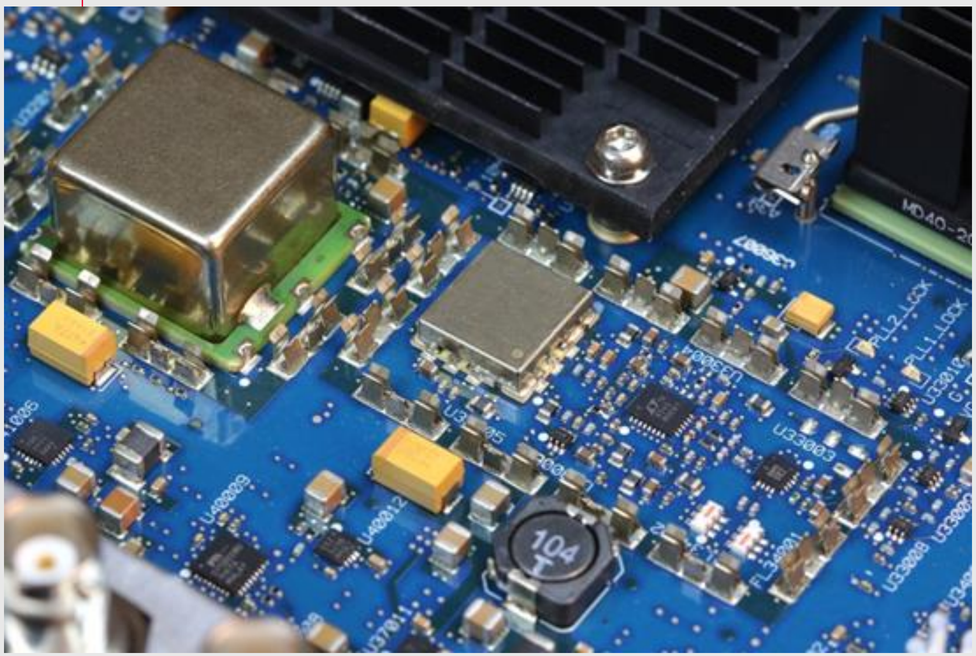
The Timebase (sample clock)



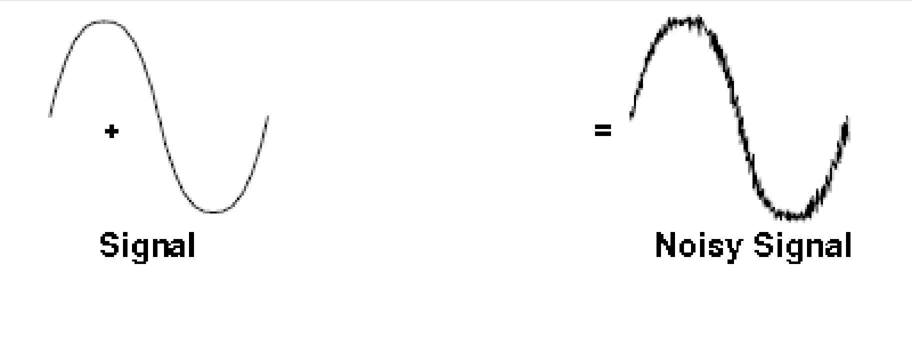
The timebase

1. Ties the pre-amplifier to the sampler to the ADC
2. Determines how well the samples of data will be placed on screen
3. Typically runs at 10 MHz, but recently scopes have began to run at 10 GHz

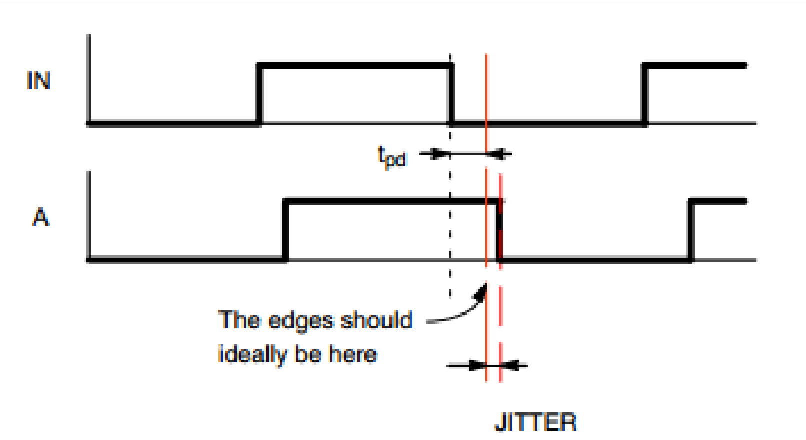
Agenda

1. The Building Blocks of an Oscilloscope
2. Four Common Errors
3. How Key Components Impact Signal Integrity
4. Understanding and Characterizing Oscilloscope Sources of Error
5. What about probing?
6. Conclusion

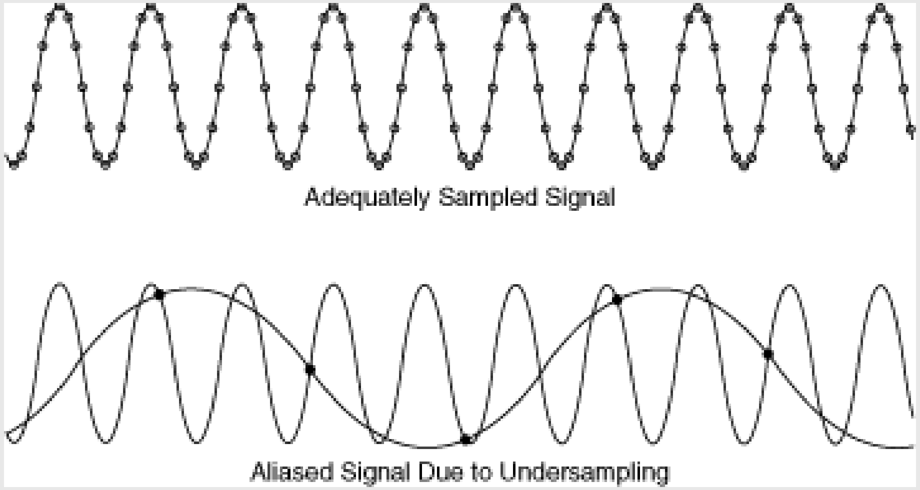
Noise



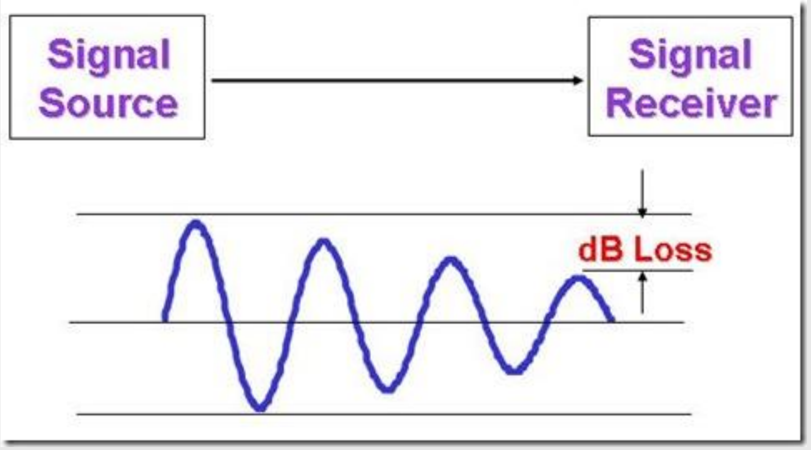
Jitter (Time Interval Error)



Aliasing



ISI (Intersymbol Interference)



Agenda

1. The Building Blocks of an Oscilloscope
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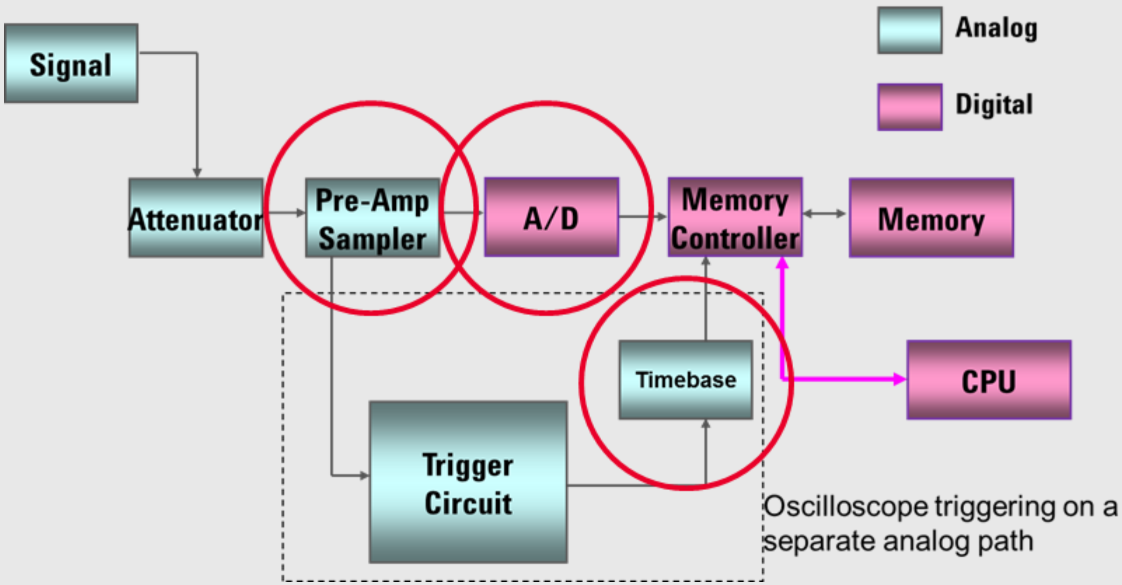
Key technology advancements introduced in the last five years



Ideally each component would have no impact on your measurement, unfortunately…

The Pre-amplifier

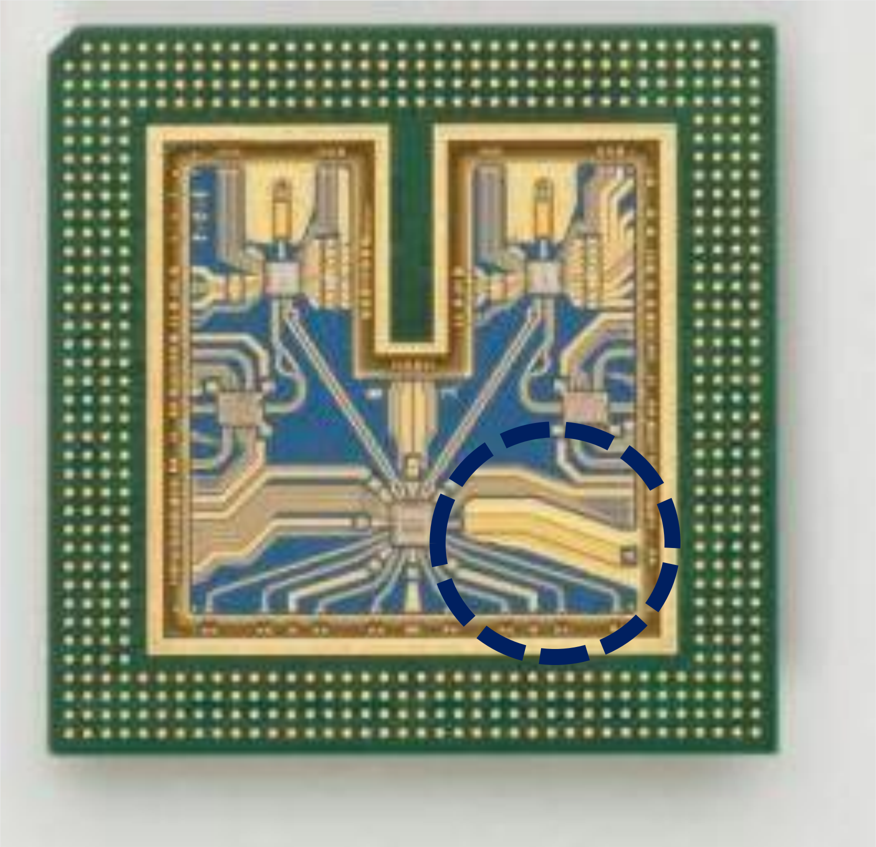
Agilent's proprietary multi-chip modules

1. Is a large component of oscilloscope noise
2. If not designed correctly will allow for the oscilloscope to be susceptible to aliasing
3. Is the single biggest contributor to any frequency response non-linearities
4. If the termination is not done correctly will cause reflections

ADC (analog to digital converter)

1. No ADC is perfect, so even though you may have an 8 bit ADC, the effective number of bits will be less than 8.
2. Impacts the quanitization error, which contributes to noise
3. Causes harmonic distortion
4. Can couple with the sample clock, causing increased noise
5. Signals may need to be boosted into the ADC, causing more noise to occur.

The Timebase (sample clock)



1. Can contribute negatively to harmonic distortion, which will erode your effective number of bits.
2. Can couple in with other components causing increased harmonic distortion.
3. Can lose lock at deep memories, causing your jitter to increase.

Agenda

1. The Building Blocks of an Oscilloscope
2. Sources of Error in an Oscilloscope Design
3. Four Common Errors
4. Understanding and Characterizing Oscilloscope Sources of Error
   - Noise Floor
   - Jitter Measurement Floor
   - Frequency Response
   - Effective Number of Bits
5. What about probing?
6. Conclusion

Oscilloscope Noise

Mainly comes from scope front-end

- ❖Negatively Impacts all oscilloscope measurements
  - ❖Increases
    - ❖eye height and width measurements
    - ❖jitter measurements
    - ❖ EVM measurements
  - ❖Additional impact with equalization and de-embedding

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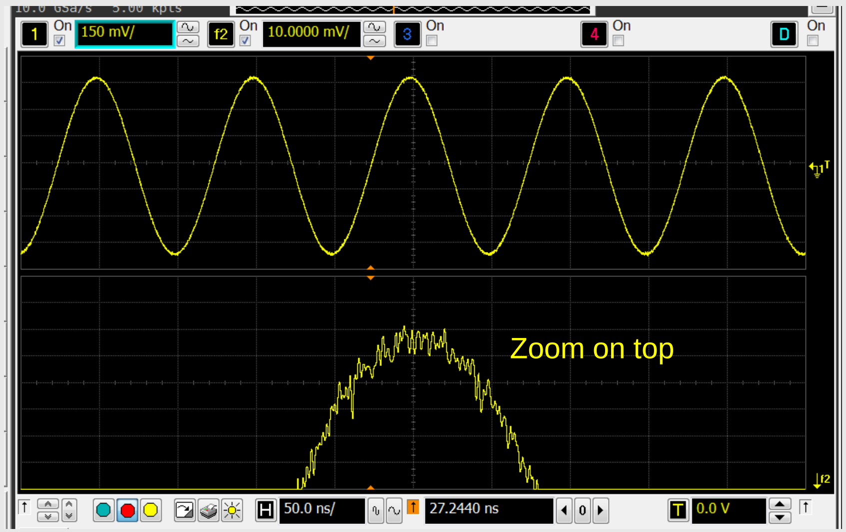
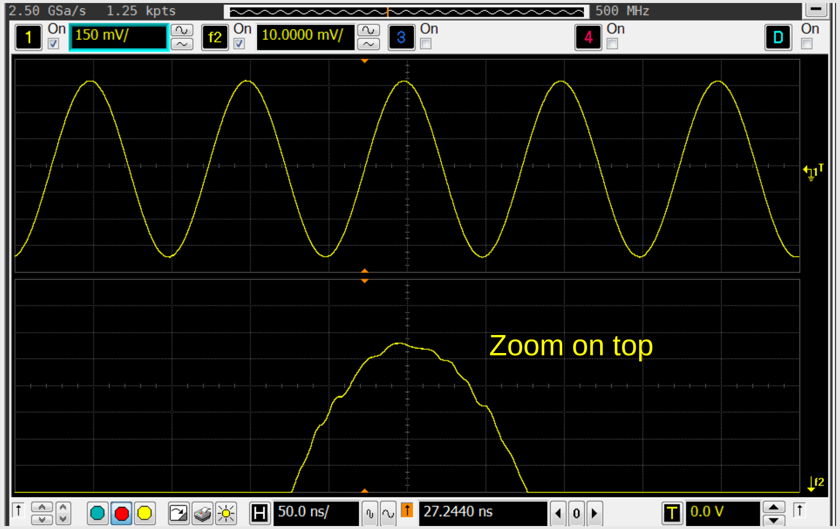
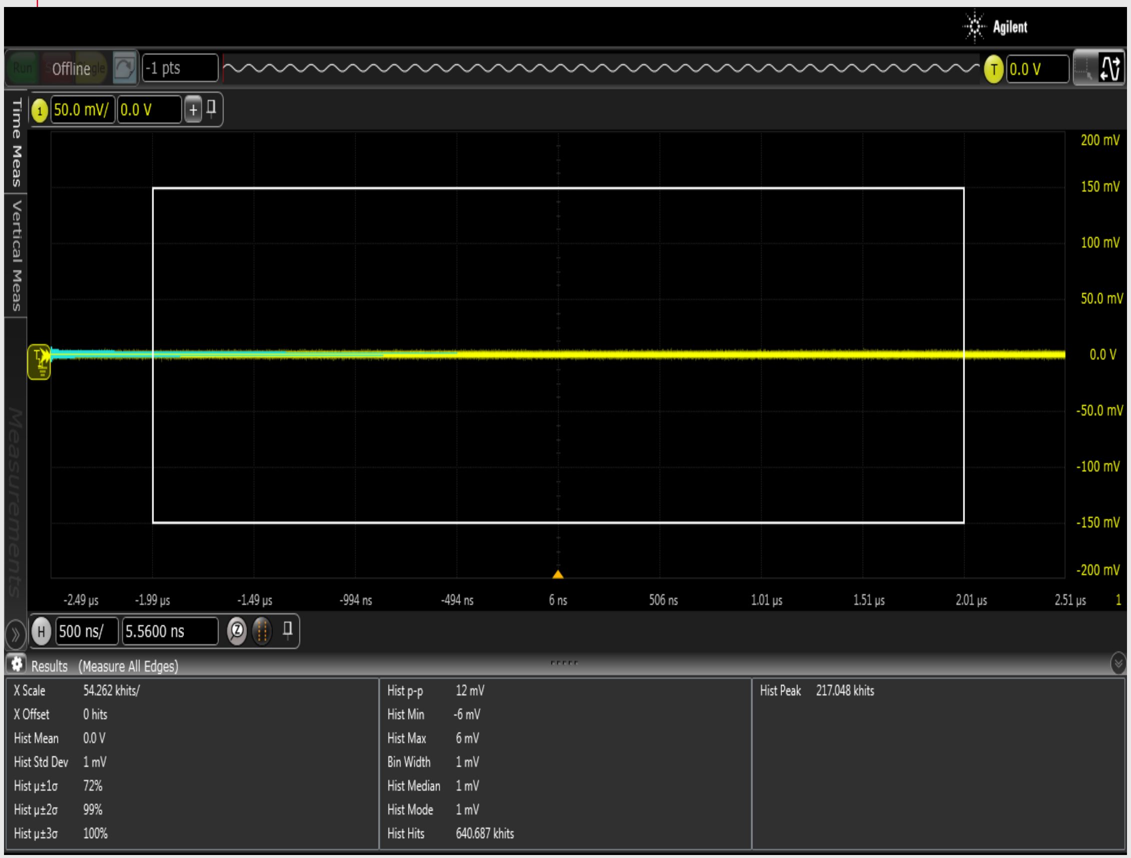
Noise Comparisons

2 Scopes with equal BW, but different noise attributes





Measuring Oscilloscope Noise (The Procedure)



1. Disconnect all inputs from the oscilloscope
2. Turn on a histogram of the oscilloscope displayed noise
3. Measure the standard deviation

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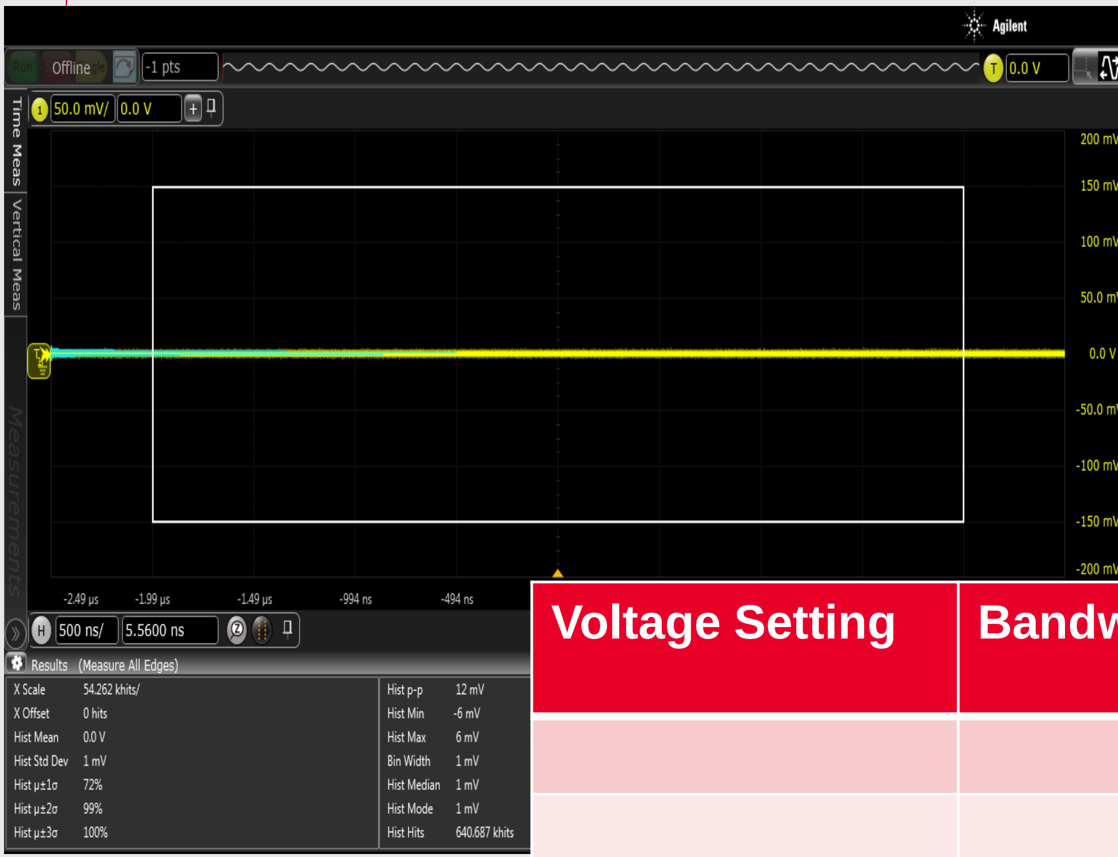
How much data is enough?



You have two variables to test:

1. Bandwidth (if you use the scope under different bandwidths)
2. V/div (if you use the scope under different voltage swings)

Voltage Setting	Bandwidth	Standard Histogram

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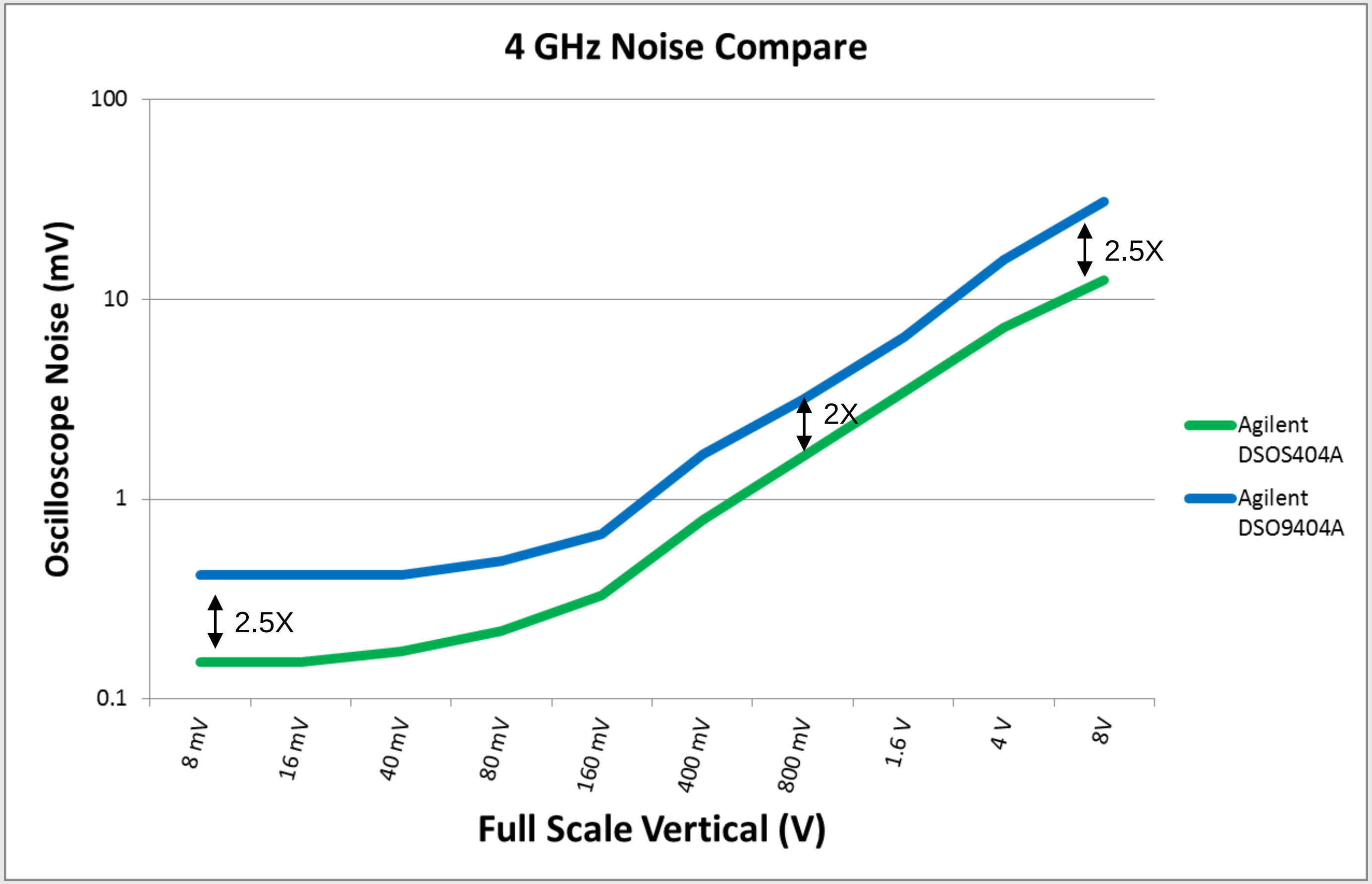
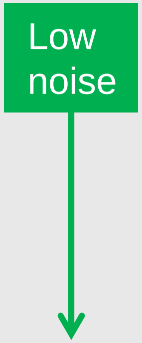
Noise Plot vs Full Scale Vertical

Compare of 2 different oscilloscopes





2. Effective Number of Bits

- Was established in 1993 as a measurement of an oscilloscope goodness and is an IEEE standard measurement
- Directly correlates with an oscilloscopes signal to noise ratio
- Does not take into account frequency response
- ENOB can impact:
  - Jitter measurements
  - Eye Height and Width Measurements
  - Amplitude measurements

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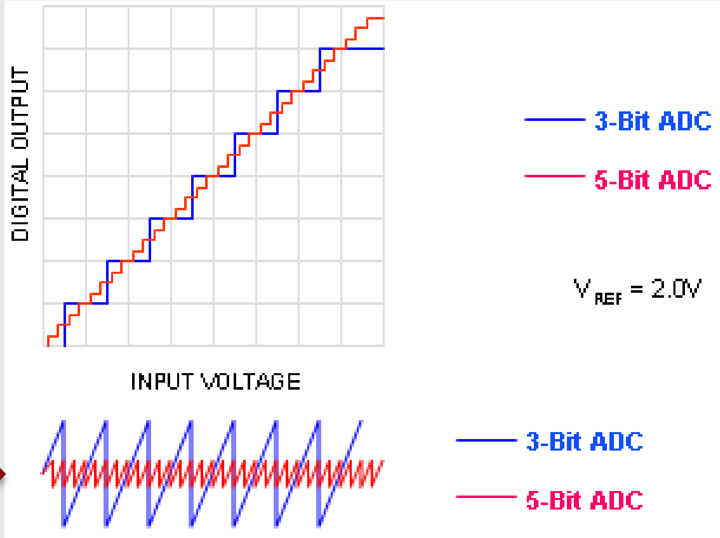
Examples of different bits of resolution

Bits of Resolution	Quantizing Levels	At 1V Full Scale 1 LSB =
8-bit	256	3900 uV
10-bit	1,024	976 uV
12-bit	4,096	244 uV
14-bit	16,384	61 uV

- Adding more bits makes each step size smaller, so the maximum error is smaller
- See the comparison to the right of a 3 bit ADC versus a 5 bit ADC

3 bit versus 5 bit error difference

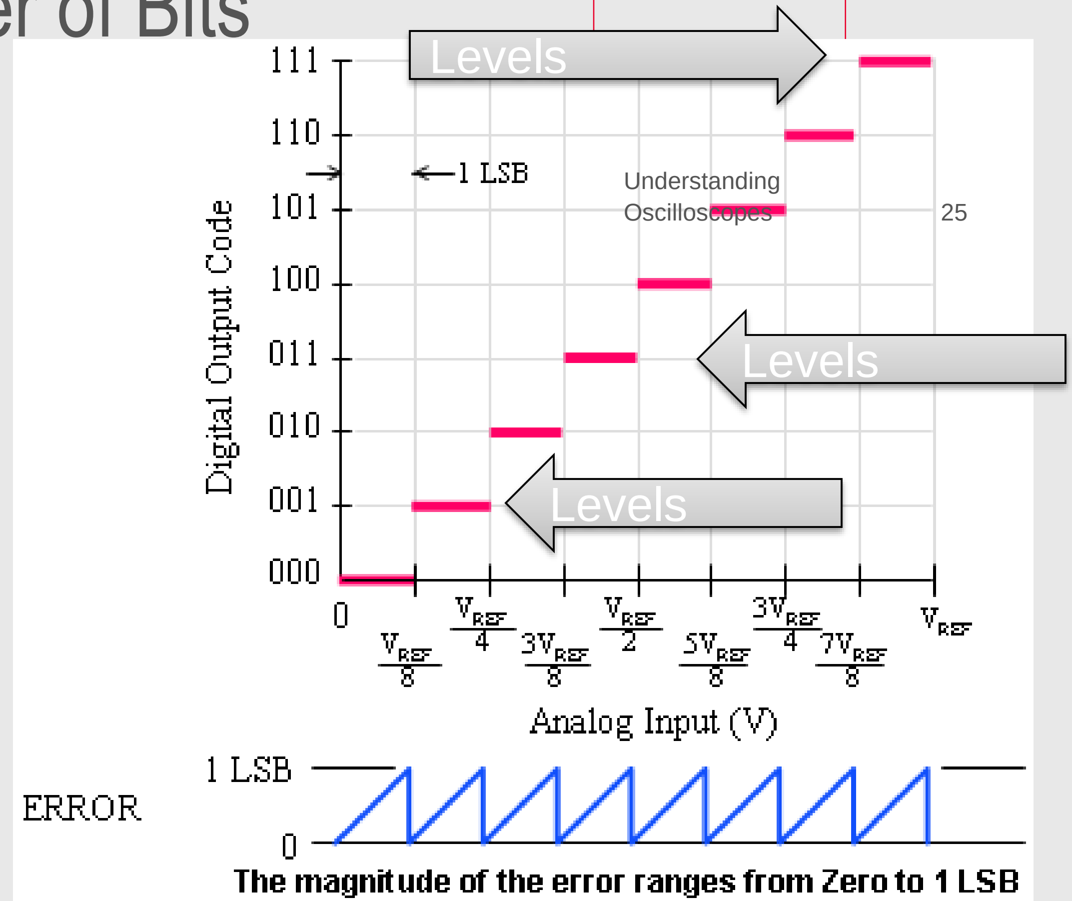


http://www.national.com/appinfo/adc/files/ABCs_of_ADCs.pdf

More on Effective Number of Bits

Bits of Resolution

- A simple 3 bit processor has 8 quantization levels (2^3)
- A signal with 0V, would have 0 errors
- Signals that increase in voltage increase in quantization errors by Vref / (2^3)
- Maximum error in this case is = Vref / 8 or +/- 1/2 least significant bit



http://www.national.com/appinfo/adc/files/ABCs_of_ADCs.pdf

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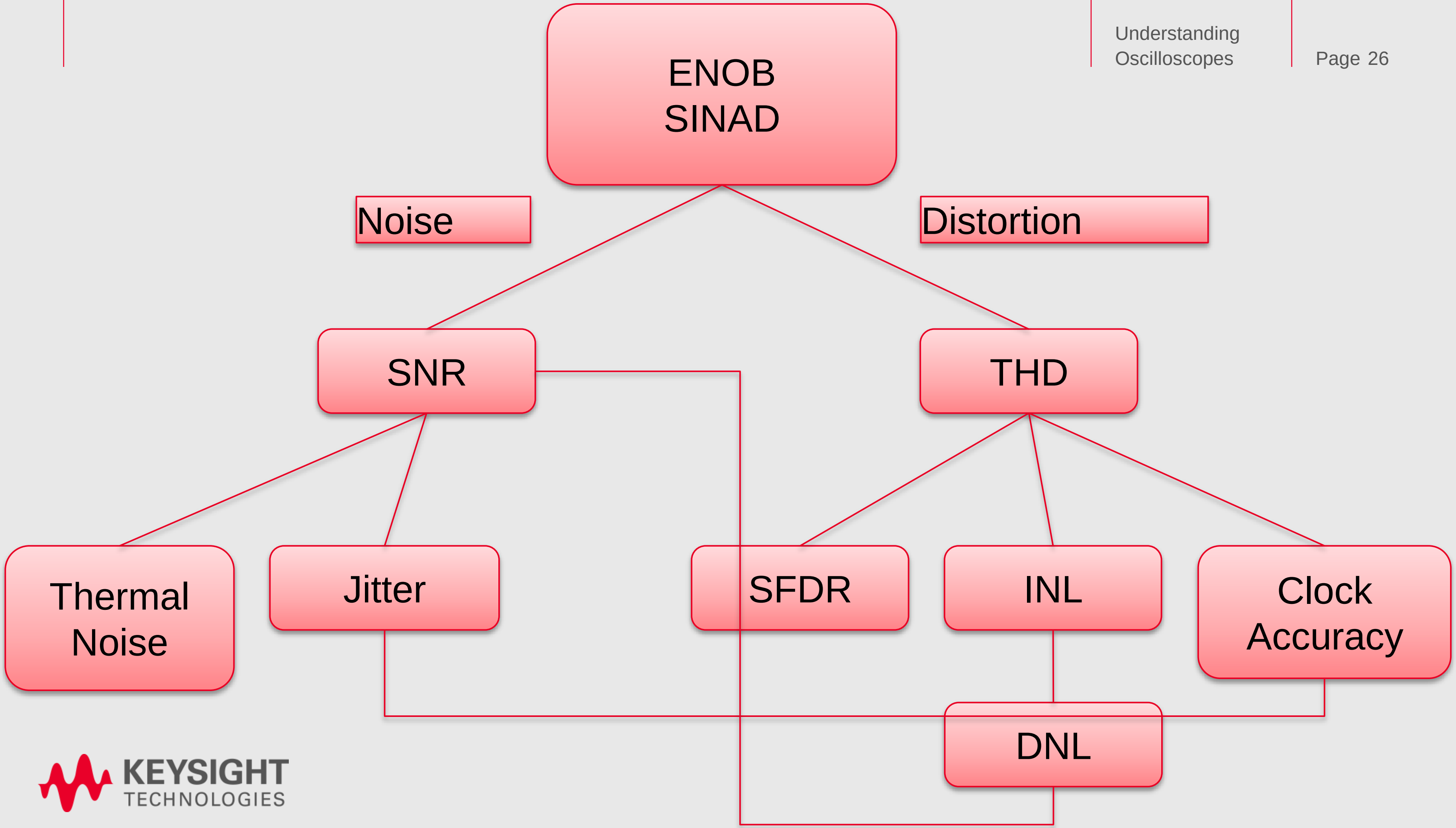
Effective bits: what erodes the ADC bits of resolution



Words of caution surrounding effective bits

- Effective bits and signal to noise ratio tend to be closely tied, but only under very ***specific*** conditions.
- Effective bits ***neglect*** key sources of error:
  - Amplitude Flatness
  - Phase Linearity
  - Gain Accuracy
  - Offset Accuracy
- Effective bits ***over-emphasize*** the effect of several measurements including harmonic distortion and high frequency timing jitter
- Effective bits ***under-emphasize*** the importance of noise floor in a system
- Effective bits ***won't*** tell you which is degrading the effective bits

Words of caution surrounding effective bits

Fig. 1. Number of effective bits versus frequency for a 10-bit, 10 Ms/s recorder.

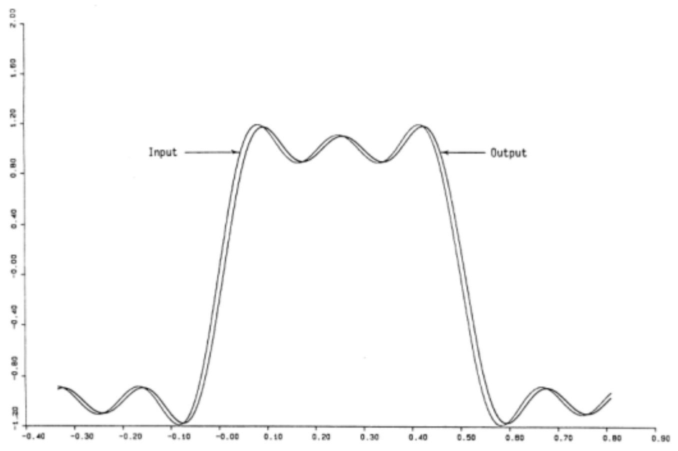


Fig. 2. Digitizer *A*: first-order pole at f_s.

Fig. 3. Digitizer *B*: first-order pole at $f_s/5$.

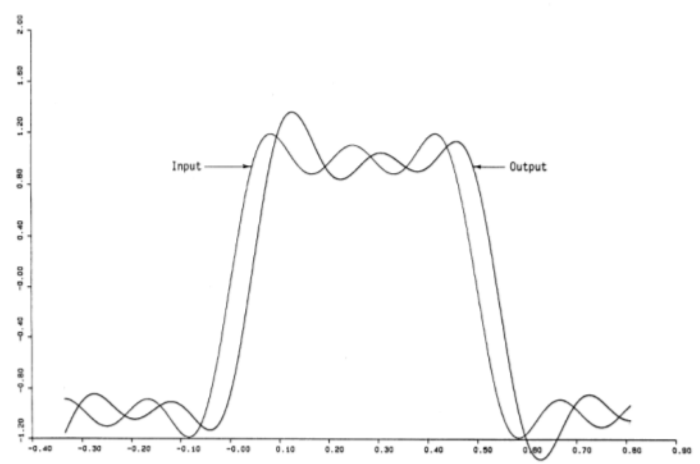


Fig. 4. Digitizer *C*: second-order, complex pole pair at $f_s/3$.

Three Oscilloscopes: All Have Same Effective Bits

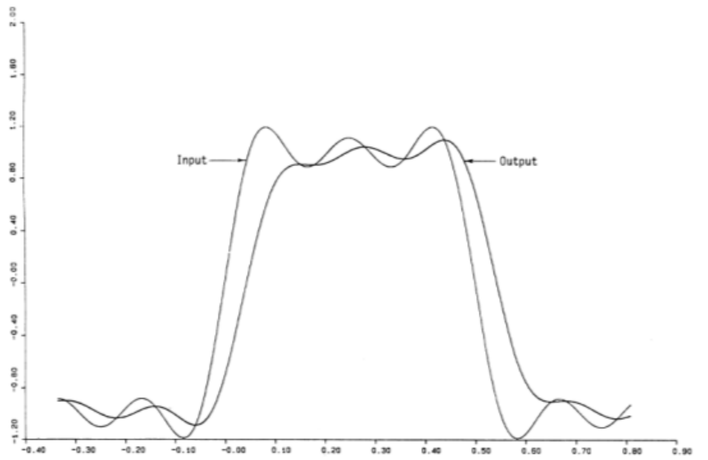


Fig. 3. Digitizer *B*: first-order pole at $f_s/5$.

Notice the effect of magnitude and phase flatness, when only considering effective bits, you could have any of the three

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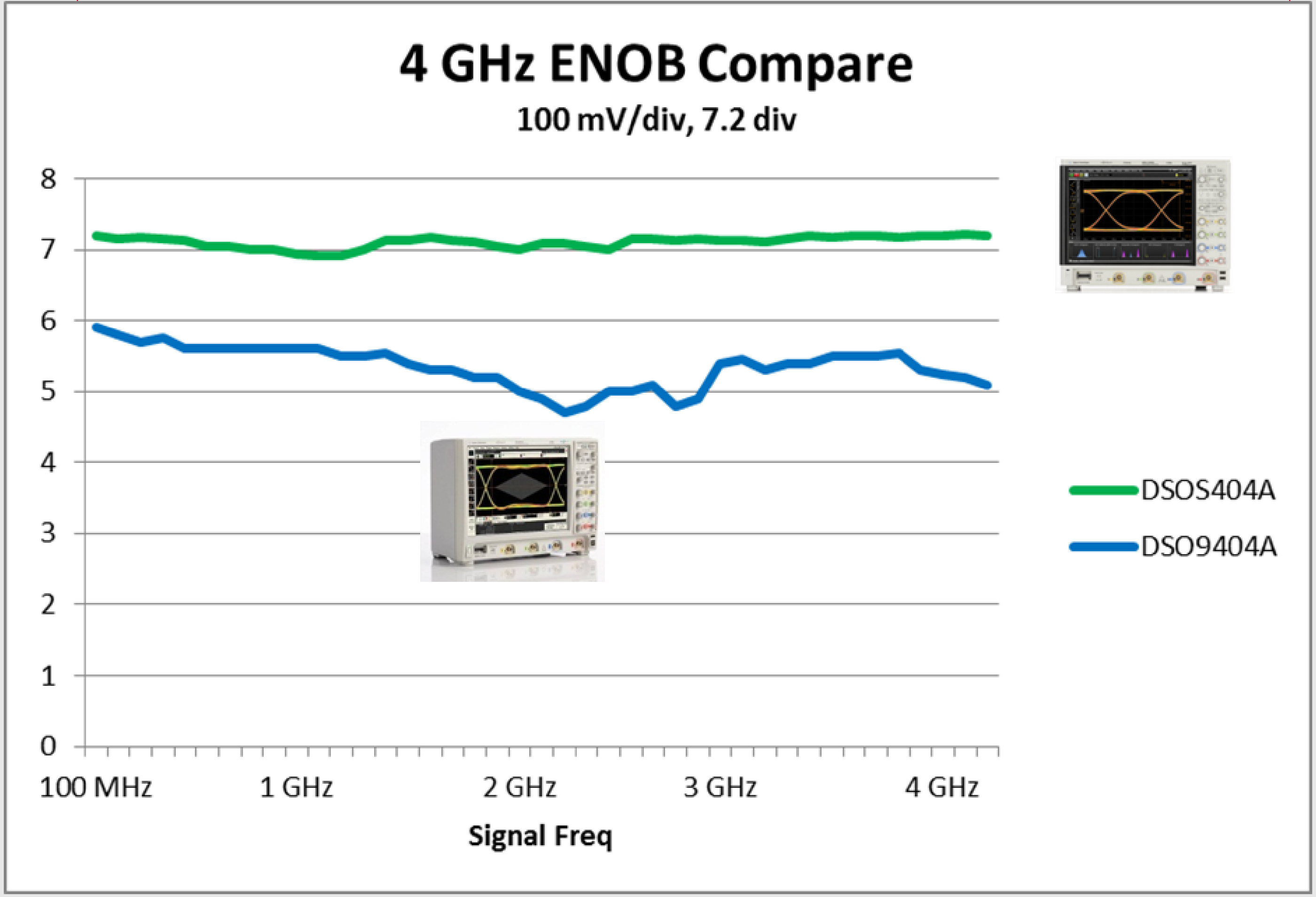
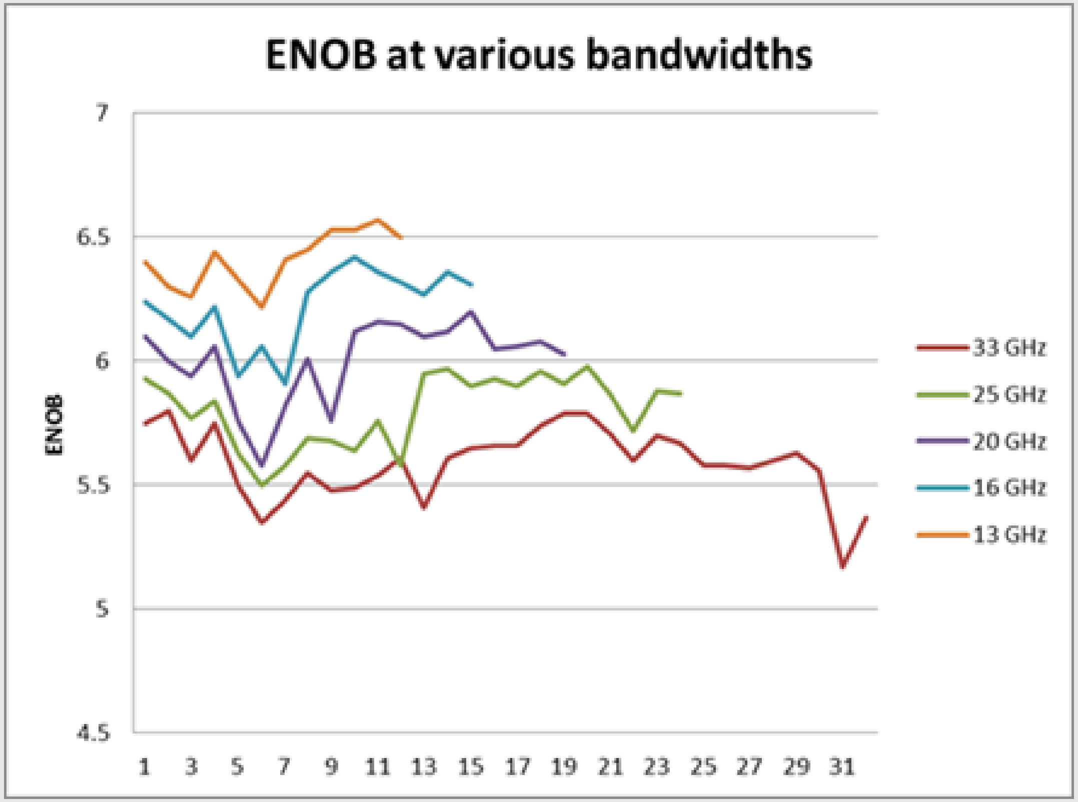
Effective Bit Comparison



Effective Bit Comparison
Infiniium 90000-X Example at Various BWs



3. Other potential measurements to consider

1. Update Rate
2. Offload Speed
3. Spurious Free Dynamic Range
4. EVM
5. Phase Linearity
6. Other Key Features
7. Probing