

Analyzing Digitizer/Scope Specifications and the Impact on Photonic Doppler Velocimetry (PDV) Measurements

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Agenda

- Digitizer and oscilloscope specifications – what you need to know
- Bandwidth
- Sample Rate
- Vertical Resolution
- Correction Done in Oscilloscopes
- Optical Probes
- ENOB

Digitizers / Real Time Oscilloscopes

- Key component of the PDV system
- Potentially largest capital investment
- Important to get the best performance
- Banner specifications don't tell the whole story



Evaluating Digitizers/Oscilloscopes

COMMON BANNER SPECIFICATIONS USED

Specification	What	Why
Bandwidth	Indicates the 3dB point of the front end of the digitizer/oscilloscope	Ensure that digitizer/scope can acquire full signal from the PDV sensor
Sample rate	Indicates the time interval between samples.	Minimum requirement for bandwidth capture. Can provide additional resolution with oversampling
Vertical resolution	Indicates the number of discrete levels used in the encoding of the output signal	Better representation of the actual signal
ENOB	Measure of the signal-to-noise-and-distortion ratio (SINAD) used to compare actual analog-to-digital converter (ADC) performance to an ideal ADC	Easy way to evaluate the “goodness” of a digitizer/scope

Bandwidth – 3dB Point

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Bandwidth	Indicates the 3dB point of the front end of the digitizer/oscilloscope	Ensure that digitizer/scope can acquire full signal from the PDV sensor
Sample Rate	Indicates the time interval between samples.	Minimum requirement for bandwidth Can provide additional with oversampling
Vertical resolution	Indicates the number of bits used in the signal	Representation of the actual
ENOB	Used to compare analog-to-digital converter (ADC) performance to an ideal ADC	Easy way to evaluate the “goodness” of a digitizer/scope

Scopes with the same BW specification may measure the same signal differently

Two Scopes with the Same BW Specification

SAME SIGNAL DIFFERENT MEASUREMENTS - WHY?



Vpp = 611mV



Vpp = 242mV

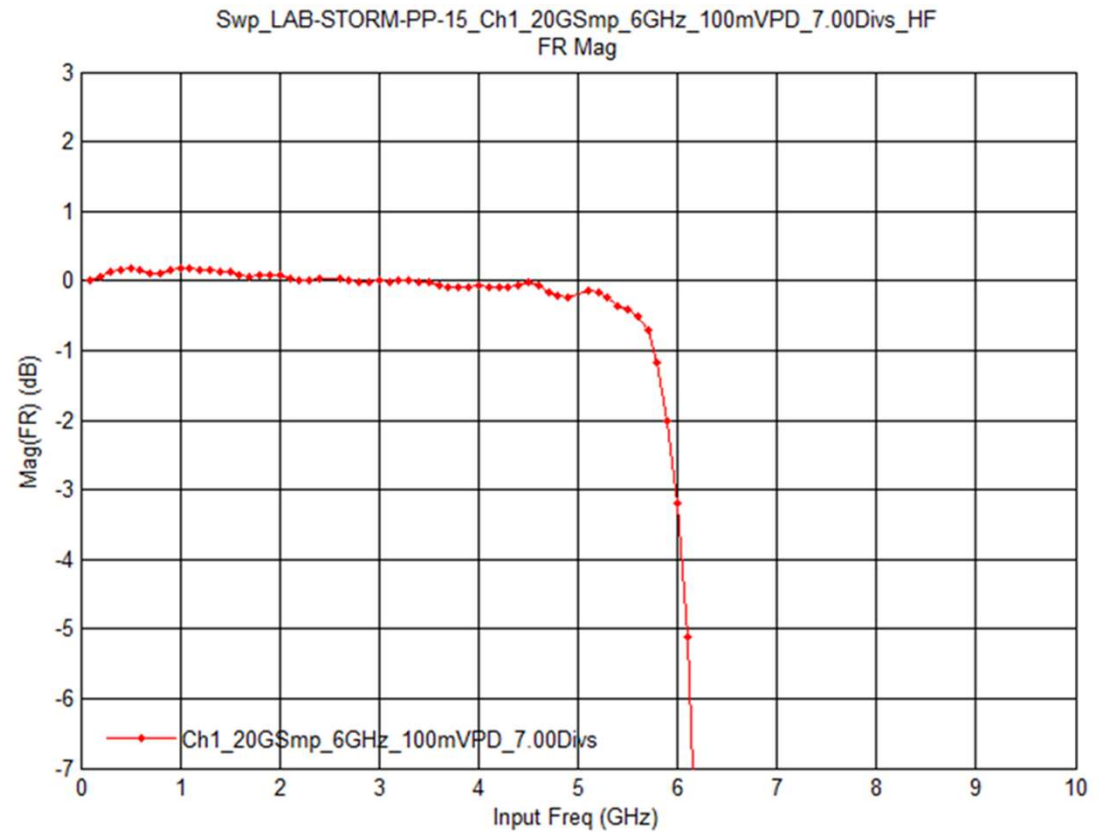
The two scopes will report different Vpp and risetime values

Bandwidth and Frequency Response

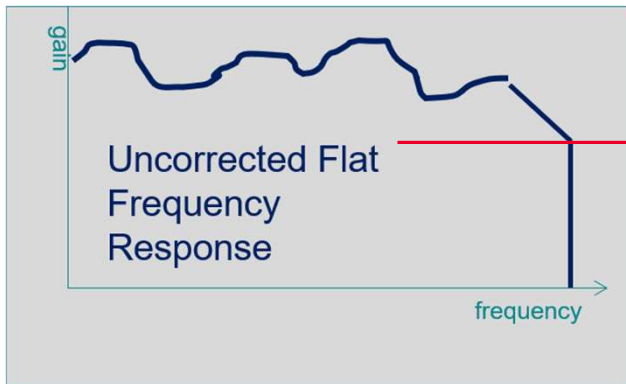
Specified bandwidth of oscilloscopes is influenced by their frequency response (-3dB point)

The frequency response of an oscilloscope impacts measurements in the following ways

- Can cause amplitude measurement inconsistencies
- Can increase ISI
- Can increase noise
- Can change wave shape



What are the Three Frequency Responses?

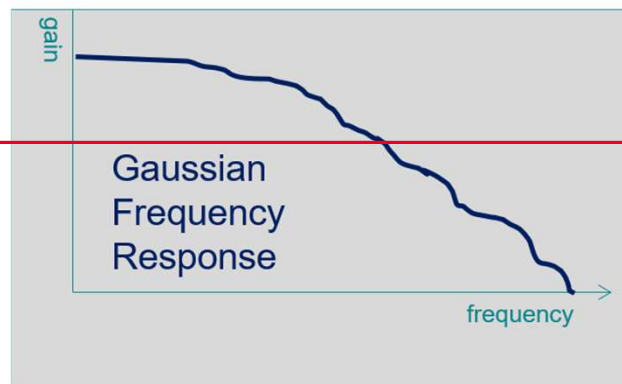


Positive:

- Runs quickly

Negative:

- Can measure incorrect signal amplitude at all pass-band frequencies
- Unknown weight of different frequency tones.
- Can increase the noise of the system

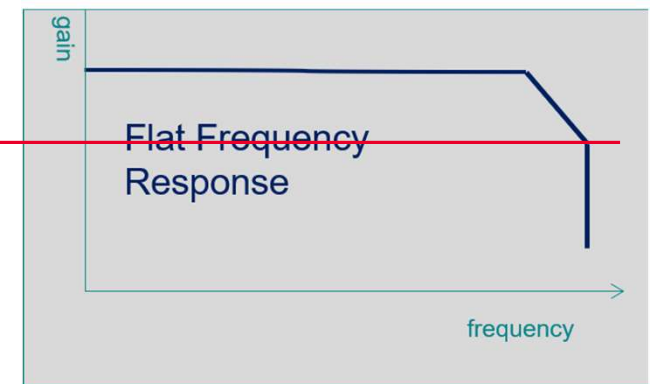


Positive:

- Will not cause ringing on fast rise times
- Has bandwidth outside of the pass-band

Negative:

- As frequencies increase on the device, amplitude measurements decrease
- Does not give equal weight to all frequencies.
- Superficially decreases noise on the system



Positive:

- Measures correct signal amplitude at all pass-band frequencies
- Will not increase the noise of the system
- Gives equal weight to all frequencies

Negative:

- If you drive the rise time faster than the scope, can see ringing

Sample Rate

Specification	What	Why
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Vertical resolution	Indicates the number of bits used in the digitizer	Better representation of the actual signal
ENOB	Indicates the effective number of bits. Signal-to-noise-and-distortion ratio (SINAD) used to compare actual analog-to-digital converter (ADC) performance to an ideal ADC	Easy way to evaluate the “goodness” of a digitizer/scope

Oversampling can provide additional resolution in the frequency domain

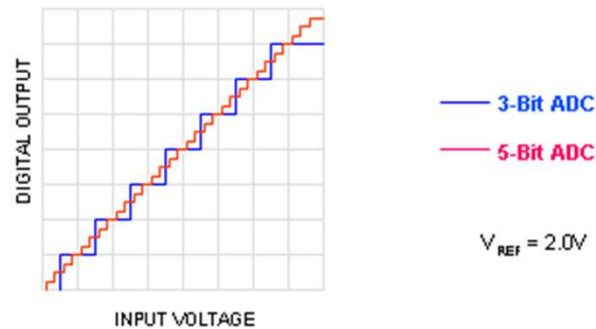
Vertical Resolution

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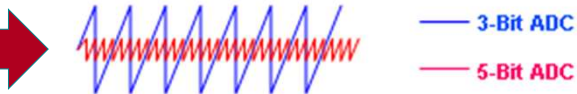
Analog to Digital Converter (ADC) Resolution

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

- ❑ 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

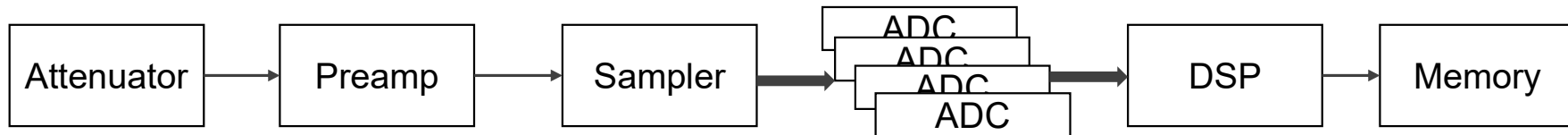


3 bit versus 5 bit error difference



Signal Path Corrections in Oscilloscopes

WHY “RAW” DATA IS NOT PRACTICAL

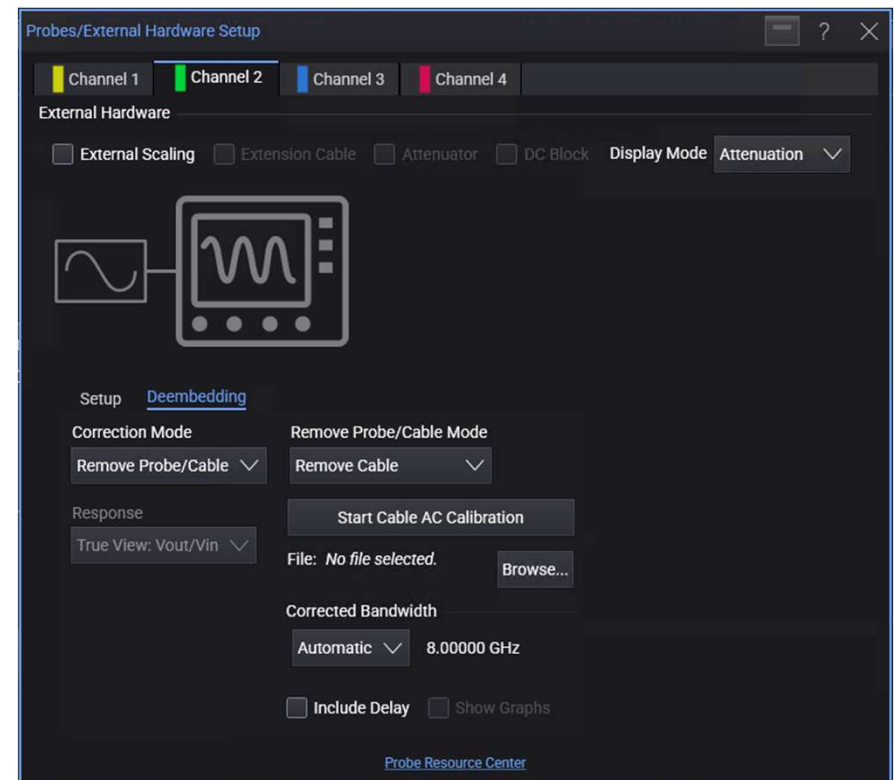


- The complexity of the data flow in an oscilloscope requires that corrections are applied to fix imperfections in the response and interleaving of the signal.
- Without this correction, any data that is provided would not be a correct representation of the real signal.
- It would be misleading to use this data.
- To meet our performance needs, this kind of process is necessary.

What Corrections Can be Done in Oscilloscopes

CORRECTIONS ON THE CHANNEL

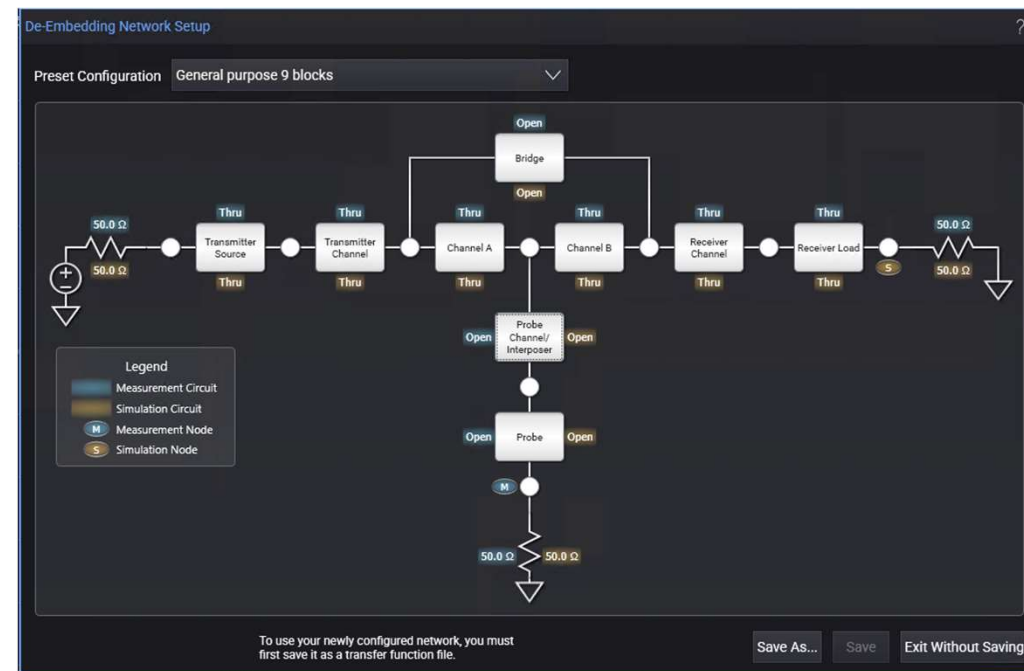
- This will be for the cable that is between the scope and the DUT.
- It is an automated process that will create the s-parameters for you, or you can load an S-Parameter file if you have one.
- This allows you to remove the effects of the cable before it is analyzed.



What Corrections Can be Done in Oscilloscopes

CORRECTIONS IN A FUNCTION

- You can add a De-Embedding function that can be used to remove even more out of the system.
- You can make it as complex as you want.
- This can consider the whole path including your probe point into the system.
- Transfer function vs S-Parameters.



Why Use an O/E Converter?

Advantages Over Simple Detectors

- **Tight integration with the oscilloscope:** Calibration information automatically passed to the scope, automatic scaling, automatic dark calibration
- **Improved noise:** Keysight O/Es include amplification, with the system optimized to minimize thermal noise, shot noise, TIA input-referred noise, etc.
- **Frequency response correction:** Keysight O/Es are individually characterized during manufacturing, with the ability to shape the response depending on the application (e.g. Bessel-Thomson or brick-wall)
- **Traceability**

Keysight Infiniium Software

Integrates with Keysight O/E products



Select a desired roll-off, inspect the frequency response



Integrated optical measurements

ENOB

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ENOB – Effective Number Of Bits

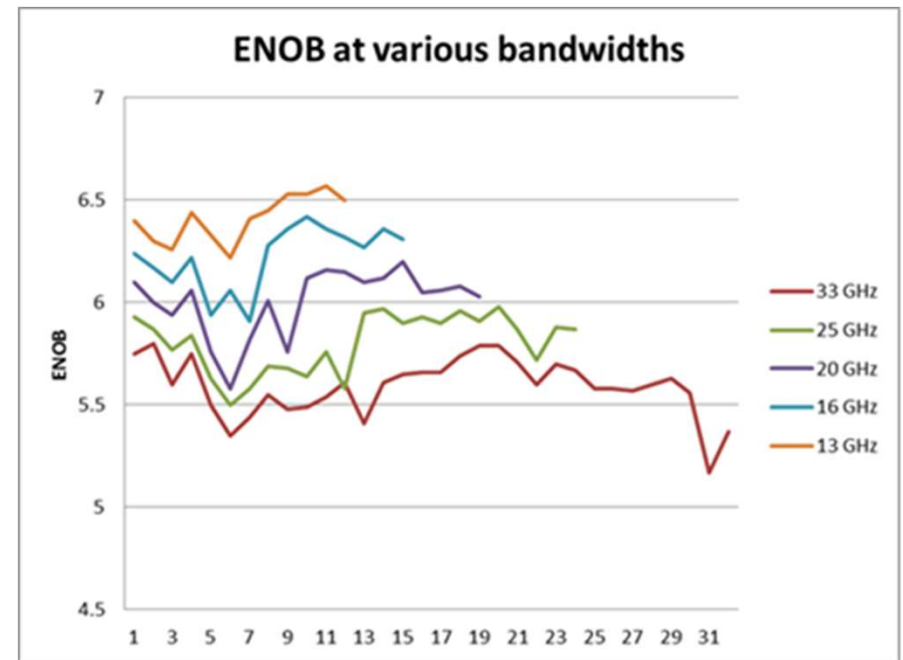
- Was established in 1993 as a measurement of a digitizer’s “goodness” and is an IEEE standard measurement
- Directly correlates with a digitizer’s signal to noise ratio
- Does not take into account frequency response
- ENOB can impact:
 - Amplitude measurements
 - Frequency measurements
 - Repeatability of measurements

Caution Around ENOB

- ENOB and signal to noise ratio closely tied
 - Under specific conditions
- ENOB neglect key sources of error
 - Amplitude flatness
 - Phase linearity
 - Gain accuracy
 - Offset accuracy
- Over-emphasis on the effect of several measurements including harmonic distortion and high frequency jitter
- Under-emphasis on the importance of noise floor in a system
- Won't tell you which is degrading the effective bits

Other Challenges with ENOB

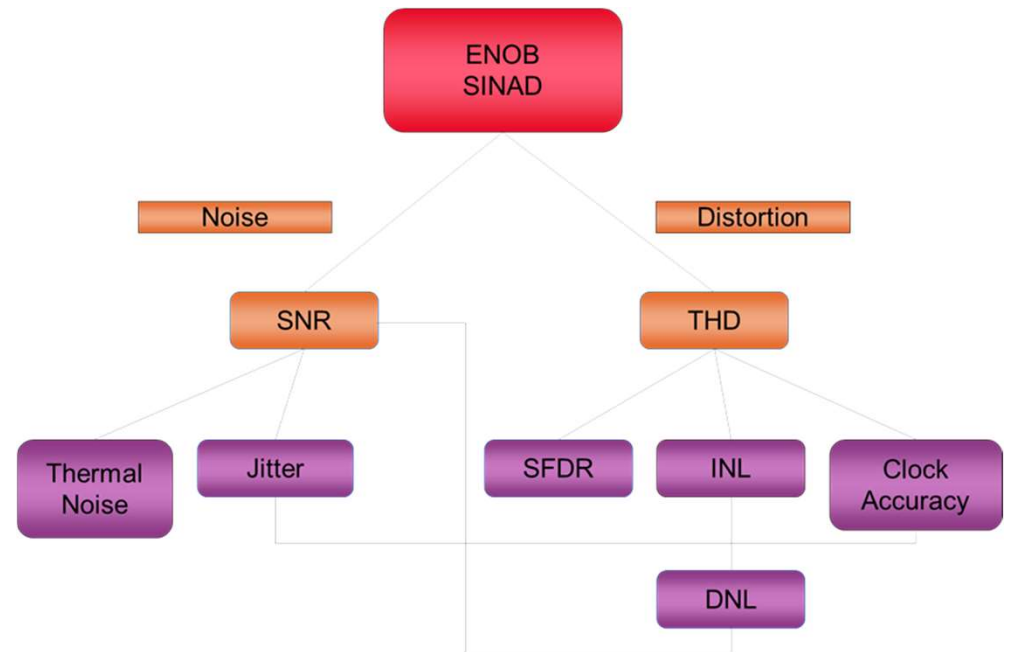
- A single number for ENOB **ONLY** describes the ENOB value at one specific frequency
- ENOB is strongly affected by Volts per division setting
- ENOB is strongly affected by input signal amplitude



Why Use ENOB?

CONVENIENT – FIRST PASS

- No other easy comparison that sums up multiple errors
- Valid comparison if you can determine ENOB for each digitizer with environment settings
 - Bandwidth
 - Volts/div setting
 - Input signal size.



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- Important to get the best performance
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Summary

BW and frequency response

- Understand frequency response of each digitizer you are considering.

Sample rate

- Processing gain is possible

ENOB

- ENOB provides a good first pass evaluation
- Many things affect ENOB
- Important to evaluate or measure at BW and levels important to your environment

Vertical resolution

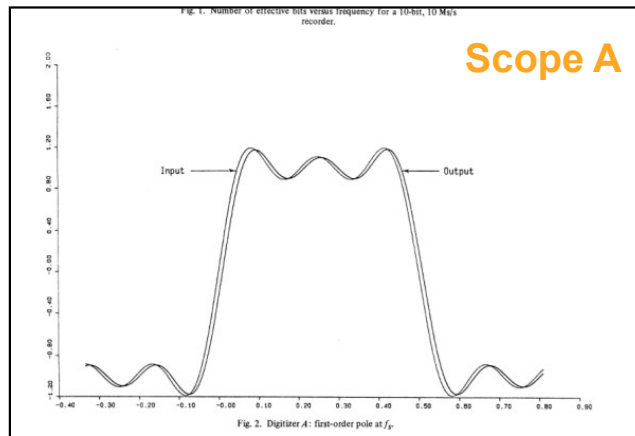
- Vertical resolution does not buy you much if noise floor is not very good.



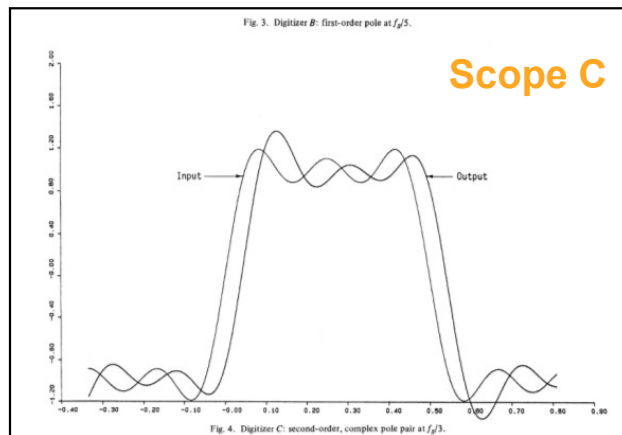
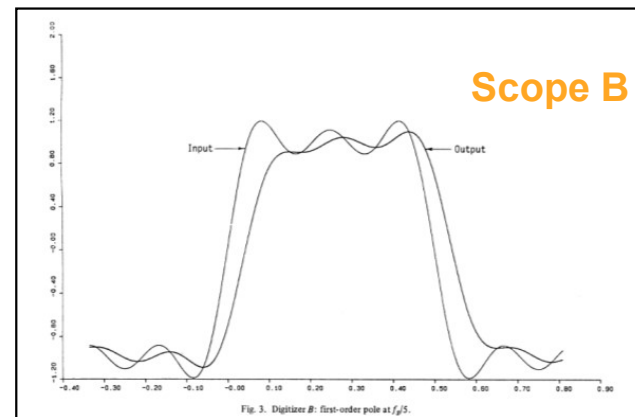
Thank you

Backup Slides

More Words of Caution



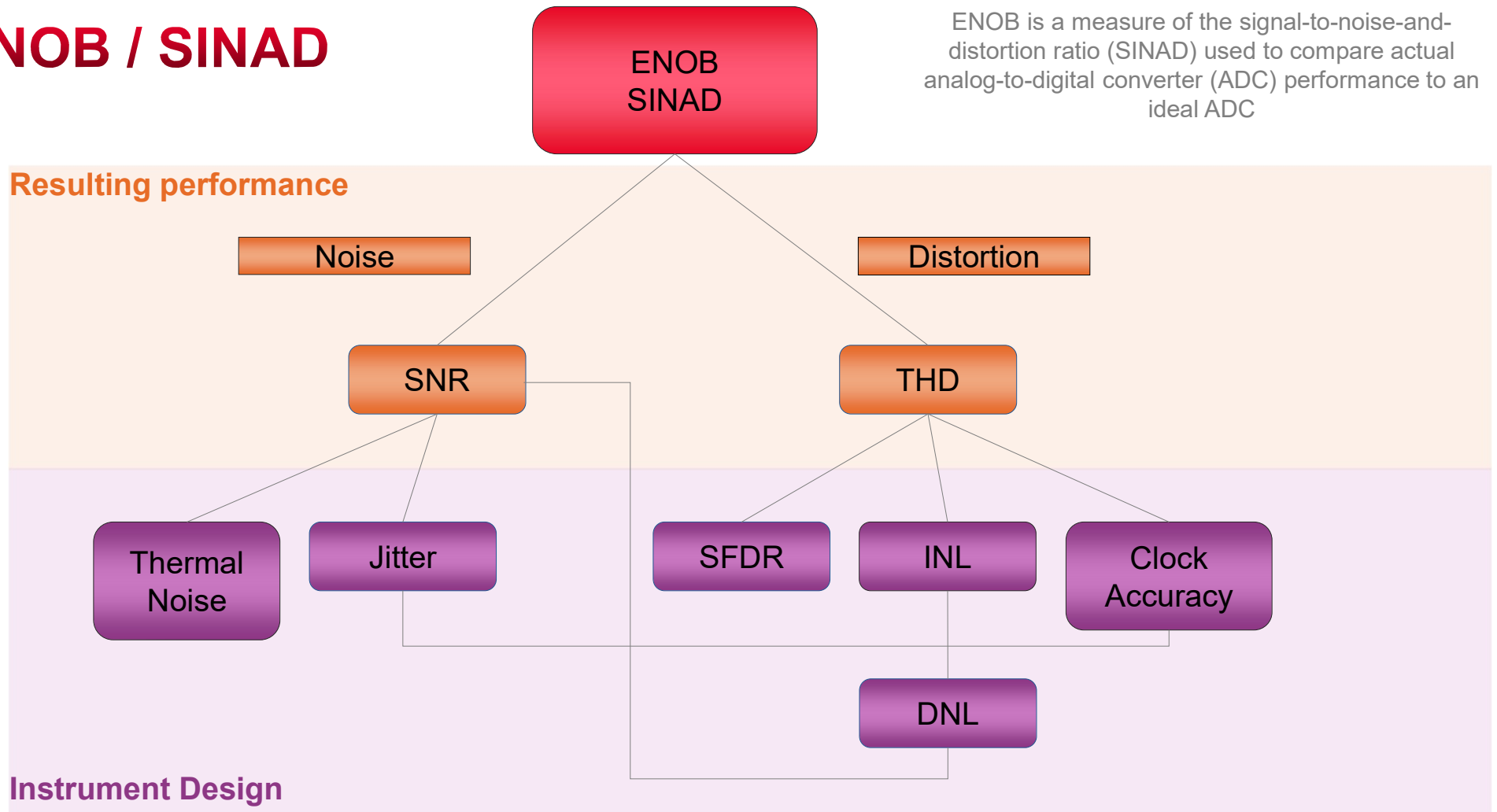
Three oscilloscopes: All have same effective bits



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

ENOB / SINAD

ENOB is a measure of the signal-to-noise-and-distortion ratio (SINAD) used to compare actual analog-to-digital converter (ADC) performance to an ideal ADC



Other Specifications

Phase linearity

Oscilloscope phase impacts waveform shape. The less linear the phase the less square a square wave will look.

Offload speed

If you do a lot of work on a PC for post processing, it is important to pull data off the scope quickly. Offload speed shows how fast the scope does this.

Spurious free dynamic range

SFDR is the strength ratio of the fundamental signal to the strongest spurious signal in the output.

Error vector magnitude (EVM)

Similar to ENOB, EVM takes into account noise, phase noise and distortions, the lower the EVM, the better the scope measurement.

N7004A

33 GHz Optical-to-Electrical Converter

- Bandwidth: DC to 33 GHz (Brickwall filter) or DC to 22 GHz (4th order Bessel Thomson filter)
- Wavelength: 750 nm – 1650 nm (single-mode and multimode fiber, FC/PC adapter)
- AutoProbe II interface — direct plug-in to Infiniium V-, X-, and Z-Series oscilloscopes
- Per-unit S-parameter correction for flat, accurate frequency response; supports optical NRZ signals up to 28 Gbaud



N7004A

N7005A

60 GHz Optical-to-Electrical Converter

- Bandwidth: DC to 60 GHz (Brickwall filter) or DC to 46.6 GHz (4th order Bessel Thomson filter)
- Wavelength: 1250 nm – 1600 nm (single-mode fiber)
- AutoProbe III interface — designed for Infiniium UXR Series oscilloscopes (up to 110 GHz bandwidth)
- Supports 56 Gbaud PAM4; enables TDECQ compliance testing with Keysight FlexRT software; up to 4 channels simultaneously for 4x100G PAM4 analysis



N7005A