Interpolation in Your DSO

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Introduction

> Main Entry: **in·ter·po·late**
> Pronunciation: in-'t&r-p&-"lAt
> Function: *verb*
> Inflected Form(s): **-lat·ed**; **-lat·ing**
> Etymology: Latin *interpolatus*, past participle of *interpolare* to refurbish, alter, interpolate, from *inter-* + *-polare* (from *polire* to polish)
> Date: 1612
> *transitive senses*
> **1 a :** to alter or corrupt (as a text) by inserting new or foreign matter **b :** to insert (words) into a text or into a conversation
> **2 :** to insert between other things or parts **:** INTERCALATE
> **3 :** to estimate values of (a function) between two known values
> *intransitive senses* **:** to make insertions (as of estimated values)

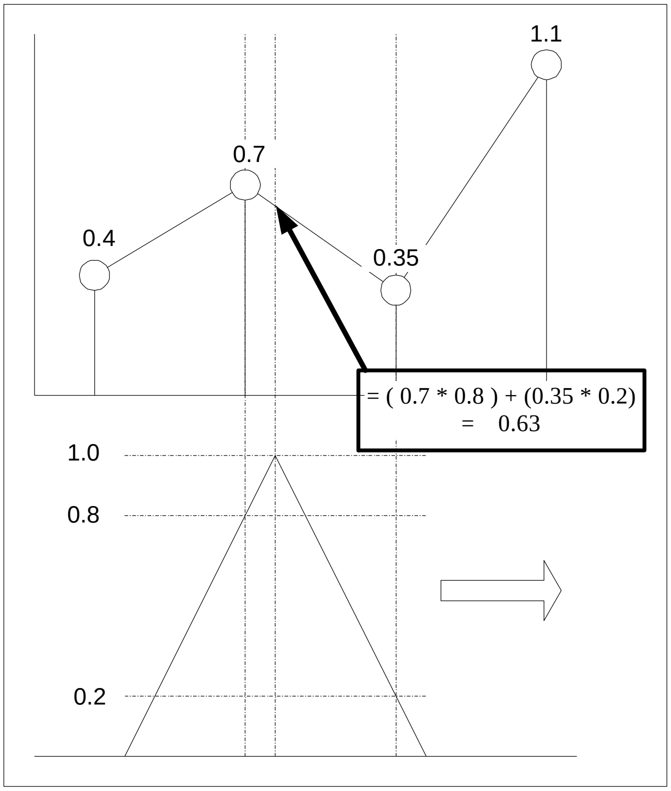
Interpolation is an important feature in today's digital oscilloscopes. The main purpose of a DSO is to analyze and view analog waveforms. To do this, the DSO samples a waveform at some finite sample rate, generating a vector of voltages with respect to time. Since this vector represents a set of points (not the actual smooth analog waveform), it is often desirable to modify the acquired waveform by generating samples that are predicted between the actual acquired points. The generation of samples that occur in between actual waveform samples is called *interpolation*. When done properly, this results in a waveform with a higher resultant sample rate that is a closer approximation of the analog waveform under analysis.

This paper will address the two most popular interpolation methods and explain basically how they work. It then addresses how to ensure good interpolation results and how to determine when interpolation is appropriate. The interpolation performance of three high-end scopes are compared with some simple experiments. Finally, differences in interpolation operation are contrasted.

Linear Interpolation

The simplest form of interpolation is linear interpolation. Linear interpolation is performed by assuming that a straight line joins each waveform sample. This is a very simple, but naïve method that provides limited results.

Definition from Merriam-Webster dictionary 2003

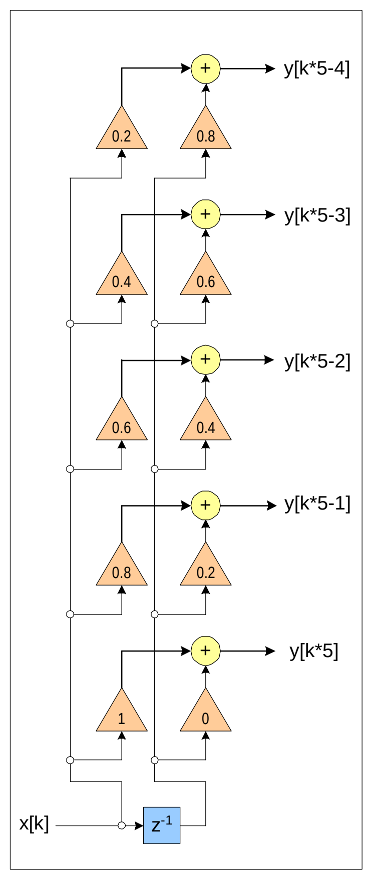


Linear interpolation can be viewed as convolution of an upsampled waveform with a triangular window.

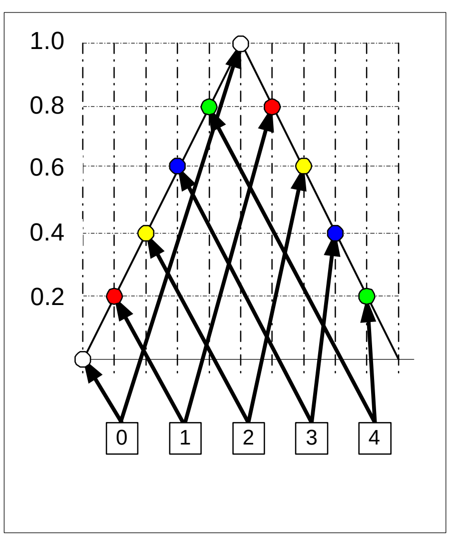
The triangular window is formed by generating a triangle that has a height of 1.0 and a width that is twice the sample period.

As the window slides to the right, interpolated points are found by calculating the sum of the values of the window multiplied by the value of actual samples at the times where the window and the sample points intersect. The interpolated sample is placed at the time of the window apex.

The width of the window defines its memory - the time over which actual samples affect the interpolated samples. Since the width of the window is twice the sample period, only samples that bracket the time of the interpolated sample affect the interpolated value.

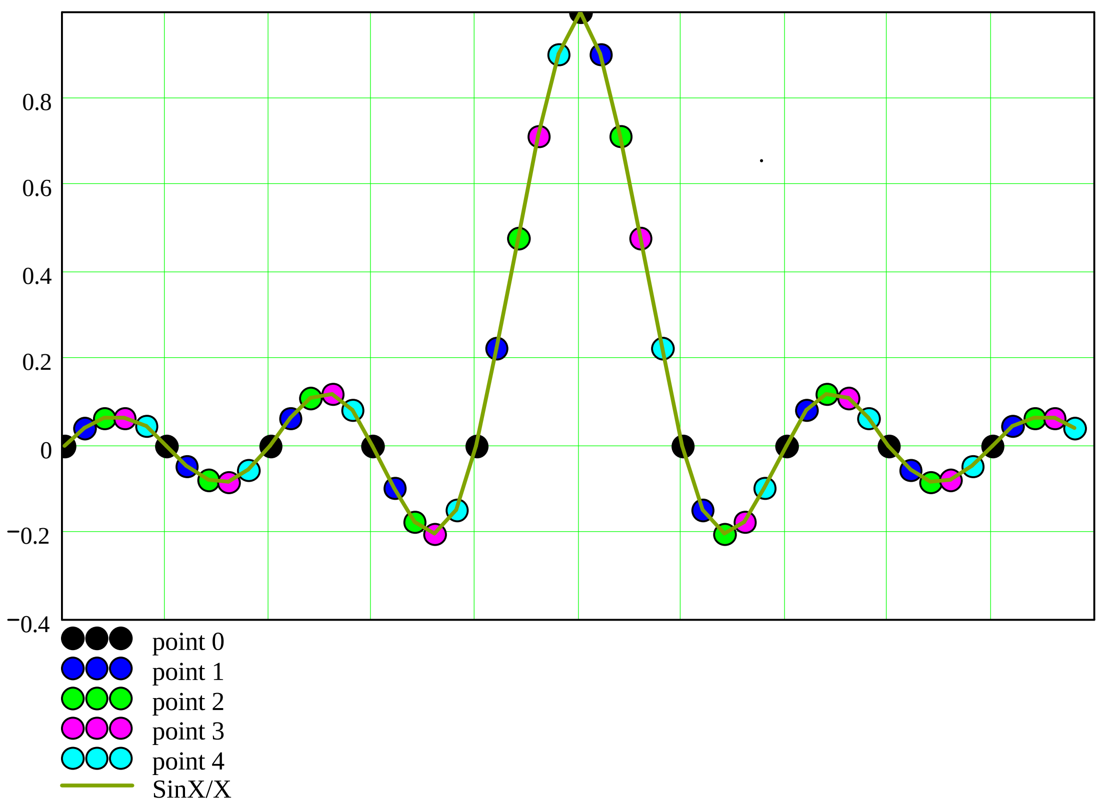


This convolution can also be realized with a digital filter in an upsampling arrangement. The arrangement shown is a 5 point upsampler. In this arrangement, every new sample produces 5 new ones. The filter output is a function only of the new input and the last one. The filter coefficients are generated by sampling the window.



By examining the diagrams, it's easy to see the pattern for developing the filter coefficients.

SinX/X Interpolation
A popular and more complicated form of interpolation is called SinX/X (also referred to as Sync or simply SinX interpolation). SinX interpolation gets its name from the well known shape of the window function used for the convolution. Unlike the narrow pointed triangle of linear interpolation, the window for SinX interpolation is a theoretically never ending damped sinewave.



This window shape derives from an important assumption that Nyquist's criterion has been obeyed in the sampling of the original waveform. In other words, it assumes that all of the frequency content in the analog waveform sampled lies below one-half the sample rate that the waveform was sampled at - a reasonable assumption. When this assumption is made, and the inverse Fourier transform of this assumed spectrum is calculated, the result is this well-known function.

In the general case, this assumption is the best assumption that can be made - but it is not always a correct assumption, as we shall see. As a result, SinX interpolation is truly the most valid interpolation method. This is understood by examining the meaning of Nyquist's criterion. Nyquist said that when all of the frequency content of a signal lies below one-half the sample rate, then the continuous analog signal can be completely determined from the sampled points. SinX interpolation is merely the mechanics for obtaining the continuous analog signal.

SinX interpolation suffers from some mathematical and practical technicalities that make it impossible for this method to be perfect. First of all, the Sync function goes forever

and must be truncated at a point where the truncation error dips acceptably low. This is due to the fact that a truly bandwidth limited signal must have infinite length implying that all sample points must be known for all time. As it turns out, the influence of points further and further from the point being interpolated diminishes rapidly and the truncation provides highly acceptable results. Another drawback is that in a sampled system, noise and artifacts due to DSO architecture like channel interleaving creep in, causing noise and distortion above the Nyquist limit. Again, the errors caused by this can be kept acceptably low.

When Is Interpolation Valid

In pure mathematical terms, neither interpolation method is valid. For example, linear interpolation implies that waveform points are joined by straight lines - a technical impossibility due to bandwidth limitations alone. SinX interpolation, as mentioned, is valid only when Nyquist's criteria is met - which is never fully the case - and when the waveform is infinitely long.

Suffice it to say, interpolation can be valid *to a large extent*. If you are uncomfortable with this concept, consider the fact that a digital oscilloscope is used to view, analyze, measure and otherwise make judgements on an analog signal. The validity of interpolation is philosophically related to the concept that statements can be made about an analog waveform utilizing only an imperfect digital representation. Since we know that depending on bandwidth, sample rate, signal fidelity etc. that we can make good assumptions about an analog waveform with the digital scope, we can also say that interpolation is a generally good method.

The two most important things to know when using interpolation are:

- How to set up the DSO for acquisition such that the assumptions needed for interpolation are as valid as possible.
- How valid the interpolation method is under the circumstances.

It cannot be overstated that these two things are actually the knowledge needed to use the DSO properly and effectively anyway and cannot be avoided.

Setting up the DSO to Enhance Validity of SinX Interpolation

All interpolation methods gain in validity as the ratio of the sample rate to the bandwidth grows. Interpolation will always improve as the sample rate is made higher. Some rules of thumb are in order. Linear interpolation works very well only when the ratio of the sample rate to the highest frequency component is at least 10 to 1. SinX interpolation works very well only when this ratio is greater than 2:1 - 3:1 is a good ratio with 4:1 usually working almost perfectly.

Using the LeCroy WaveMaster 8620A as an example, SinX interpolation is almost perfectly valid at the highest channel sample rate of 20 GS/s. This is because the bandwidth of the scope is 6 GHz, with such a sharp dropoff in response that the signals are greatly attenuated at and above 7 GHz. Since the Nyquist rate at 20 GS/s is 10 GHz,

Nyquist's criterion is met and SinX interpolation is highly effective. In effect, the bandwidth limitation of the scope ensures that interpolation is always valid at 20 GS/s.

At lower sample rates, you must do some thinking if you want to use SinX interpolation - you must determine the highest frequency in your input signal. Another useful rule of thumb is the bandwidth*risetime multiplier. On the LeCroy WaveMaster DSO, the bandwidth and risetime are related by:

$$bandwidth \cdot risetime = 0.45$$

This means that a signal with greater than 90 ps risetime will have a bandwidth requirement of less than 5 GHz. While the bandwidth point is not the highest frequency content, only the point where the content drops 3 dB below the DC content, it provides some practical ability to estimate the frequency content, and therefore the sample rate required where interpolation works well. For example, a 150 ps risetime signal has a bandwidth of 3 GHz, making SinX interpolation work very well at 10 GS/s.

Determining the Validity of SinX Interpolation

The best piece of good news is that the validity of SinX interpolation can be determined. It is possible to determine this not only qualitatively but also quantitatively. Not only that, it can be determined without the slightest bit of Fourier transforms and without pen, paper or computer. All you need is the scope and a repetitive signal.

The scope is easy, for the analysis will only be good on the particular scope you use. This is because so many idiosyncratic differences exist between scopes made by different vendors that the test provides scope specific results only.

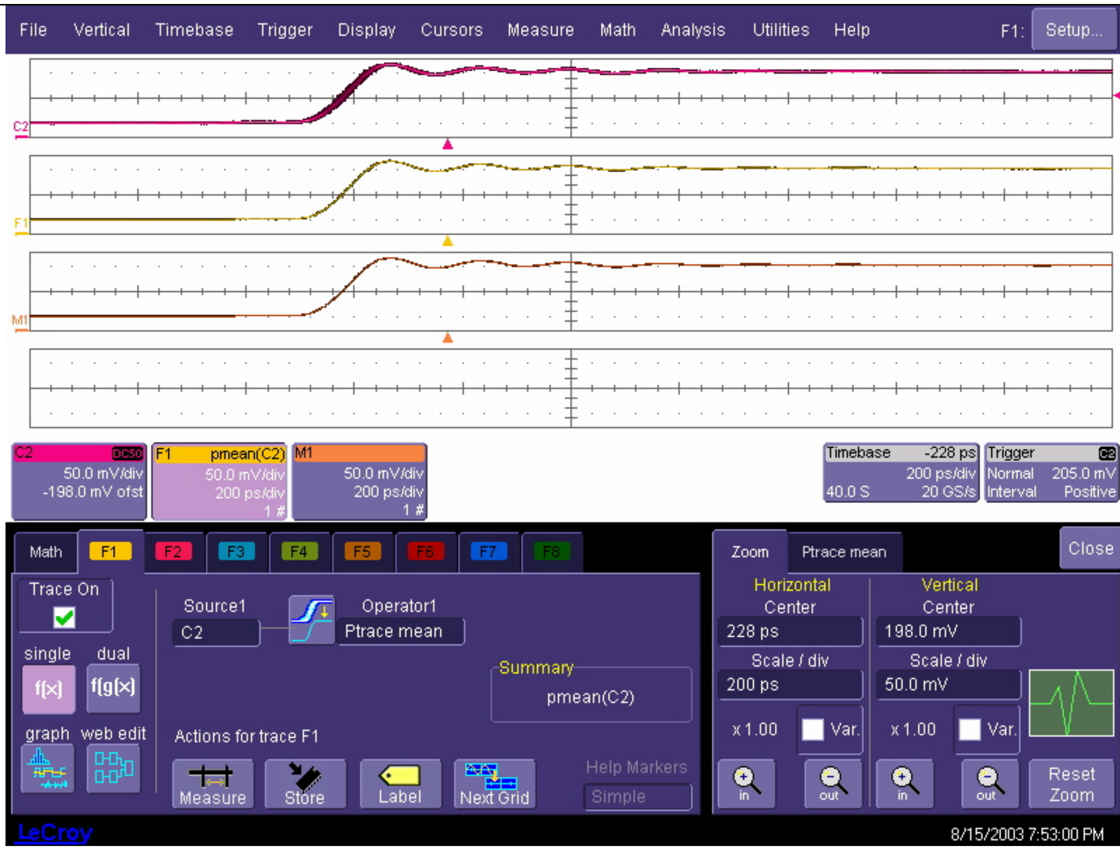
The repetitive waveform may not be so easy, for the real-time DSO is usually utilized to analyze time varying waveform characteristics, but you can usually find a way. For example, if all you have is a random data pattern, try to arrange the input signal so you can trigger on a particular pattern repetitively, or try to make the system generate a repeating constant pattern. The repetitive waveform is only needed to examine the interpolation validity.

Simply set up the scope to trigger repetitively on the waveform and build a persistence map of the waveform to ensure that the waveform is repetitive. Make sure that interpolation is turned off at this step. If the waveform is repetitive, it will build a tight persistence map. Then, once the repetitiveness is determined, you need a high effective sample rate rendition of the waveform as a reference. Most high-end DSOs provide an equivalent time mode (called RIS on LeCroy scopes) and this mode can be used to acquire the reference trace. LeCroy DSOs also provide a processing function called *Persistence Trace Mean* that extracts the mean waveform from a persistence map. Save the reference waveform for later compare. If you cannot figure out how to save a reference waveform, simply print out the persistence view for comparison.

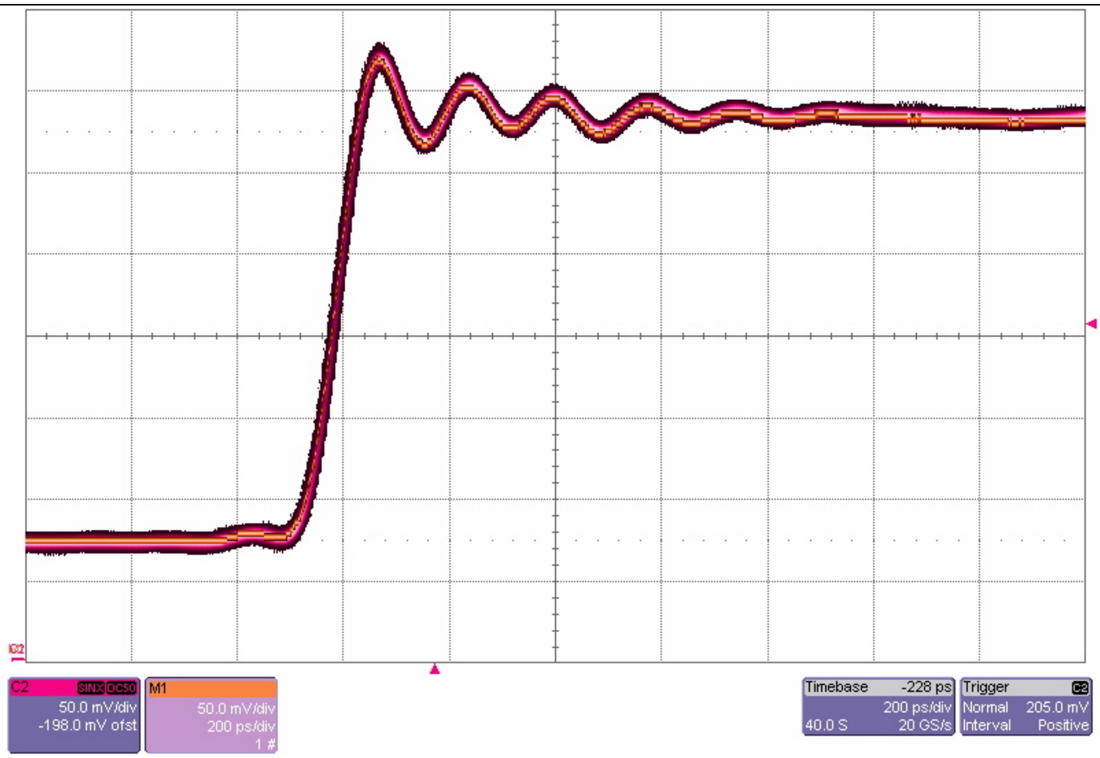
Then, turn on SinX interpolation and repetitively trigger on the waveform building up a new persistence map. The test criterion is simple - the degree to which the new

persistence map matches the reference waveform (or original persistence map) determines the degree of validity of the interpolation method.

Here is an example of this test applied on a WaveMaster 8620A:



This picture demonstrates how to test SinX interpolation validity with a WaveMaster scope. The repetitive signal is applied in this case to channel 2 with persistence turned on and SinX interpolation disabled. F1 is defined as the Persistence Trace Mean of channel 2. Over time, the persistence plot is filled in and the Ptrace mean function generates a clean picture of the input analog waveform. F1 is saved to memory M1 and becomes the reference trace.



M1 is left on the screen as the reference, F1 is turned off, and SinX interpolation is enabled on channel 2. The scope is triggered repeatedly, generating a new persistence plot of the repeatedly acquired waveform and its interpolated samples. Since the new persistence map is essentially an exact replica of the reference (barely visible and located in the center of the persistence plot), the test concludes that under these conditions, SinX interpolation is good to use. By the way, since the applied edge is extraordinarily fast, you can conclude that the WaveMaster 8620A will always provide proper SinX interpolation when operated at its maximum sample rate of 20 GS/s regardless of the input signal applied.

Why Does This Simple Test Work?

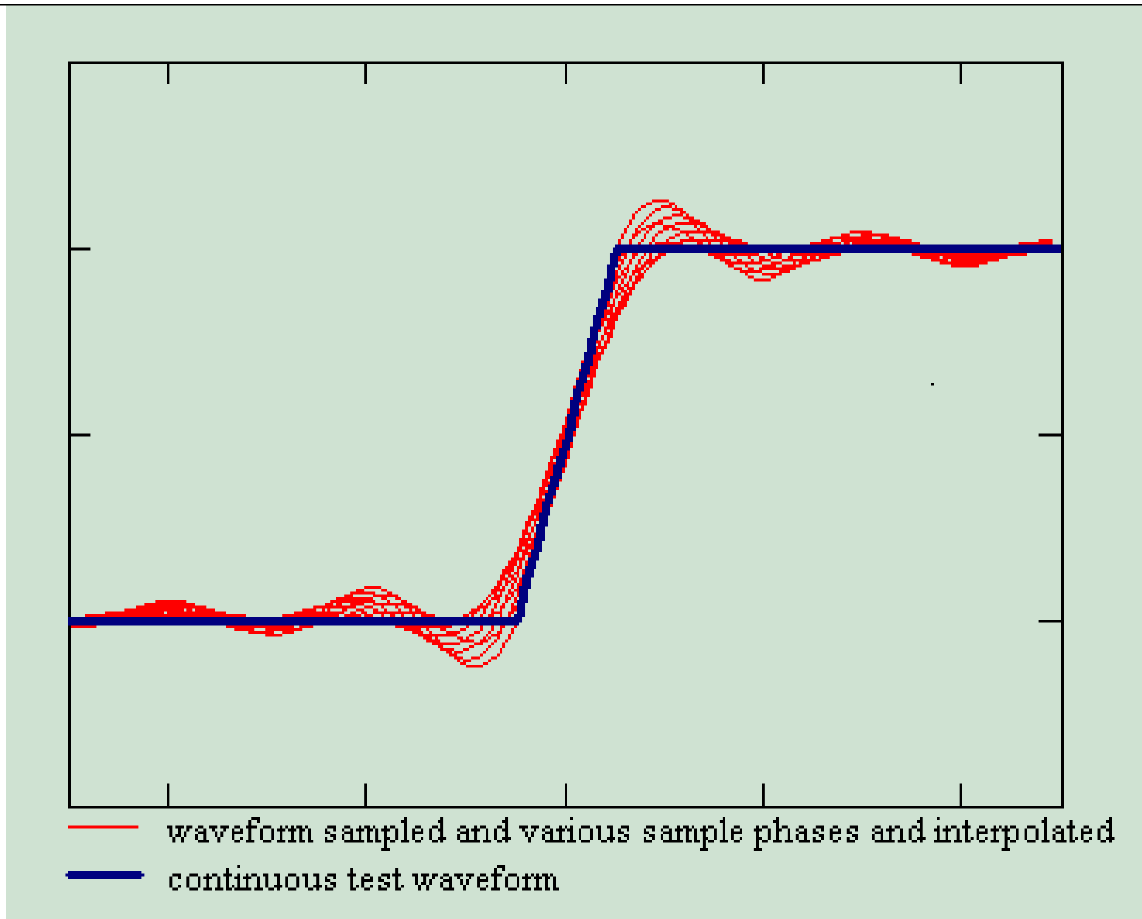
If you look carefully at the points acquired when the DSO repeatedly triggers on a repetitive signal, you will see that the *sampling phase* varies. The sampling phase is the offset of the actual sampled points from the trigger position.

The sampling phase for a given acquisition depends on the relationship between the time of the trigger and the internal scope sample clock. Since the input waveform and scope sample clock are not related, except under very special cases, the sampling phase is actually random. If you were to histogram the time from the trigger to the first sample, you would find that it forms a uniform distribution of between 0 and 1 sample period.

Because the sampling phase is random, repeatedly triggering on a waveform in persistence will cause the scope to sample on all possible locations in the waveform over time. As long as the points that fill in the persistence plot are actual sample points, then

the scope will generate a picture of the actual analog waveform over time. We use this as the reference.

The scope's ability to place interpolated points on the actual analog waveform when provided only with the samples taken on each acquisition determines the validity of the interpolation. In other words, on any given acquisition, the interpolated points should fall on the actual analog waveform, regardless of the sample phase.



Here is a picture of a test applied using a MathCAD spreadsheet. The continuous waveform is piece-wise linear with a rising edge transition time of 100 ps. The sample rate is 10 GS/s. The continuous waveform is sampled at 10 different sampling phases and expanded through SinX interpolation by a factor of 10. The overlaid traces show the degradation expected. Utilizing techniques like this, the effect of interpolation can be determined mathematically. Furthermore, measurement effects can be determined in this environment. For example, jitter degradation can be determined quantitatively by histogramming the 50% crossing time.

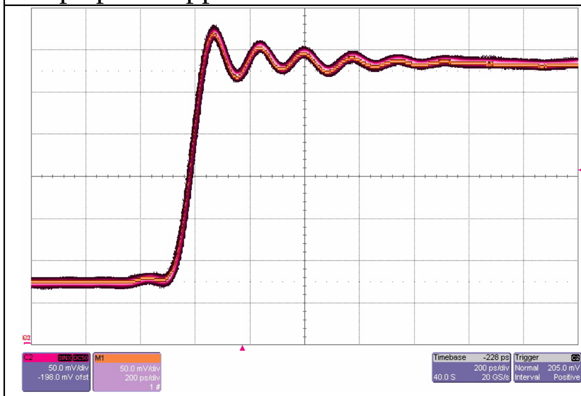
Some Simple Experiments

Simple experiments were made with three competitive DSOs. They are the LeCroy Wavemaster 8620A, Tektronix 6604, and Agilent 54855A. All three oscilloscopes have a 6 GHz bandwidth specification and a maximum sample rate of 20 GS/s. Six different

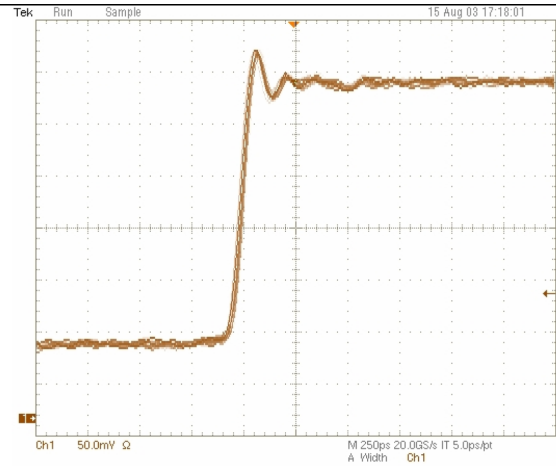
signal and sample rate combinations were utilized that illustrate how the SinX interpolation algorithms perform.

Experiment	**Expectation**
31 ps step applied at 20 GS/s	All scopes should demonstrate good SinX interpolation with the fastest risetime edge possible at their maximum sample rates
31 ps step applied at 10 GS/s	Degradation in SinX interpolation is expected as the frequency content of this step exceeds the 5 GHz Nyquist rate.
3 GHz sinusoid applied at 10 GS/s	All scopes should demonstrate reasonable SinX interpolation because 3 GHz is sufficiently below the 5 GHz Nyquist rate.
4 GHz sinusoid applied at 10 GS/s	Degradation in SinX interpolation is expected as 4 GHz is approaching the 5 GHz Nyquist rate.
6 GHz sinusoid applied at 10 GS/s	This is an absurd case that is simply illustrative of what happens when the Nyquist criterion is not met.
6 GHz sinusoid applied at 20 GS/s	All scopes should demonstrate good SinX interpolation with a sinewave at the bandwidth frequency at their maximum sample rate.

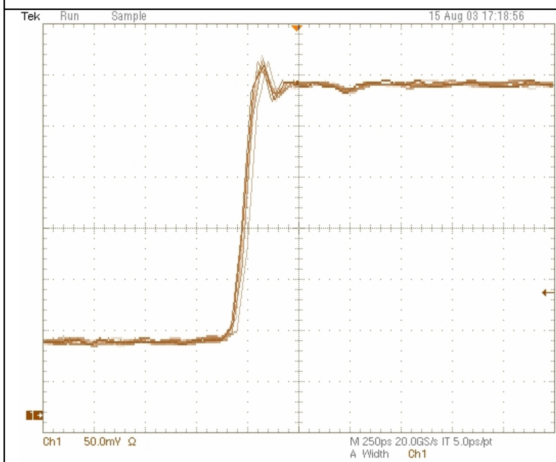
Experiment:
31 ps pulse applied at 20 GS/s



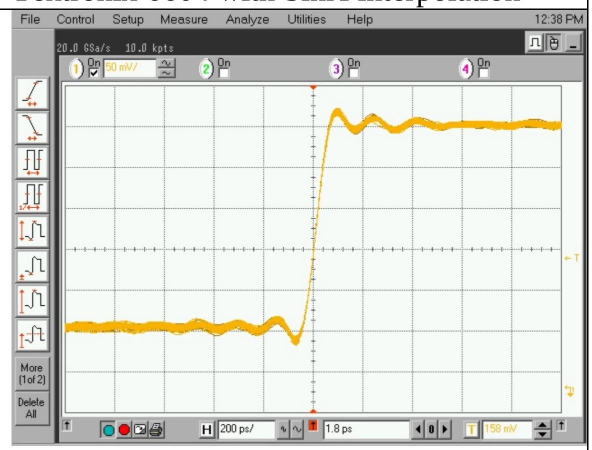
LeCroy WaveMaster 8620A with SinX interpolation



Tektronix 6604 with SinX interpolation



Tektronix 6604 with Linear interpolation



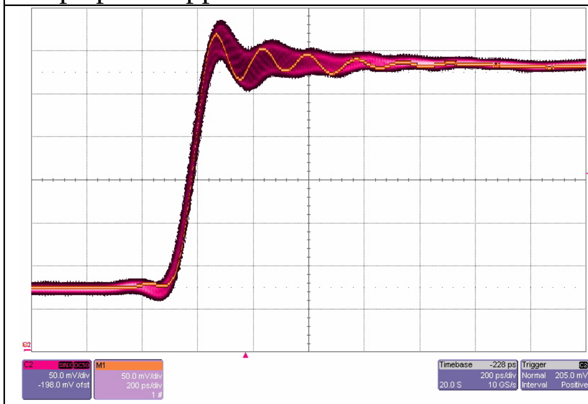
Agilent 54855A with SinX interpolation

Comments:
All scopes exhibit a tight persistence plot with SinX interpolation that matches the persistence plot generated without interpolation. Since a 31 ps edge supplies the maximum frequency content of any edge these scopes will ever see, this result indicates that for all of these scopes, SinX interpolation is perfectly valid at the maximum sample rate of 20 GS/s, regardless of the signal applied.

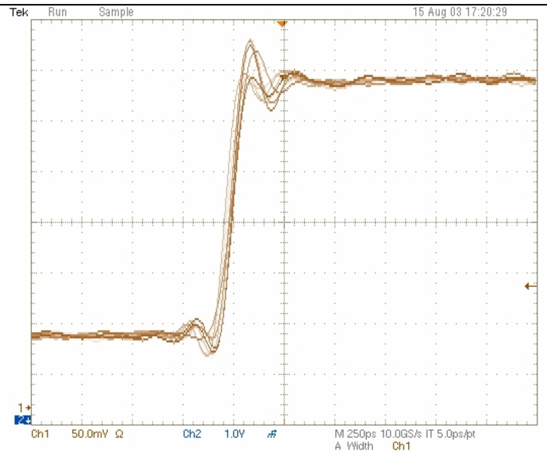
The Agilent scope has some signal fidelity issues with preshoot that is independent of whether Sinx interpolation is enabled or not.

Linear interpolation for the Tektronix scope is shown and exhibits some degradation. The Tektronix scope defaults to SinX interpolation and Linear interpolation should not be used for high-speed signals, if at all.

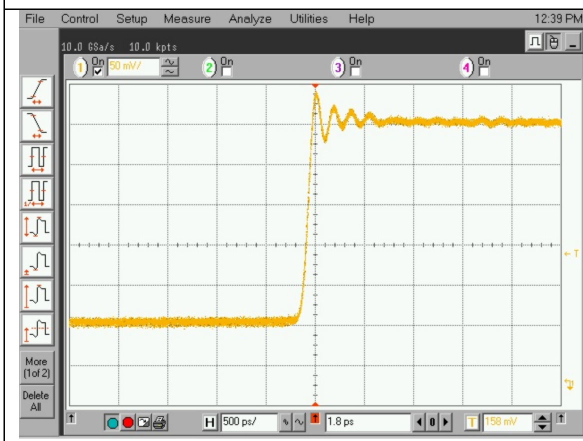
Experiment:
31 ps pulse applied at 10 GS/s



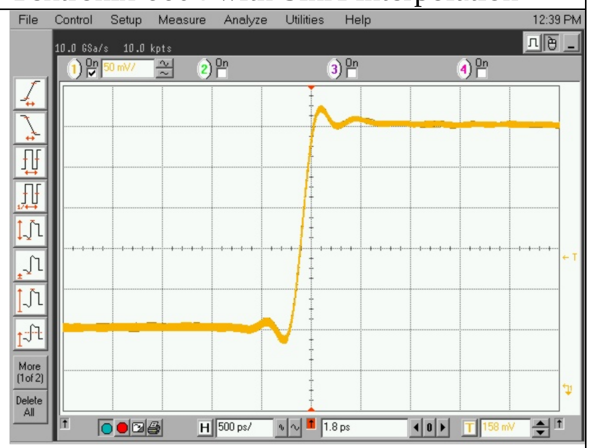
LeCroy WaveMaster 8620A with SinX interpolation



Tektronix 6604 with SinX interpolation



Agilent 54855A with interpolation turned off



Agilent 54855A with SinX interpolation

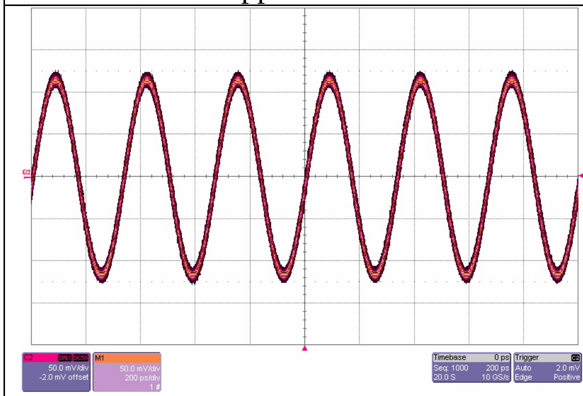
Comments:
The LeCroy and Tektronix scopes exhibit predicted degradation with SinX interpolation due to the fact that the frequency content of the edge exceeds the Nyquist rate of 5 GHz.

It is important to note that on the LeCroy scope, SinX interpolation is disabled by default, so a user would have to explicitly turn on SinX to get this result. On the Tektronix scope, this behavior is the default behavior. On the Tektronix scope, the only way to avoid this behavior would be to select "intensified samples" in the display setup.

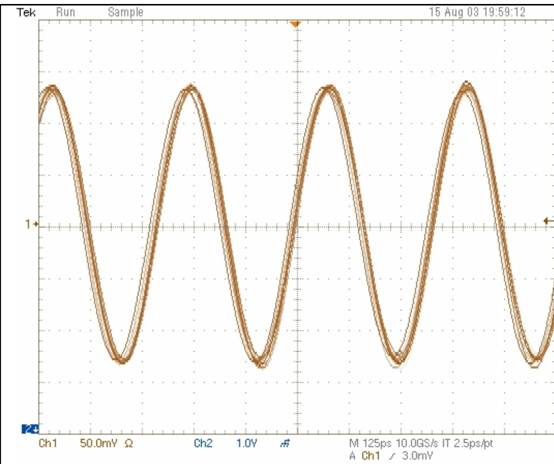
The Agilent scope shows a confusing result. First, the 10 GS response is completely different from the 20 GS response shown previously. Secondly, the SinX interpolated response shows another completely different response. Regarding interpolation, it is surprising that the Agilent scope can generate a tight persistence plot with SinX interpolation turned on despite the fact that the edge contains frequency content in excess of the 5 GHz Nyquist rate.

Experiment:

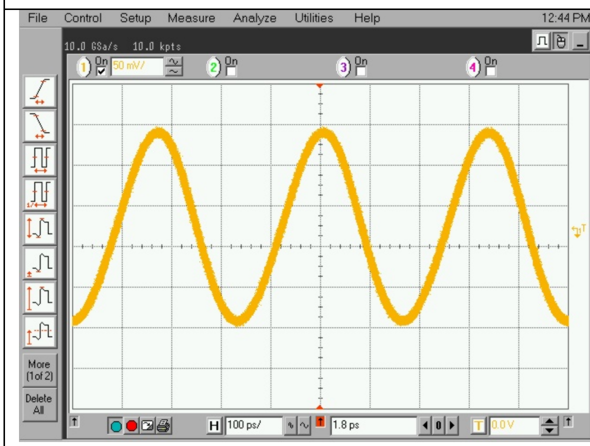
3 GHz sinusoid applied at 10 GS/s



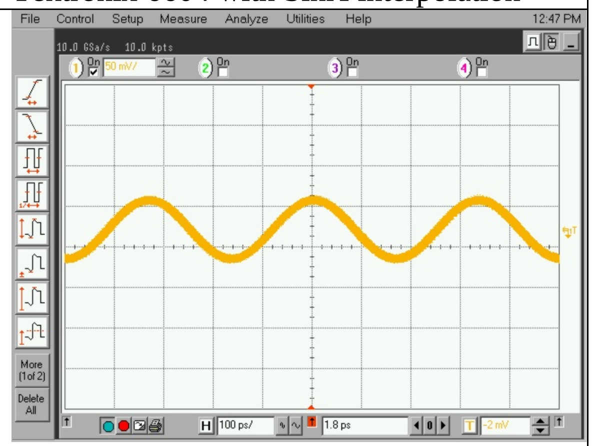
LeCroy WaveMaster 8620A with SinX interpolation



Tektronix 6604 with SinX interpolation



Agilent 54855A with interpolation turned off



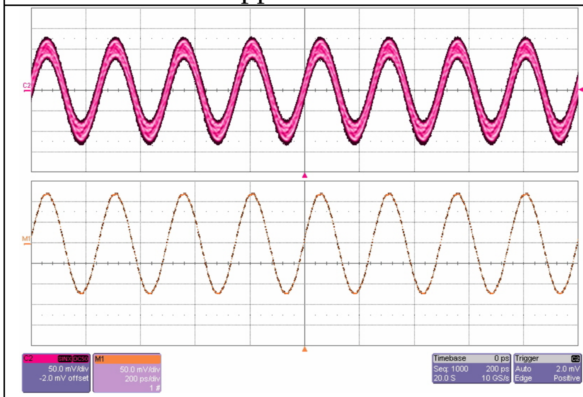
Agilent 54855A with SinX interpolation

Comments:

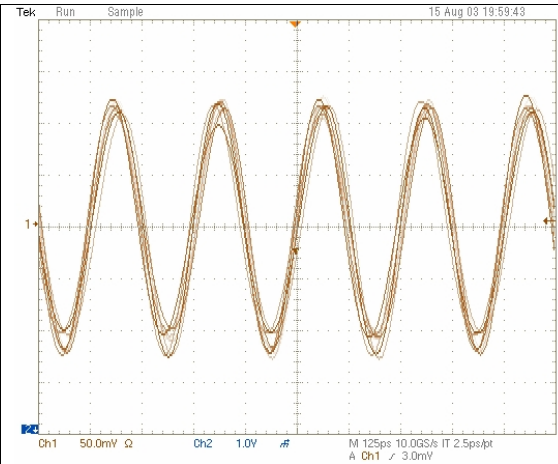
The LeCroy and Tektronix scopes exhibit no degradation as expected since the 3 GHz sinusoid is well below the Nyquist rate of 5 GHz. Despite the fact that the Tektronix scope shows some multiple traces in the persistence plot, this is thought to be due to poor trigger performance and not interpolation.

The Agilent scope demonstrates completely incorrect operation and demonstrates misapplication of interpolation. The 3 GHz waveform is attenuated greatly and should be regarded as an erroneous result. The workaround is to avoid SinX interpolation, or always operate this scope at 20 GS/s.

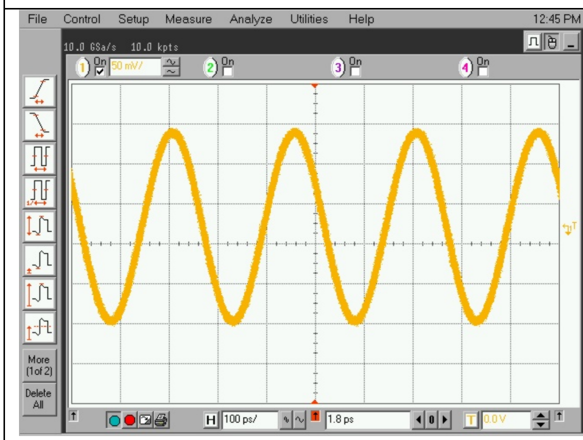
Experiment:
4 GHz sinusoid applied at 10 GS/s



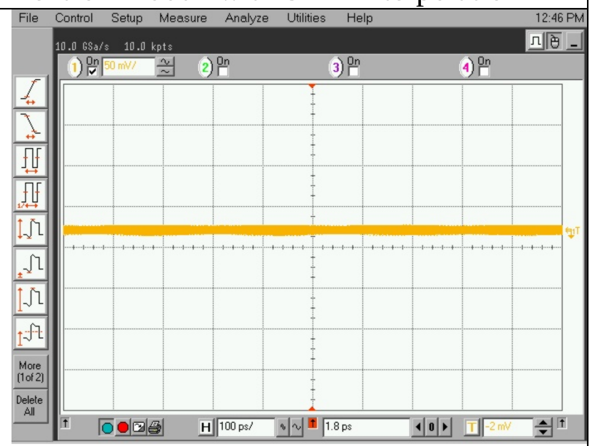
LeCroy WaveMaster 8620A with SinX interpolation



Tektronix 6604 with SinX interpolation



Agilent 54855A with interpolation turned off

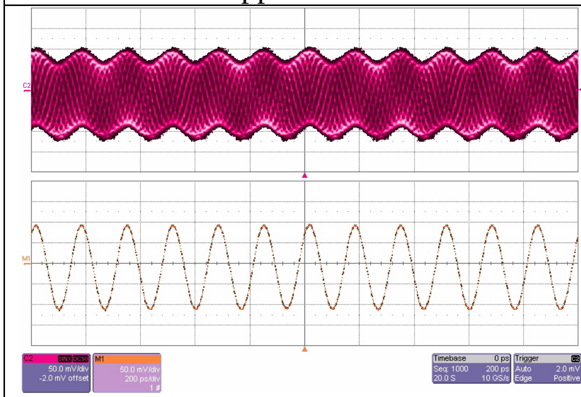


Agilent 54855A with SinX interpolation

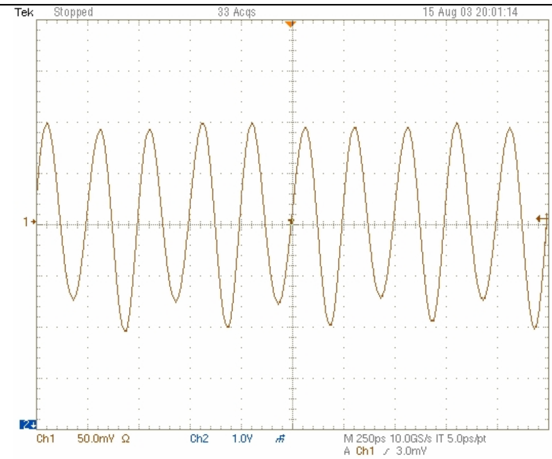
Comments:
The LeCroy and Tektronix scopes exhibit predictable degradation as expected since the 4 GHz sinusoid is approaching the Nyquist rate of 5 GHz. It was very difficult to generate a stable trigger on the Tektronix scope at this frequency.

The Agilent scope demonstrates complete failure of the SinX algorithm. The 4 GHz waveform is completely destroyed by interpolation. The workaround is to avoid SinX interpolation, or always operate this scope at 20 GS/s.

Experiment:
6 GHz sinusoid applied at 10 GS/s



LeCroy WaveMaster 8620A with SinX interpolation

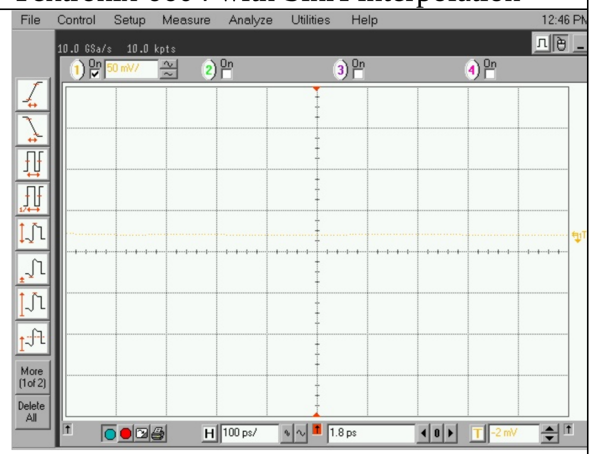


Tektronix 6604 with SinX interpolation

Comments:
This experiment is illogical in the sense that 6 GHz exceeds the Nyquist rate of 5 GHz, but is used to illustrate what happens when SinX interpolation breaks down.

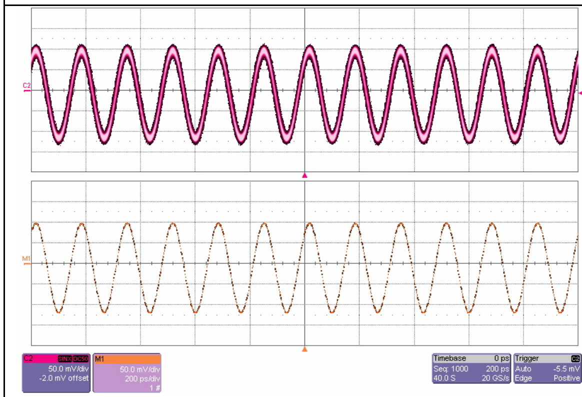
Only the LeCroy and Agilent scope could trigger on this waveform with some difficulty, so the Tektronix scope is auto triggered.

The LeCroy and Tektronix scopes exhibit predictable breakdown in the algorithm. The Agilent scope only produces a line. This is not the expected behavior, but this is an absurd case anyway that should be avoided.

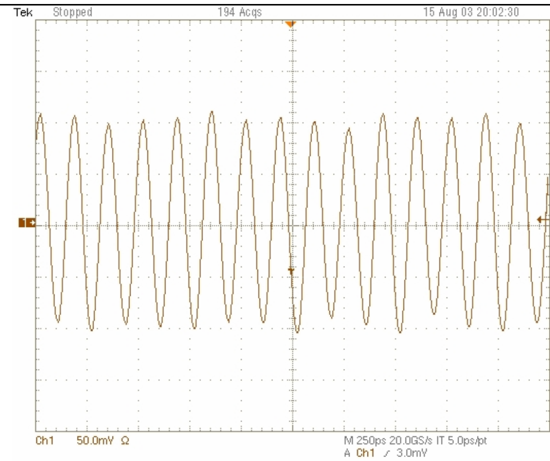


Agilent 54855A with SinX interpolation

Experiment:
6 GHz sinusoid at 20 GS/s



LeCroy WaveMaster 8620A with SinX interpolation

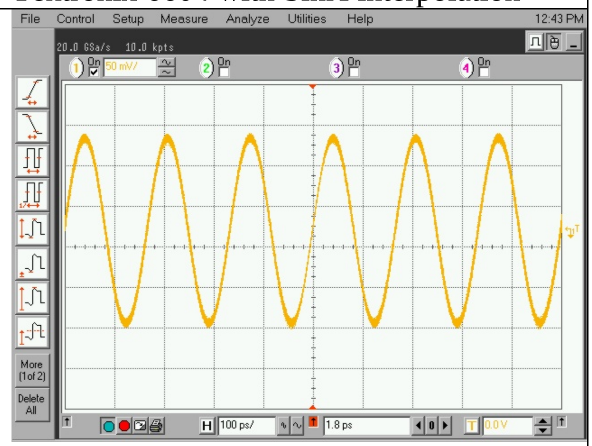


Tektronix 6604 with SinX interpolation

Comments:
Only the LeCroy and Agilent scope could trigger on this waveform with some difficulty, so the Tektronix scope is auto triggered.

The LeCroy and Agilent scopes exhibit perfect SinX interpolation performance as expected because of the high sample rate.

The Tektronix scope shows some amplitude modulation in the result, but this thought not to be a result of interpolation, but instead interleaving performance. It is difficult to determine the source of this degradation without generating a stable trigger.



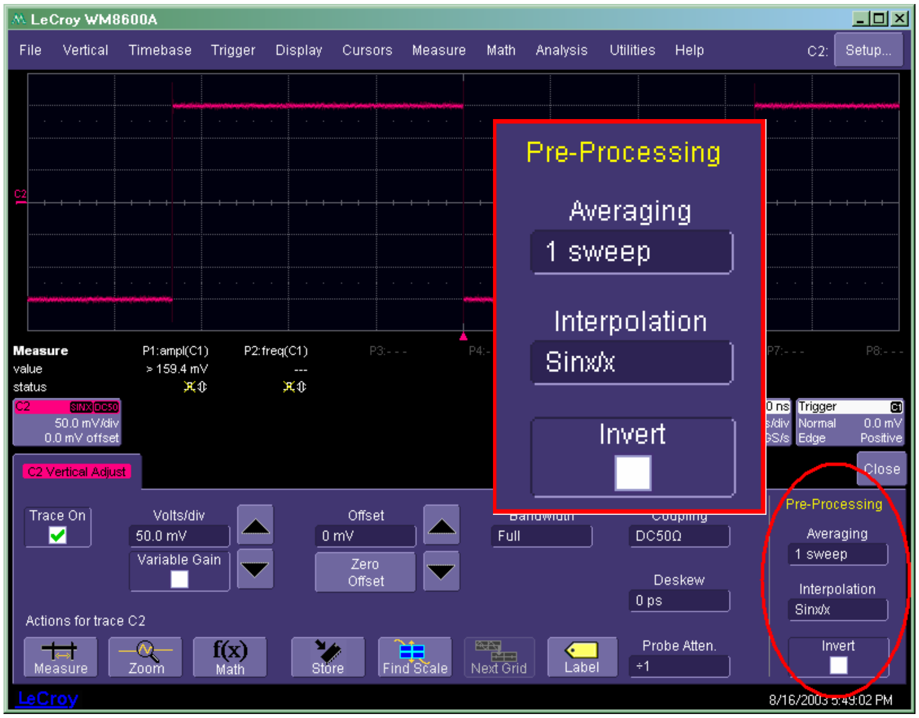
Agilent 54855A with SinX interpolation

Interpolation Implementation Differences In High-End DSOs

The experiments applied in the previous section were devised to demonstrate interpolation validity as a function of signal frequency content and scope sample rate but the side effect was an additional demonstration of important differences in interpolation algorithm implementations.

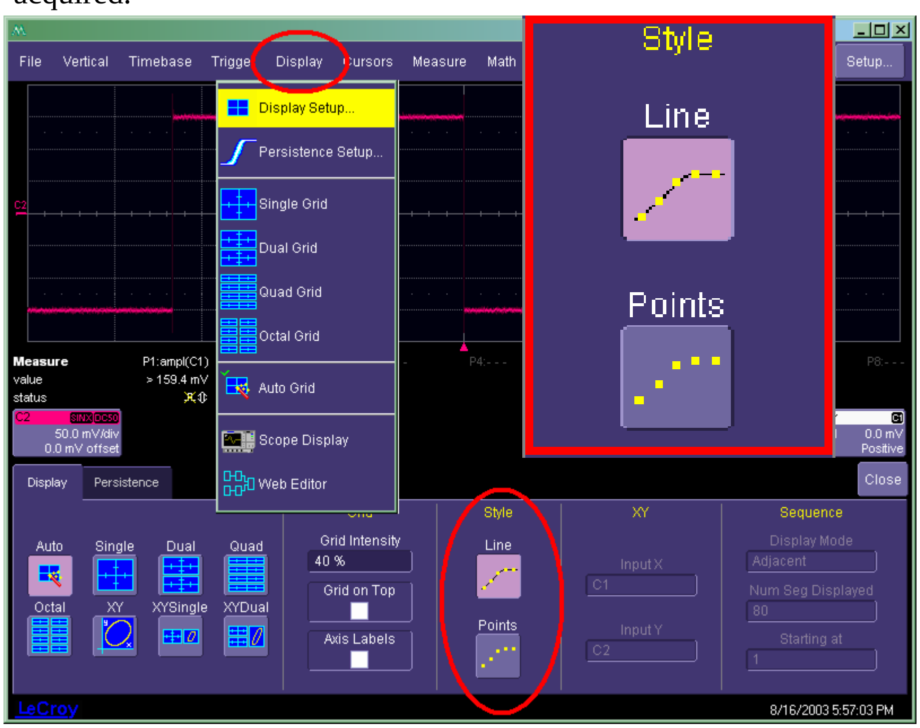
Other important differences among scopes are the rules governing interpolation.

All LeCroy DSOs offer SinX interpolation mode. On all of LeCroy's line of X-Stream DSOs (the WaveMaster and WavePro 7000 series), interpolation can be controlled through the channel setup menu enabling different interpolation selections for each



channel. On Previous LeCroy scope models, SinX interpolation is offered through a math trace.

The WaveMaster offers two interpolation choices - Linear or SinX in the channel setup menu. This description is actually a misnomer in that the selection of linear interpolation is really no interpolation. The selection of SinX interpolation causes the scope to generate nine extra points between every actual sample taken, thus multiplying the sample rate by a factor of ten. Linear (or no) interpolation is selected by default. LeCroy's policy is that, not knowing the input signal, interpolation should be off by default, and the scope should default to using only the waveform points acquired.



The display can be set to display either points or lines. When points is selected, only the waveform points, including any interpolated points are displayed. When line is selected, a line is drawn between every waveform point, including any interpolated points on the display only.

The rules for how interpolation is applied and how waveforms are displayed on the WaveMaster can be described concisely with the following table.

		Interpolation	
		Linear (off)	**SinX**
Display Style	**Dots**	Waveform contains only points acquired. Only waveform points shown on screen	Waveform contains nine extra interpolated values between every sample point Only the waveform points including the interpolated points are shown on screen
	Lines	Waveform contains only points acquired. Waveform is shown on screen with lines connecting points	Waveform contains nine extra interpolated values between every sample point The waveform points including the interpolated points are shown on screen with lines connecting points

LeCroy WaveMaster Interpolation Behavior

Agilent and Tektronix have significantly different interpolation functionality.

Tektronix scopes offer two waveform interpolation choices - Linear and SinX, but unlike the LeCroy implementation, linear interpolation actually interpolates the additional points. SinX interpolation is on by default. Whether interpolation is actually utilized in the generation of the waveform depends on the timebase setting and the number of points requested. Basically, Tektronix divides the acquisition duration by the sample period and if this number is less than the number of points requested, it interpolates to generate the number requested. Regardless of whether points are interpolated in the waveform, the Tektronix scope seems to utilize SinX interpolation for its internal measurements. Tektronix offers three display modes - dots, vectors (lines) and intensified samples. The only way to disable interpolation in waveform generation is to use the intensified samples display mode.

Agilent allows SinX interpolation that can be turned on or off and allows dots or lines in the display mode. Like Tektronix, Agilent bases its decision on whether to interpolate or not on the timebase setting and will interpolate up to 16 additional points at time/div settings below 500 ps/div to no additional points above 50 ns/div. If lines are selected for the display style, lines are drawn between points, even the interpolated points. This is similar to the LeCroy implementation, except that these lines appear in the persistence plot as well - LeCroy never places lines in the persistence plot.

		Interpolation	
		Linear	**SinX**
Display Style	**Dots**	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample rate) is less, then additional points are linearly interpolated. Only waveform points including the interpolated points are shown on screen	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample rate) is less, then additional points are SinX interpolated. Only the waveform points including the interpolated points are shown on screen
	Lines	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample period) is less, then additional points are linearly interpolated. The waveform points including the interpolated points are shown on screen with lines connecting points	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample period) is less, then additional points are SinX interpolated. The waveform points including the interpolated points are shown on screen with lines connecting points
	Intensified Samples	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample period) is less, then additional points are added, but the inserted points are bogus samples Only waveform points actually acquired are shown on screen	Waveform contains number of points requested (minimum of 500). If number acquired (TDIV times 10 divided by sample period) is less, then additional points are added, but the inserted points are bogus samples Only waveform points actually acquired are shown on screen

Tektronix 6604 Interpolation Behavior

		Interpolation	
		off	**SinX**
Display Style	**Dots**	Waveform contains only points acquired. Only waveform points shown on screen and in persistence plots.	Waveform contains between 16 additional points at time/div below 500 ps/div to no additional points at time/div above 50 ns/div Only the waveform points including the interpolated points are shown on screen and in persistence plots
	Lines	Waveform contains only points acquired. Waveform is shown on screen with lines connecting points Vectors are shown in persistence plots	Waveform contains between 16 additional points at time/div below 500 ps/div to no additional points at time/div above 50 ns/div The waveform points including the interpolated points are shown on screen with lines connecting points Vectors between waveform points including interpolated points are shown in persistence plots.

Agilent 54855A Interpolation Behavior

The scope behaviors can be contrasted as follows:

	LeCroy WaveMaster	**Tektronix 6604**	**Agilent 54855A**
If interpolation is turned off…	No additional points are interpolated	It cannot be turned off	No additional points are interpolated
If interpolation is turned on, the interpolation method is…	SinX	Linear (which has very limited usefulness due to the 10:1 oversampling requirement) or SinX. (user configurable)	SinX
If interpolation is turned on, the number of extra points interpolated are…	9 extra sample points between every sample.	If the number of points acquired (TDIV times 10 divided by sample period) is less than the number of points requested, (minimum of 500), then additional points are interpolated otherwise no interpolation is performed	Ranges from 16 extra sample points between every sample at time/div less than 500 ps/div to no interpolation above 50 ns/div.
If interpolation is turned on, the new effective sample rate is….	10 times the sample rate at which the waveform was acquired.	Approximately TDIV times 10 divided by points requested.	Ranges from 16 times the sample rate at time/div less than 500 ps/div to no change in sample rate above 50 ns/div.
Interpolation is configurable…	For each channel independently	Globally for all channels	Globally for all channels
If interpolation is turned off measurements are made with…	Generally linear interpolation between acquired sample points[1]	Measurements are always made utilizing SinX interpolation	Generally linear interpolation between acquired sample points
If interpolation is turned on measurements are made with…	Generally linear interpolation between acquired and interpolated sample points		Generally linear interpolation between acquired and interpolated sample points

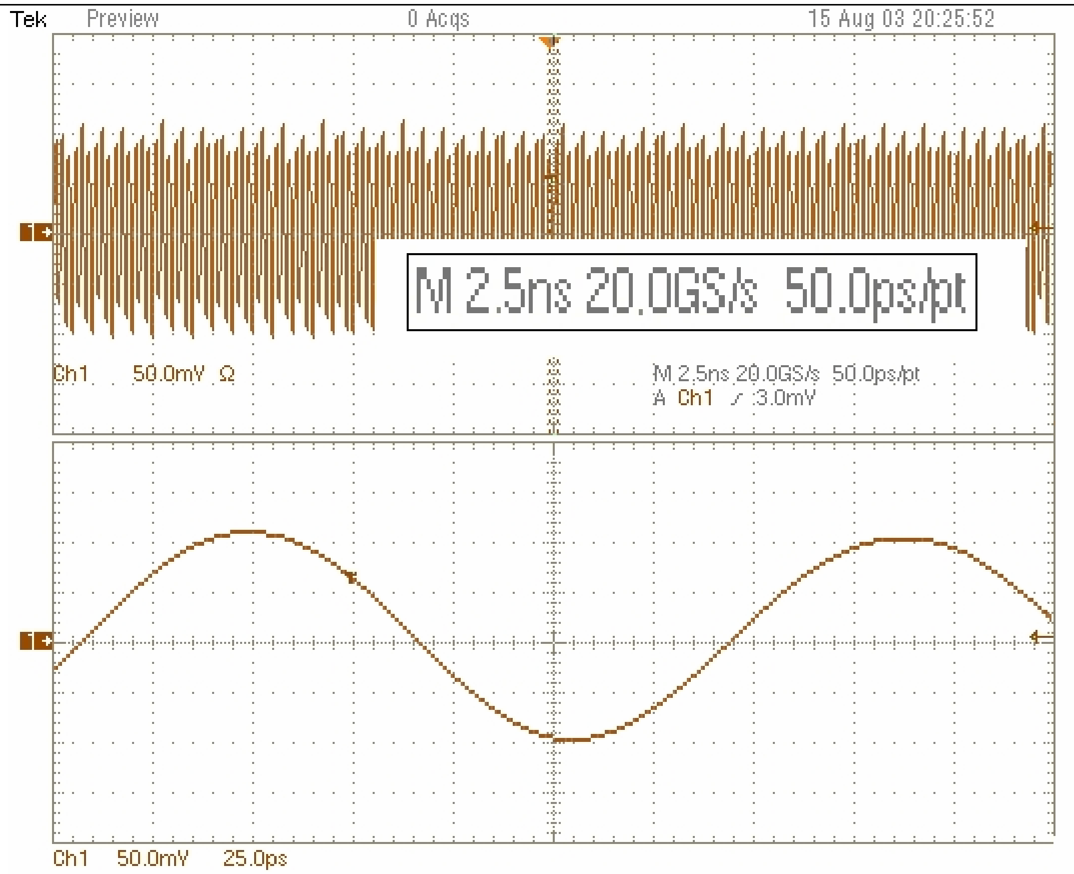
At this point, it would be reasonable for the reader to wonder at all of the variations in operation. I will conjecture that some of the reason may be hardware limitations between scopes. Additionally, because interpolation is processing intensive, there is some attempt to diminish the update rate reduction affects of interpolation for large waveforms, thus complicating the rules in competitive scopes.

The reason that the LeCroy WaveMaster can achieve the simplicity of operation in this area is because the X-Stream™ architecture is designed to process large amounts of data

[1] some special measurements employ interpolation other than linear

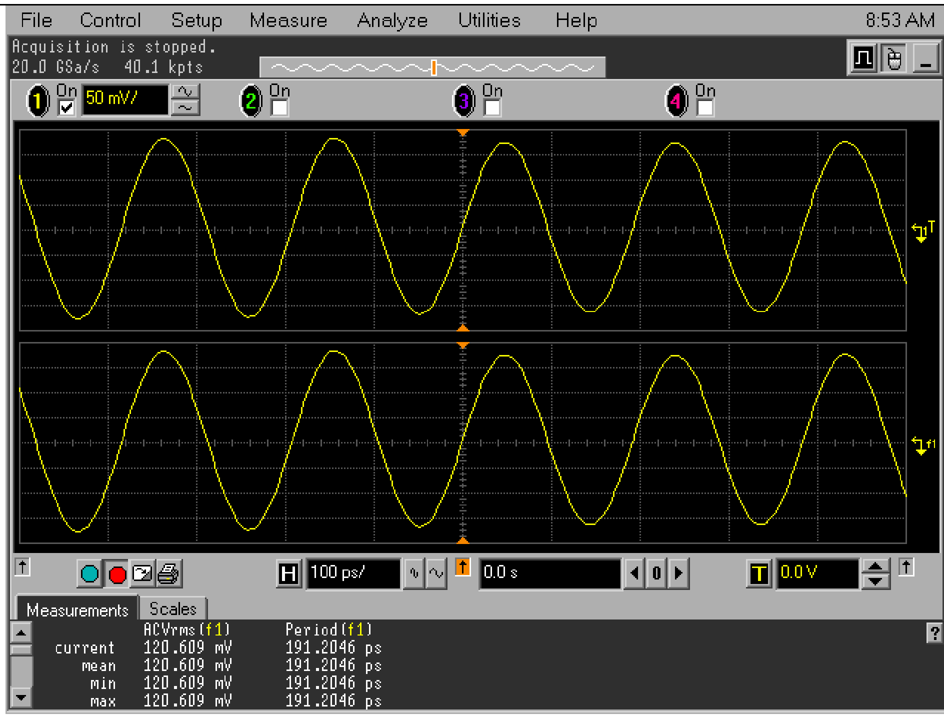
with incredible efficiency. The WaveMaster makes heavy use of its Pentium 4 processor operating at 2.53 GHz, the most powerful processing engine in any scope.

But another reason for the differences in functionality stems from the basic philosophy between LeCroy and the other scope vendors. Agilent and Tektronix alter the interpolation behavior depending most notably on the time/division setting. Effectively both competitive scopes resist interpolation when the acquisition time duration becomes large. In other words, the sample rate improvement with interpolation diminishes as the acquisition time duration is made larger. Since larger time/division settings tend to diminish a user's view of waveform features, unless a zoom is employed, the fundamental message in this behavior is: *There is no need for higher resolution and precision in the waveform acquisition unless the fine features are being viewed.* LeCroy takes serious issue with this type of instrument behavior. We believe that the measurement results in your waveform analysis should not depend on what you are currently viewing on the screen.

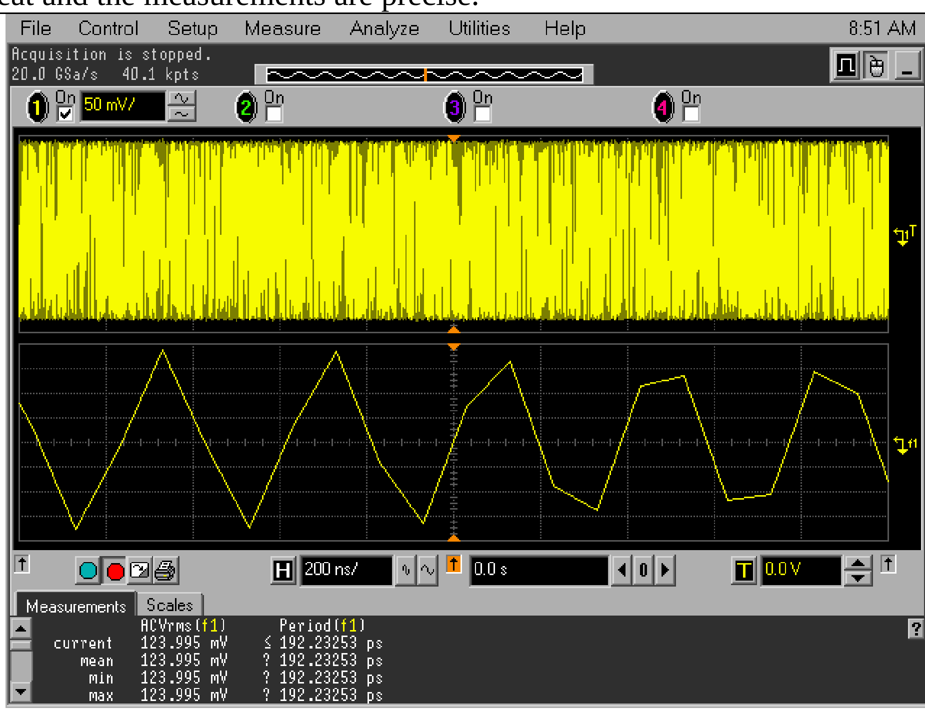


Here, the time/division is set to 2.5 ns/div and number of points is set to 500. The Tektronix scope determines that interpolation is not necessary. But if you zoom in on the waveform, it interpolates the zoom trace - by quite a lot.

The Tektronix scope apparently utilizes SinX interpolation for internal measurements no matter what scope settings you use.



The Agilent scope at 20 GS/s, 100 ps/div, SinX interpolation turned on. The sine wave looks great and the measurements are precise.



The timebase is set to 200 ns/div in an effort to acquire lots of samples. The view of the sine wave on the screen is obscured due to the longer acquisition time. At this setting, the measurements show ? indicating that the scope cannot make proper measurements. Only setting up a zoom math trace shows the source of the problem - the scope has stopped interpolating. The scope has determined that the interpolation is not necessary for longer time acquisitions.

Summary

Interpolation of waveform points is an important and useful algorithm in the use of the DSO. Two types of interpolation algorithms are employed, SinX interpolation and the less useful linear interpolation.

Linear interpolation performs well when the sample rate is ten times the highest frequency signal content. SinX interpolation works well the sample rate is at least three times the highest frequency content.

A simple method exists to determine the validity of the interpolation strategy employed.

Scopes vary drastically in interpolation performance among scope vendors.

Scopes vary drastically in the rules governing when and how much interpolation is performed under various scope operating conditions.

The LeCroy WaveMaster scopes offer the simplest and most consistent interpolation performance with SinX interpolation providing an effective 10X improvement in sample rate.

The LeCroy WaveMaster DSO embodies the philosophy that SinX interpolation should be specified explicitly by the scope user - the default state is off - and that when SinX interpolation is specified, the scope consistently interpolates nine extra samples between actual sample points, independent of other scope settings such as time/division.