Oscilloscopes for Physicists

Short overview by Keysight Technologies

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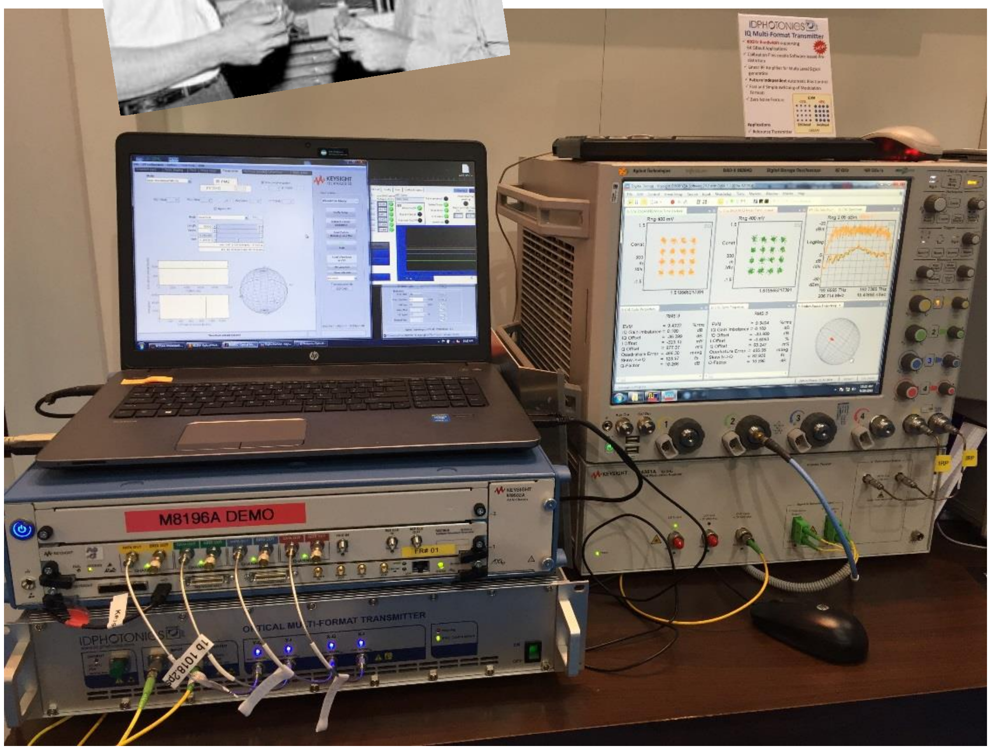
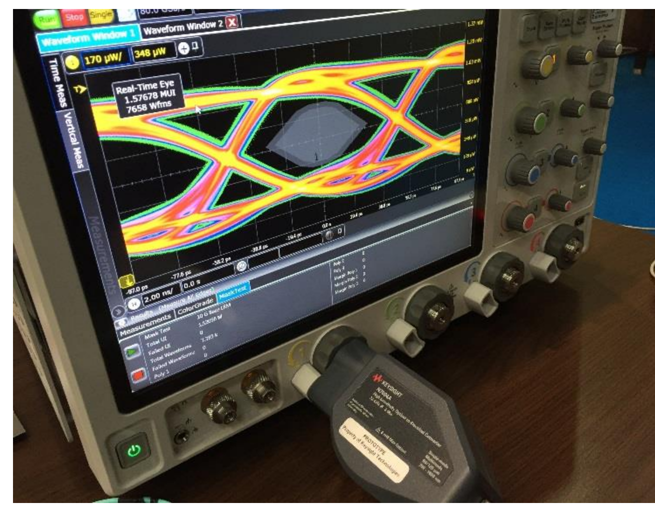
Keysight Technologies: 76 years Measurement Science

1939–1998	Hewlett-Packard
1999–2013	Agilent Technologies
2014	Keysight Technologies

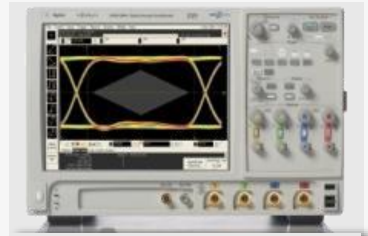




Keysight *Measurement Science* : Oscilloscopes

Infiniium 86100D DCA-X
Optical/Electrical Sampling Scopes

Infiniium V- and Z-Series
63 GHz-to-8 GHz Real-time Bandwidth



Infiniium 90000A Series
13 GHz-to-2.5 GHz Real-time Bandwidth

Infiniium S-Series
8 GHz-to-500 MHz Real-time Bandwidth

InfiniiVision 6000 X-Series
6 GHz-to-1 GHz Real-time Bandwidth

InfiniiVision 4000 X-Series
1.5 GHz-to-200 MHz Real-time Bandwidth

InfiniiVision 3000T X-Series
1 GHz-to-100 MHz Real-time Bandwidth

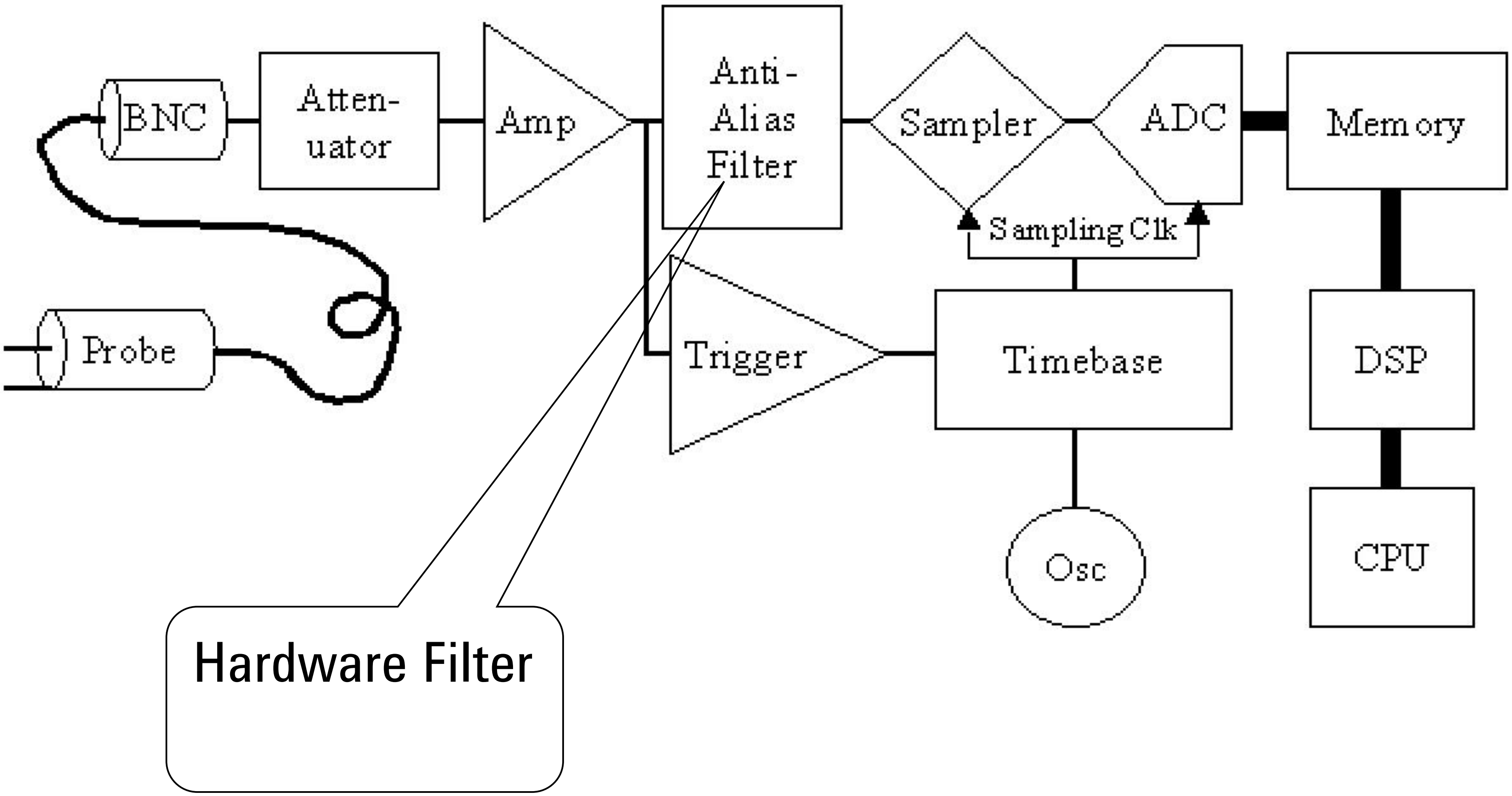
InfiniiVision 2000 X-Series
200 MHz-to-70 MHz Real-time Bandwidth

1000 Series
200 MHz-to-50 MHz Real-time Bandwidth

Example Oscilloscope used as PCIe analyzer

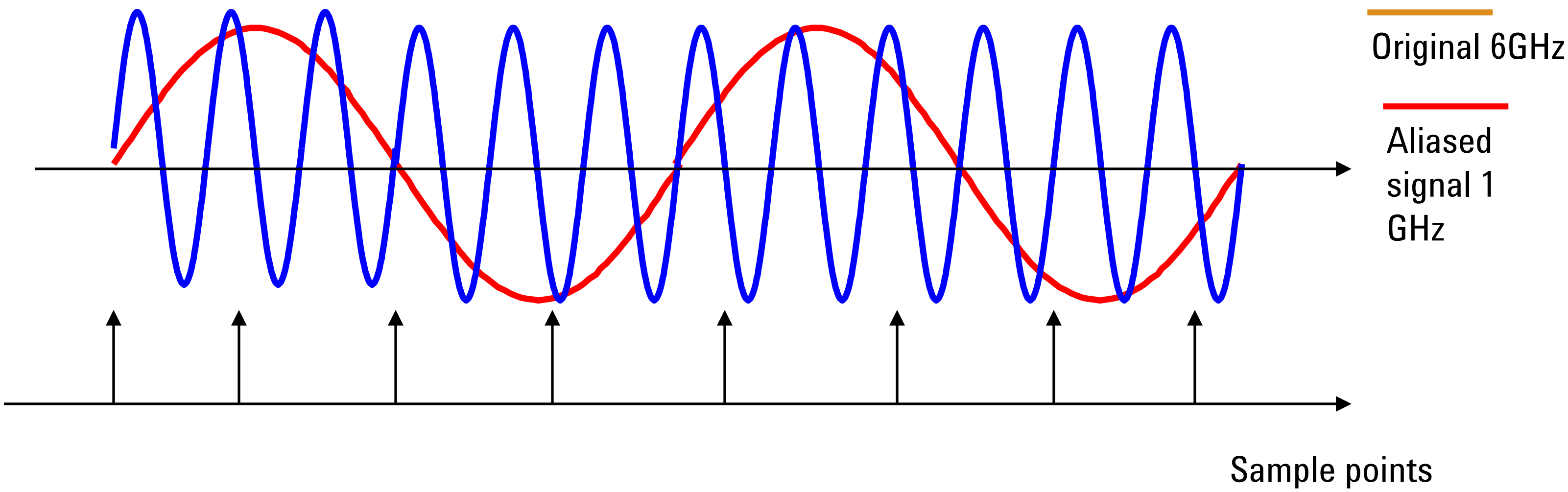
Contrast versus “inside chipscope”: Measuring on “outside signals”

Oscilloscope block diagram



To prevent aliasing on realtime scopes filtering is needed

Aliasing will appear when the sample rate is too low, an incorrect waveform of a lower frequency due to undersampling of the waveform.

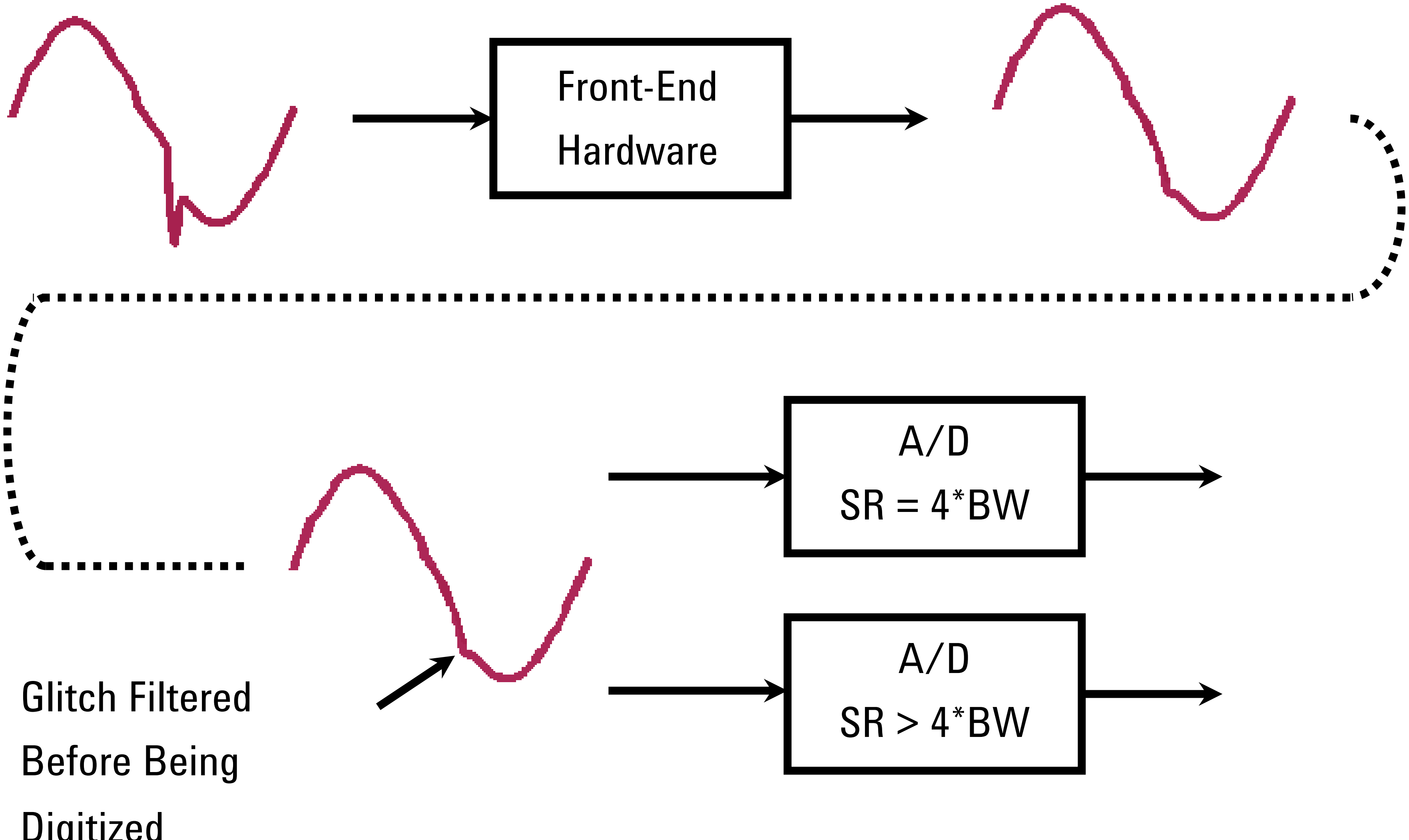


Question:

- Assume for your experiment you would need to have an realtime oscilloscope with 1 GHz analog bandwidth.
- In your lab you have two different 1 GHz oscilloscopes:
  - 1x with 4 Gsample/sec ADC
  - 1x with 40 Gsample/sec ADC.
- Which one would you choose?

Scope Sampling Rate (versus Scope Bandwidth)

No Major Benefit of SR > 4 * BW_{scope}



Question:

- An Engineer needs to measure time delay between 2 rising edges. One rising Edges on channel 1 and one rising Edge on Channel 2. Requested accuracy is +/- 10 picoSeconds.
- Model# 54855A/9000 has an 20 GSample ADC. This translates into an 50 picosecond sample interval.
- Model# DSO 81004A/90000 has an 40 GSample ADC. This translates into 25 picoSecond sample interval.
- Does the Engineer to request budget for an oscilloscope with an 1/10pS = 100 Gsample ADC?

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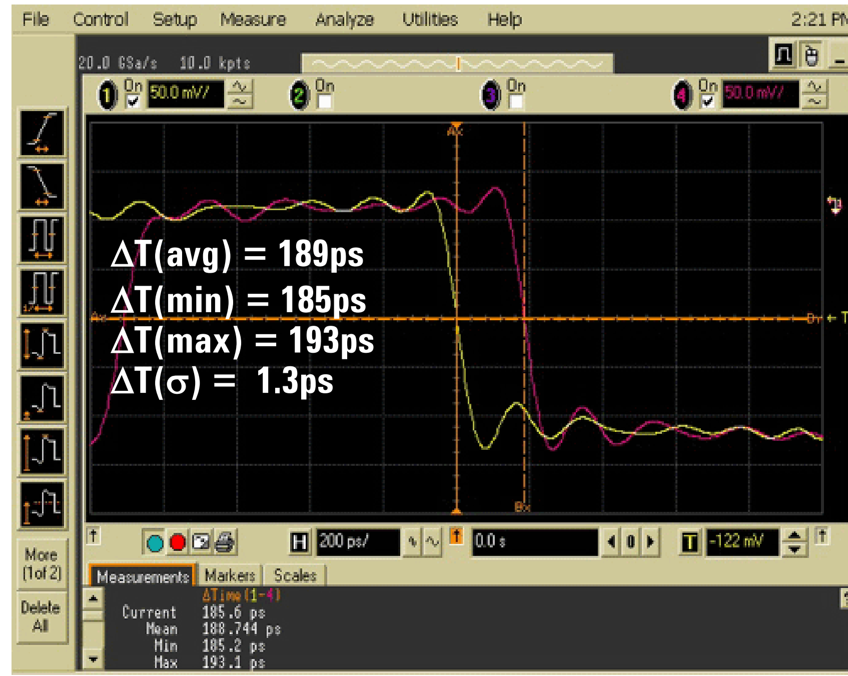
Answer for 10 pSec accuracy

40 GSample/25picoSecond on DSO 81004A 10GHz BW

20 GSample/50 picosecond on 54855A 6GHz BW



Channel to Channel Delta time Measurement

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DSO 81004A has an 40 GSample ADC. This translates into 25 picoSecond sample interval.

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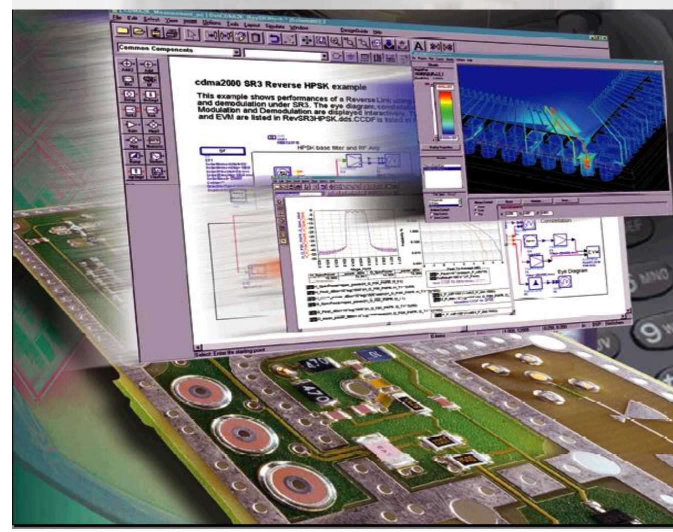
Addendum Interpolation:

Interpolation in Digitizing Oscilloscopes



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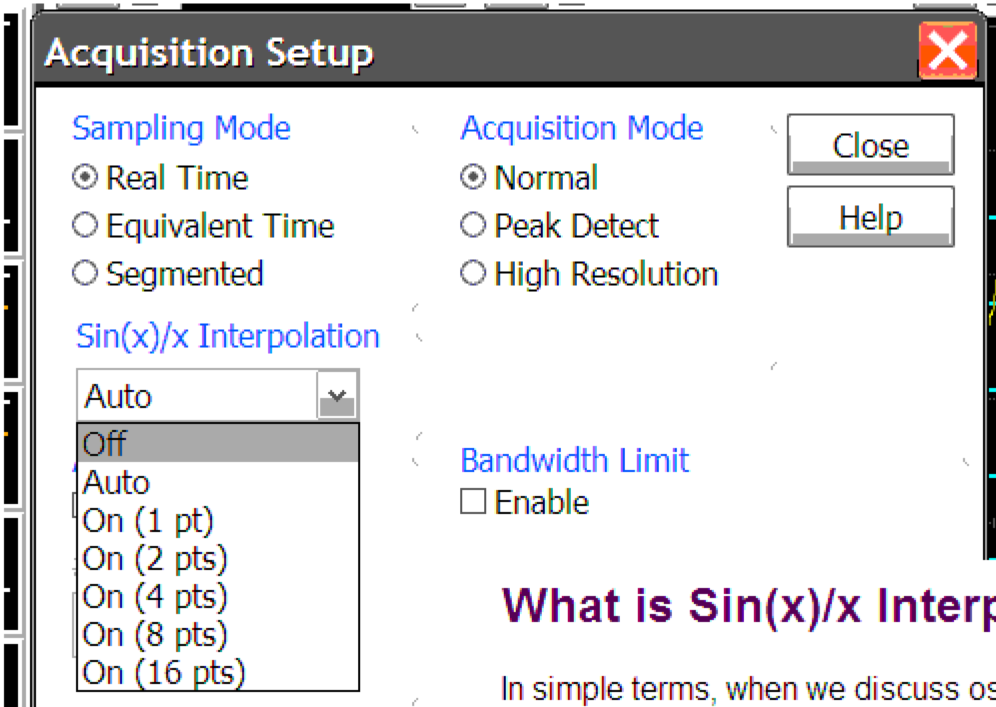
Example Interpolation on infiniium scope



What is Sin(x)/x Interpolation? (return to top)

In simple terms, when we discuss oscilloscope sampling, we are referring to sampling a continuous waveform at discrete points in time. In order for the continuous waveform to be accurately reproduced by these discrete points, Nyquist's Theorem should be satisfied. If the Nyquist's criteria are met, you can perfectly reconstruct the signal using sin(x)/x interpolation. The Sin(x)/x Interpolation Filter is a sin(x)/x finite impulse response (FIR) digital filter that improves the reconstruction of the waveform by adding data points between the acquired data points. The interpolated data points are used to improve the accuracy of the measurements.

When the sin(x)/x interpolation filter is enabled, it adds interpolated points between sampled waveform points when the number of sampled points are too few to adequately display the waveform.

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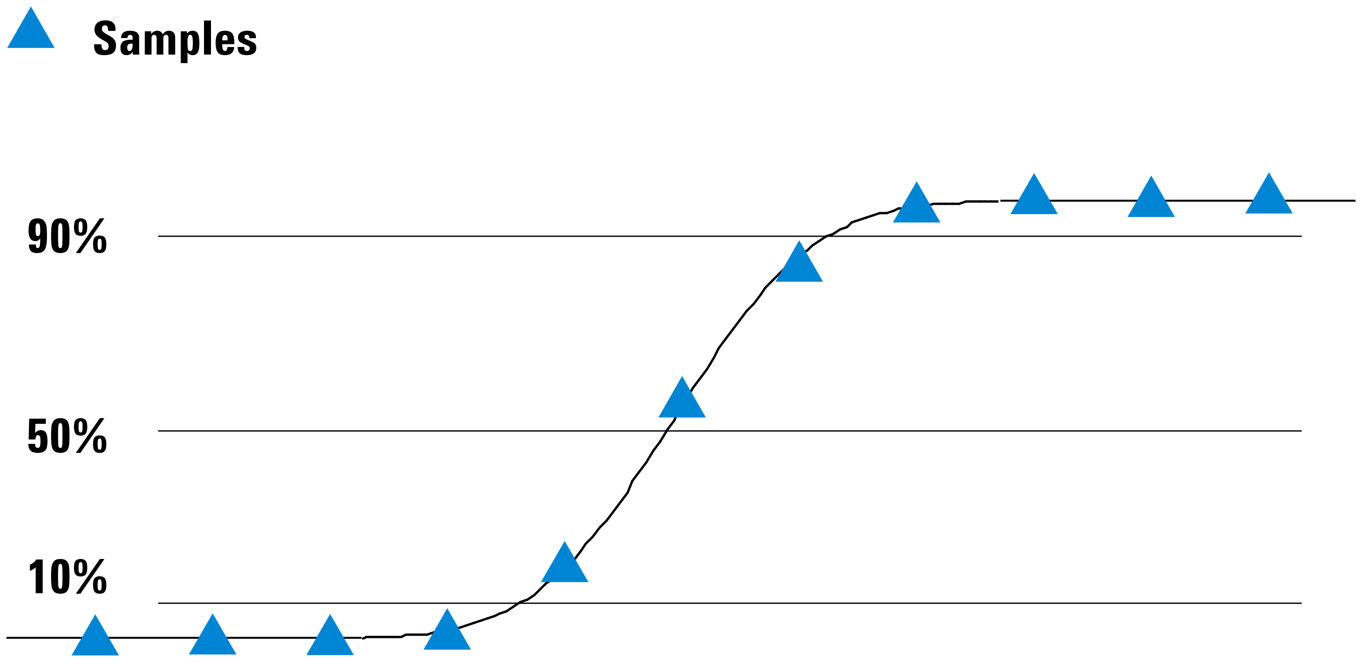
Why Interpolation?



Why Interpolation?

The scope samples your waveform and places the samples in memory. If your waveform has a fast rise time compared to the scope's sampling rate, there can be a small number of samples taken from the rising edge. For example, if the scope is sampling at 4 Gsa/s, then the time between samples is 250 ps. If your waveform has a rise time of 1 ns then there are only 4 samples stored in memory representing the edge. This can cause problems when trying to make an automated rise time measurement

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How Interpolation: Waveform reconstruction

The reconstruction filter creates waveform points between sample points using the sampled waveform points. At sample rates less than 20 GSa/s, if the highest frequency in your waveform is less than the sampling frequency divided by 4 (fs/4), the reconstruction filter will accurately reproduce your waveform. At 20 GSa/s the highest frequency must be less than the bandwidth of the scope. The interpolation technique was proven to accurately reproduce the original waveform by Shannon in 1947.

How Interpolation: Make use of "Sampling Theorem"

From http://en.wikipedia.org/wiki/NyquistShannon_sampling_theorem :

- **The Nyquist–Shannon sampling theorem is a fundamental theorem in the field of information theory, in particular telecommunications, created by Claude Shannon and Harry Nyquist, and is sometimes simply referred to as the *sampling theorem*.**
- **The theorem states the conditions under which the samples of a signal can be used to reconstruct the signal perfectly:**
  - ***When sampling a bandlimited signal (e.g., through analog to digital conversion) the sampling frequency must be greater than twice the signal's bandwidth in order to be able to reconstruct the original perfectly from the sampled version***

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What Is Interpolation?

- *Interpolation* increases the effective sampling density of a waveform consistent with the *bandwidth* allowed by the original sample rate. This process is *required* for optimal waveform *viewing* as well as for making accurate *measurements.*

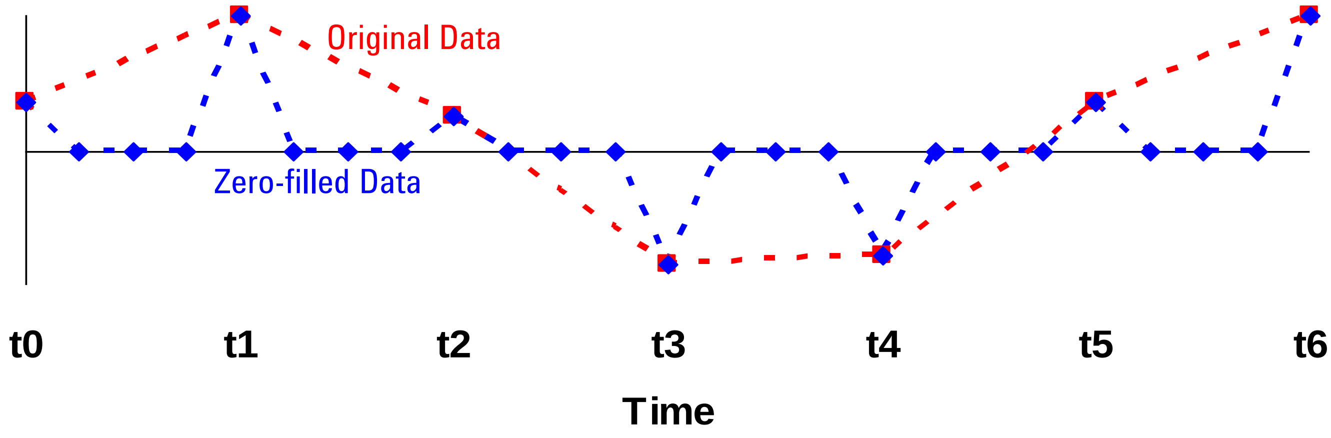
- *Interpolation* cannot add *information* about the signal which was not present in the original samples.

- *Interpolation* is (for Keysight oscilloscopes) a process which follows the rules of linear systems theory, and can be observed in the time and frequency domains. IE we just follow Shannon's and Nyquist's rules

The Interpolation Process

The first step in Interpolation is to *add* zero-valued samples to achieve the desired sample *density*. For 4:1 interpolation, 3 zeros are added for each actual sample.

Note the presence of *high frequency* components (abrupt slope changes) in the zero-filled signal.



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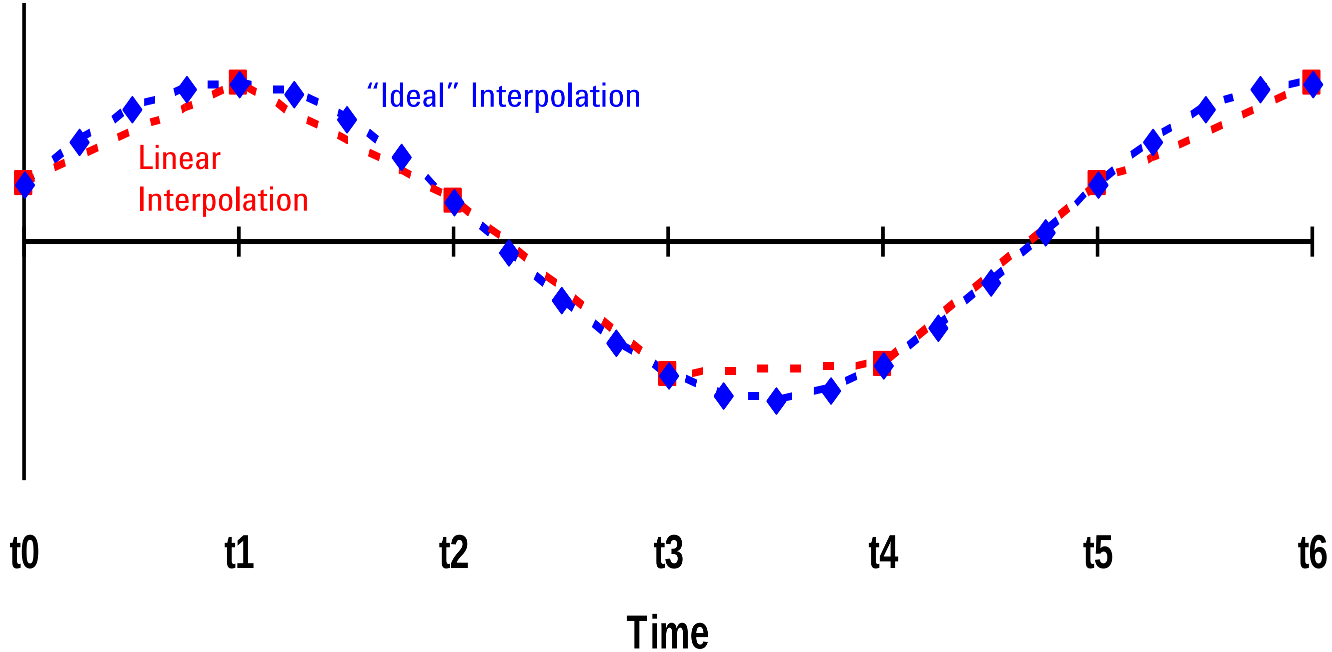
The Interpolation Process

The reconstructed waveform has *smooth* edges relative to simple *linear* interpolation.



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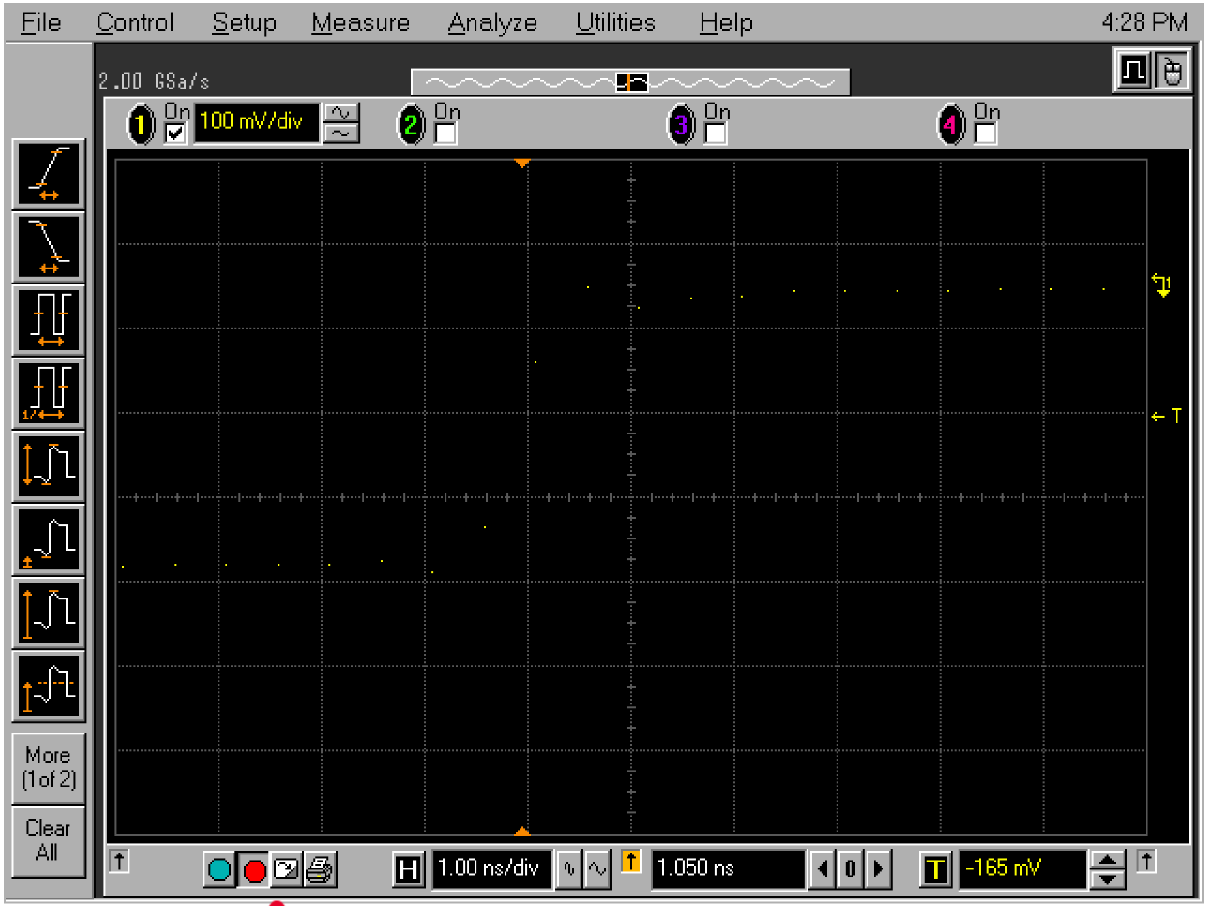
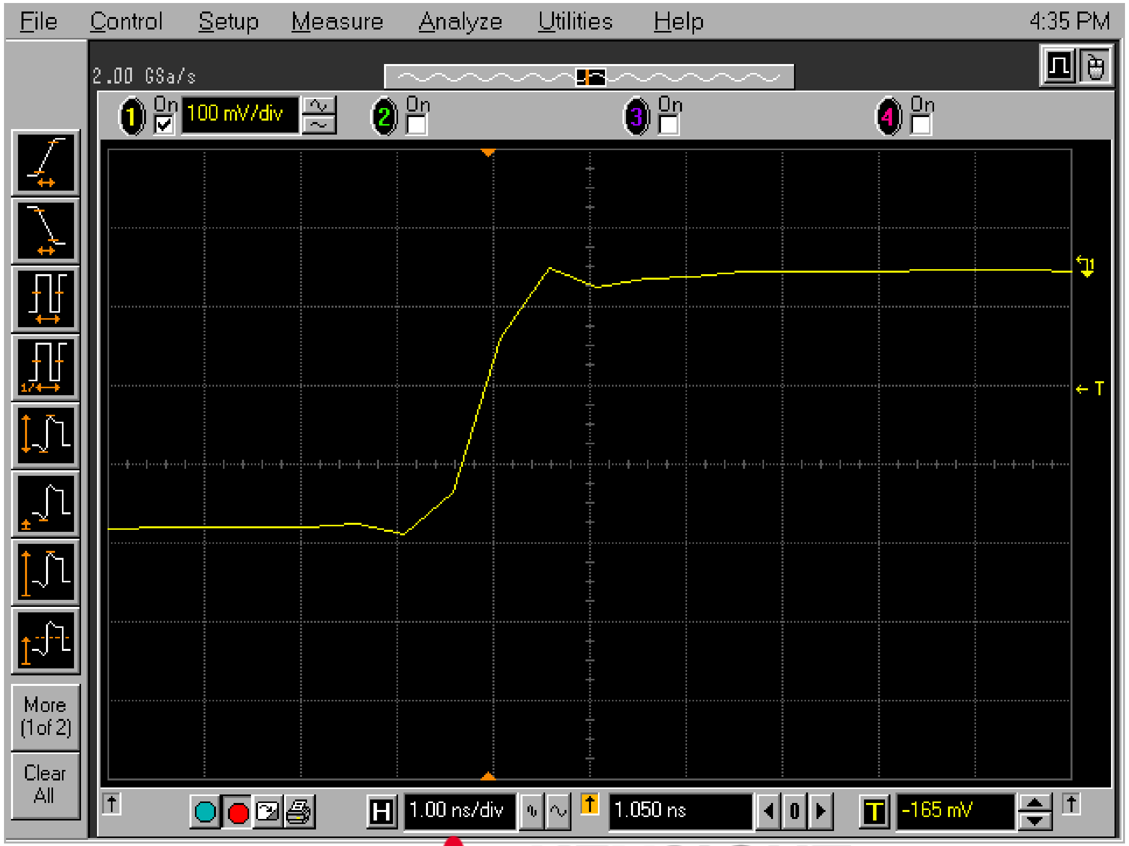
Oscilloscope example: Interpolation turned off

- **Only each dot is displayed as a series of independant points**
- **Hard to read!**



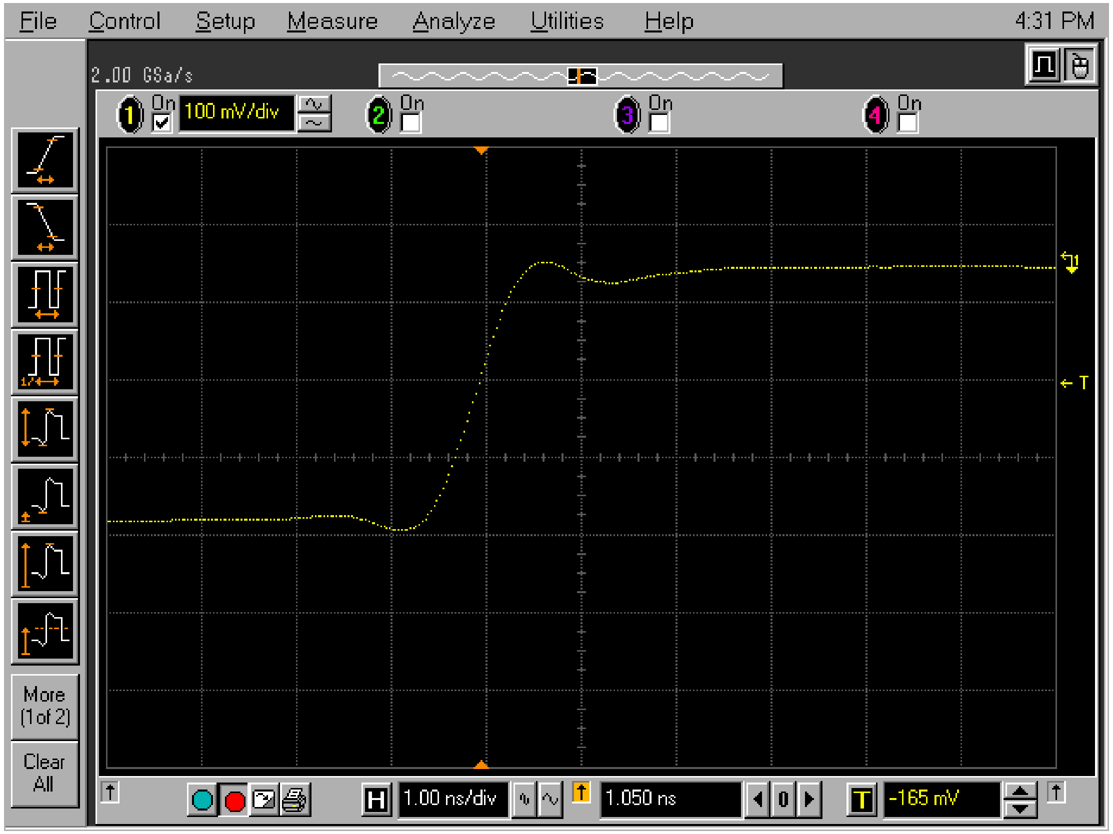
Oscilloscope example: Just connect the Dots

- No Interpolation The dots are connected with straight lines.
- Gives you a simplified view of the actual signal



Oscilloscope example: Interpolation “turned on”

- **With interpolation (reconstruction) turned on the signal is much easier to read.**



Summary of Interpolation

Interpolation is required for viewing or making measurements on high bandwidth real time signals.

Interpolation is a *mathematically linear* process which consists of adding zero-valued samples, then low-pass filtering.

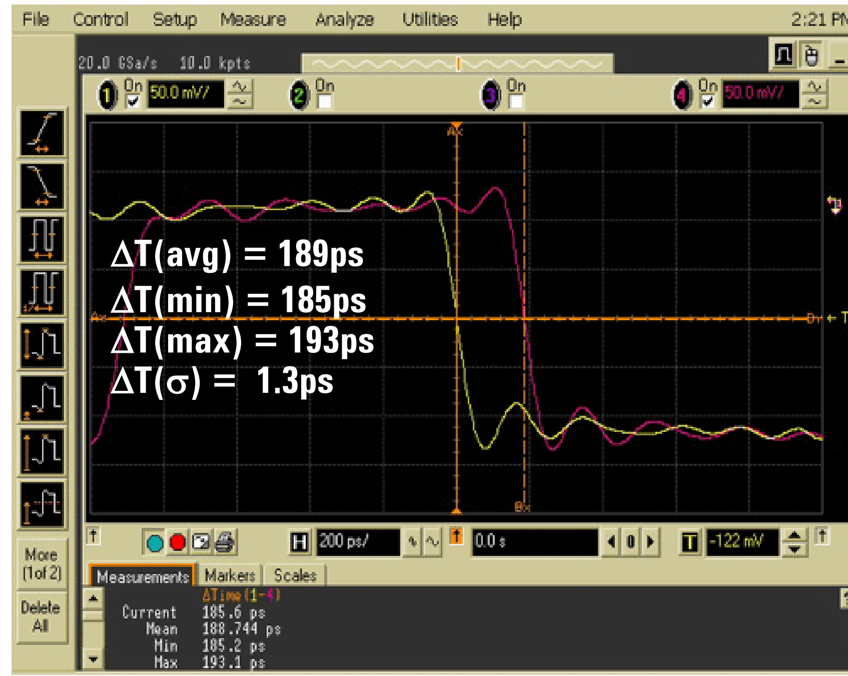
Interpolation just follows Shannon Rule

So interpolation *does not add information.*

Example Interpolation & answer Question 10 pSec accuracy

40 GSample/25picoSecond on DSO 81004A 10GHz BW

20 GSample/50 picosecond on 54855A 6GHz BW



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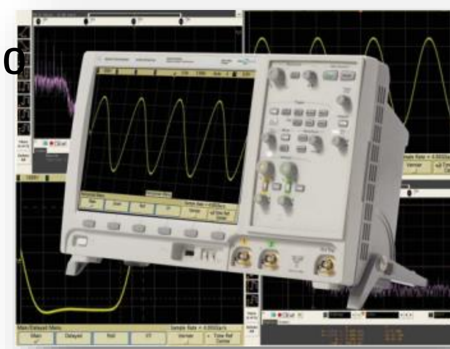
Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity: How to Make the Most Accurate Digital Measurements

Keysight Application Note 1587

This application note demonstrates a counterintuitive concept: scopes with higher sample rates *can exhibit poorer* signal fidelity because of poorly aligned interleaved analog-to digital converters (ADCs).

This application note also will show how to easily characterize and compare scope ADC sampling fidelity using both time-domain and frequency-domain analysis techniques.



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