

Jitter Analysis Techniques Using an Agilent Infiniium Oscilloscope

Product Note

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Introduction

With higher-speed clocking and data transmission schemes in the computer and communications industries, timing margins are becoming increasingly tight. Sophisticated techniques are required to ensure that timing margins are being met and to find the source of problems if they are not.

This product note discusses various techniques for measuring jitter and points out their advantages and disadvantages. It describes how to set up an Agilent Infiniium oscilloscope to make effective jitter measurements and the accuracy of these measurements. Some of the measurement techniques are only available on Agilent 54845A/B and 54846A/B oscilloscopes with version A.04.00 or later software. These measurement techniques are indicated as such in the text.

Jitter Fundamentals

Jitter is defined as the deviation of a transition from its ideal time. Jitter can be measured relative to an ideal time or to another transition. Several factors can affect jitter. Since jitter sources are independent of each other,

a system will rarely encounter a worst-case jitter scenario. Only when each independent jitter source is at its worst and is aligned with the other sources will this occur. As a result, jitter is statistical in nature. Predicting the worst-case jitter in a system can take time.

Jitter can be broken down into two categories:

- **Random jitter** is uncorrelated jitter caused by thermal or other physical, random processes. The shape of the jitter distribution is Gaussian. For example, a well-behaved phase lock loop (PLL) wanders randomly around its nominal clock frequency.
- **Deterministic or systematic jitter** can be caused by inter-symbol interference, crosstalk, sub-harmonic distortion and other spurious events such as power-supply switching. It is important to understand the nature of the jitter to help diagnose its cause and, if possible, correct it. Deterministic jitter is more easily reduced or eliminated once the source has been identified.



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Jitter Measurement Techniques

This product note will discuss four methods that can be used to characterize jitter in a system:

- Infinite persistence
- Histograms
- Measurement statistics
- Measurement functions

Infinite Persistence

Agilent's Infiniium oscilloscopes present several different views of jitter. One way to measure jitter is to trigger on one waveform edge and look at another edge while infinite persistence is turned on.

To use this technique, set up the scope to trigger on a rising or falling edge and set the horizontal scale to examine the next rising or falling edge. In the Display dialog box, set persistence to infinite.

This technique measures peak-to-peak jitter and does not provide information about jitter distribution. Infinite persistence is easy to set up and will acquire data quickly, giving you the best chance to see worst-case jitter. However, since the tails of the jitter distribution theoretically go on forever, it will take a long time to measure the worst-case, peak-to-peak jitter.

It is important to understand the error sources of this measurement.

This technique is subject to oscilloscope trigger jitter—the largest contributor to timing error in an oscilloscope. Trigger jitter results from the failure to place the waveform correctly relative to when a trigger event occurs. Since the infinite persistence technique overlaps multiple waveform acquisitions onto the scope display, and each acquisition is subject to trigger jitter, the accuracy of this technique can be limited. If your jitter margins are being met using this technique, then more advanced measurement techniques are not necessary. This product note will discuss Infiniium's timebase and trigger specifications in detail in a later section.

Histograms

This technique not only shows worst-case jitter, but also gives a perspective on jitter distribution. Histograms do not acquire information as quickly as infinite persistence since each acquisition must be counted in the histogram measurement.

To set up a histogram, trigger on an edge and set the horizontal scale and position so that you can view the next rising or falling edge. In the Histogram dialog box, turn on a horizontal histogram and set both Y window markers to the same voltage. For example, if a clock threshold is at 800 mV, set both Y markers to this voltage. Set the X markers to the left and right of the edge (figure 1).

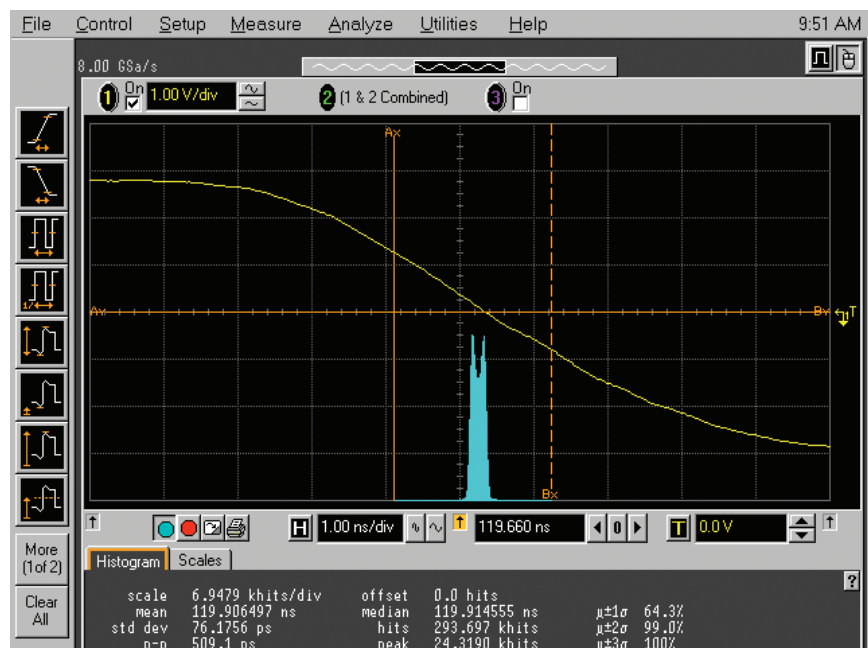


Figure 1. Histogram of edge showing bi-modal distribution

Jitter Measurement Techniques (continued)

It is often possible to determine if the jitter is random or deterministic by the shape of the histogram. Random jitter will have a Gaussian distribution. Infiniium displays the percentage of points within mean ± 1 , 2, and 3 standard deviations to help in determining how Gaussian the distribution is. For a Gaussian distribution these values should be 68%, 95%, and 99.7%, respectively. Non-Gaussian distributions usually indicate that the jitter has deterministic components.

This technique has the same limitation on accuracy as the infinite persistence technique. Multiple acquisitions contribute to the histogram and they all contain the oscilloscope trigger jitter mentioned above.

Measurement Statistics

The next method involves computing statistics on waveform measurement results. For example, the scope can measure the period of a waveform on successive acquisitions. Simply drag the period measurement icon to the waveform that is to be measured. The statistics will indicate the mean, standard deviation, and min and max of the period measurements. You can let the scope run for a while to determine the amount of clock jitter present.

This measurement is not subject to trigger jitter because it is a delta-time or relative measurement. Even if the waveform is not placed correctly relative to the trigger, the edges are measured accurately relative to each other.

This measurement is subject to the timebase stability of the instrument, which is typically very good. This is a valid measurement technique but is slow to gather statistical information. Since the scope acquires a waveform, makes a measurement, and then acquires a waveform at a later time, most clock periods are not measured.

With this technique, it is impossible to see how the period jitter varies over short periods of time. For example, if you have spread-spectrum clocking, this measurement will lump the slowest and fastest periods together.

The Agilent 54845A/B and 54846A/B Infiniium oscilloscopes can compute statistics on every instance of a measurement in a

single acquisition. To enable this capability, select the Jitter tab, then check “Measure all edges” in the Measurement Definitions dialog box (figure 2).

For example, instead of only measuring the first period on every acquisition or trigger event, **every** period can be measured and statistics gathered. This greatly increases the speed at which statistics are gathered and reduces the overall time to make jitter measurements. Statistics are accumulated across all measurements in the acquisition and across acquisitions.

Pressing “Clear Display” will reset the measurement statistics. This feature is useful if you are probing the clock at different locations and want to reset the measurements.

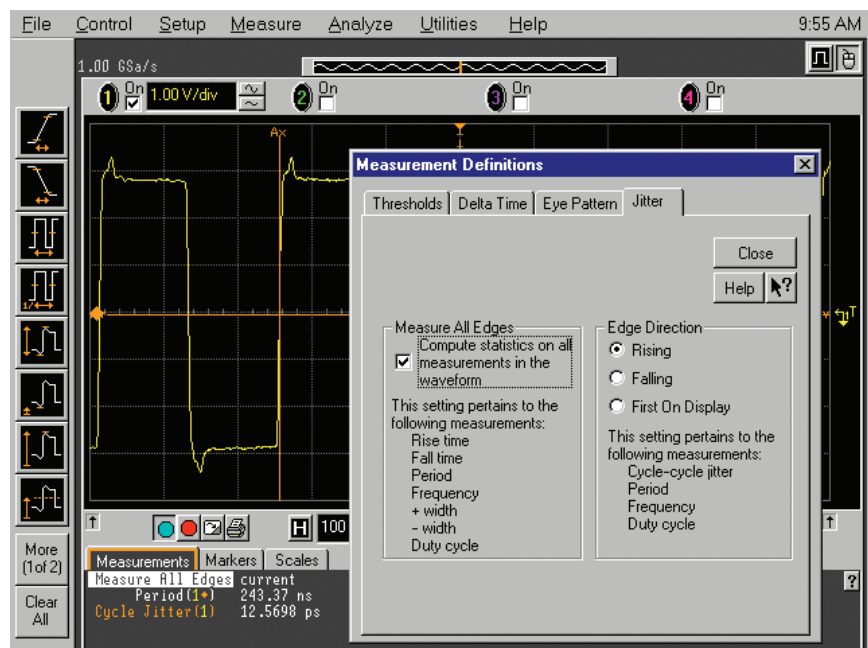


Figure 2. Setting up a jitter measurement

Jitter Measurement Techniques (continued)

It is important to set up the scope correctly to make effective jitter measurements. Set the vertical scale of the channel being measured to offer the largest waveform that will fit on screen vertically. This will make the most effective use of the scope's A/D converter.

The scope should be set to real-time acquisition mode in the Acquisition dialog box. Since equivalent-time sampling can combine samples from different acquisitions, the scope's trigger jitter would adversely affect jitter measurements. The averaging function should be turned off since, again, this combines multiple acquisition data.

You may want to set the scope to its maximum memory depth. This will make the scope less responsive to operate, but the scope can make many measurements on a single acquisition. Since jitter measurements are statistical, many measurements are desirable. Taking many acquisitions of small records will give a more random selection but will take longer than fewer large acquisitions. Having extremely deep memory is not necessary to getting good jitter measurements.

Normally, measurements are made at 10%, 50%, and 90% of the waveform amplitude. This is convenient for quickly making measurements; however, when making measurements across acquisitions and combining their statistics this is not the best solution.

In the Measurement Definition dialog box, Thresholds tab, the measurement thresholds should be set to absolute voltages. For example, if you are making cycle-cycle jitter or period measurements, set the middle voltage threshold to your clock threshold. Set the upper and lower voltage thresholds to roughly +/- 10% of the signal amplitude in voltage. This will establish a band around the threshold that the edge must go through to be measured and will eliminate false edge detection.

In addition to the period jitter measurement, the cycle-cycle jitter measurement uses the same technique. The cycle-cycle jitter measurement, available on Agilent 54845A/B and 54846A/B oscilloscopes, is the difference of two consecutive period measurements.

$$P_i - P_{(i-1)}, 2 \leq i \leq n$$

Where

P is a period measurement and

n is the number of periods in the waveform.

Cycle-cycle jitter is a measure of the short-term stability of a clock. It may be acceptable for the clock frequency to change slowly over time but not vary from cycle to cycle. For this measurement, every period in the acquisition is measured regardless of how the "Measure all edges" selection is set. In this case, the statistics represent all of the cycle-cycle jitter measurements in one acquisition, or all acquisitions if the scope is running.

If absolute clock stability is required, then a period measurement should be made. If your system can track with small changes in the clock frequency, then cycle-cycle jitter should be measured.

Again, if your timing margins are being met with this technique, more advanced techniques are not necessary. It is only fairly recently that tighter timing margins have caused engineers to need other jitter measurement techniques.

Jitter Measurement Techniques (continued)

Measurement Function

Agilent 54845A/B and 54846A/B Infiniium oscilloscopes can plot measurement results correlated to the signal being measured. For example, if every period is measured, as in the case above, the measurement function will plot period measurement results on the vertical axis, time-correlated to the waveform that the period measurement is measuring (figure 3).

In this example, the second period is slightly longer than the first. The third period is shorter than the second. Also notice that the lengths of the measurement function lines correspond to the period and their placement corresponds to channel 1 because we are measuring period on channel 1.

Using this technique, the shape of the jitter is apparent. For example, with spread-spectrum clocking you can see the modulation frequency as the period gets progressively slower and faster. This allows you to see sinusoidal shapes or other patterns in the measurement function plot (figure 4). It is also possible to correlate poor jitter results with the source waveform that caused them. This can aid not only in your design but can also ensure that the scope is measuring appropriate voltage levels when gathering jitter statistics.

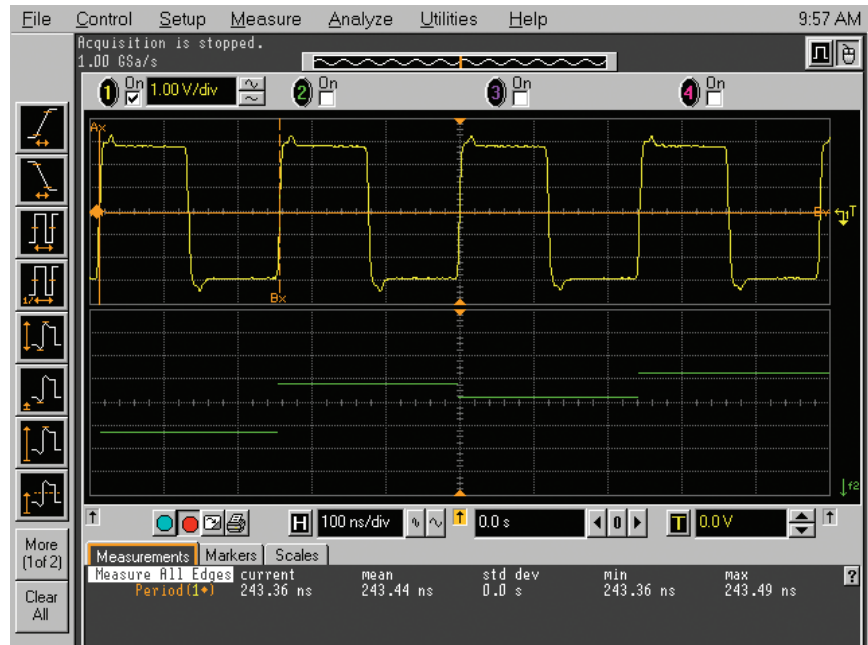


Figure 3. Measurement function on a few cycles



Figure 4. Measurement function on many cycles

Jitter Measurement Techniques (continued)

To turn on the measurement function, first turn on the desired measurement to track.

Measurements that can be tracked with the measurement function are rise time, fall time, period, frequency, cycle-cycle jitter, + width, - width and duty cycle. The measurement function is enabled in the Waveform Math dialog box (figure 5). Select a function that is a different color than the channel you are measuring to make it easier to see. Set the function operator to “measurement.” Select the measurement you wish to track and turn on the measurement function. The math function now plots the measurement results on the vertical axis, time-correlated to the channel being measured.

Only one measurement function can be enabled at a time; however, the function can be set to track any of the currently active measurements listed above.

Set up the acquisition by selecting the maximum memory depth in the Acquisition dialog box. Turn off averaging and Sin(X)/X interpolation in the Acquisition dialog box. Set the sample rate so that you are getting at least several sample points on the edges that you are measuring. Measurements are made on the data that is windowed by the screen. To see something slower that may be coupling into your clock, for example, you will need to compress the channel data on the screen.

Now that the memory depth and sample rate are fixed, you can adjust the horizontal scale so that all of the acquired data is on screen. In order to make full use of the A/D converter and separate the waveforms on the display, you may want to split the grid into two parts. If you have a very dense waveform that is being measured, it will be nearly impossible to see the measurement function on top of it. Turn on the split grid in the Display dialog box.

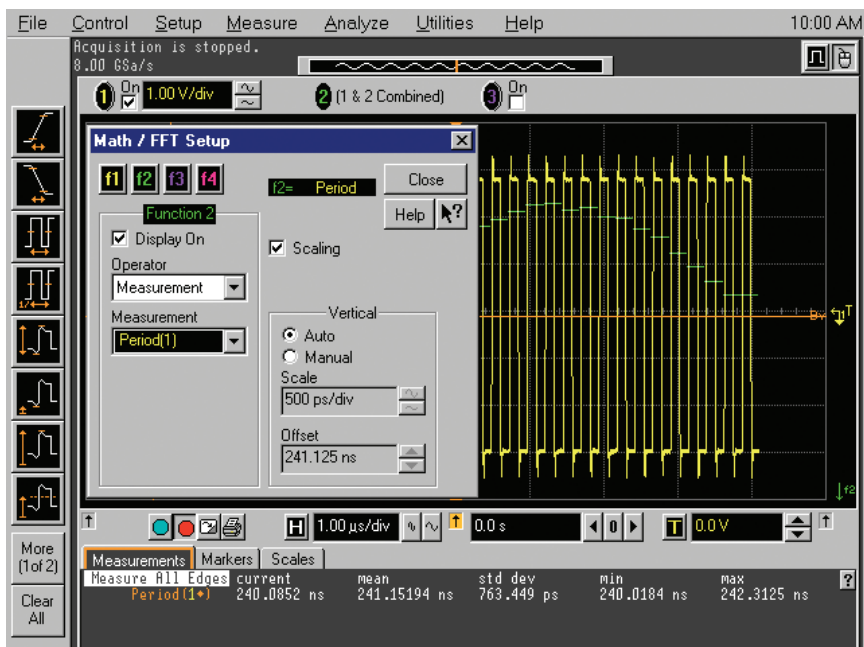


Figure 5. Setting up a measurement function

Sources of Measurement Error

In this section we will examine some of the principal sources of jitter measurement error. For best accuracy, the scope should be making measurements at the same temperature as when the scope was last calibrated. If the temperature has varied by more than 5 degrees, the software self-calibration should be performed again. The Calibration dialog box shows the change from the calibration temperature.

Trigger Jitter

The most common source of error across multiple acquisitions is trigger jitter. This is the error associated with placing the first point and all subsequent points of the waveform relative to when the trigger occurs.

For Infiniium models 54830B, 54831B, and 54832B, trigger jitter is 8 ps RMS. For the 54845A/B and 54846A/B, trigger jitter is 8 ps RMS. Figure 6 shows a 54845B measuring its trigger jitter using its own aux out signal.

If the jitter is Gaussian, you can convert RMS jitter to peak-to-peak jitter by multiplying the RMS jitter by 6. Trigger jitter is only relevant if you are measuring absolute times as opposed to relative times. For example, the histogram technique described above has this error source, but a period measurement does not since it is a delta-time or relative measurement.

This source of error can also be present in period measurements if the scope is in equivalent time. In equivalent time, the scope may combine data points from multiple acquisitions. The scope also combines points from multiple acquisitions in real-time averaging mode. If it is possible, jitter measurements should be made relative to other edges in real-time, non-averaged mode.

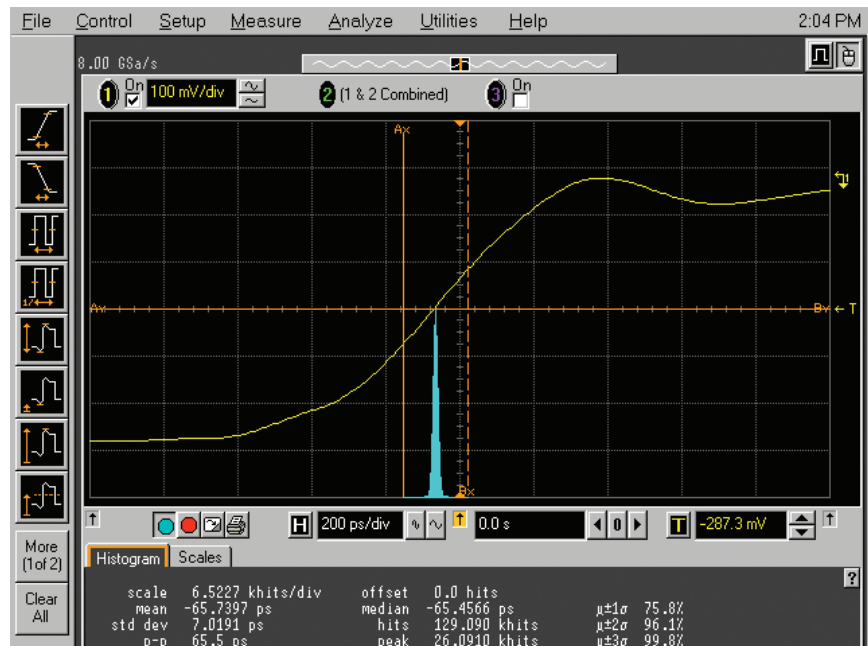


Figure 6. Histogram of trigger jitter

Sources of Measurement Error (continued)

Timebase Stability

Infiniium uses a highly stable crystal oscillator as a source for the sample clock. Errors resulting from instability of the timebase are the least significant. Timebase stability is not a specified quantity but is typically 5 ps RMS for the 54845 and 54846. For the 54830, 54831, and 54832, it is typically 2 ps RMS. These measurements were made at the same temperature as the calibration.

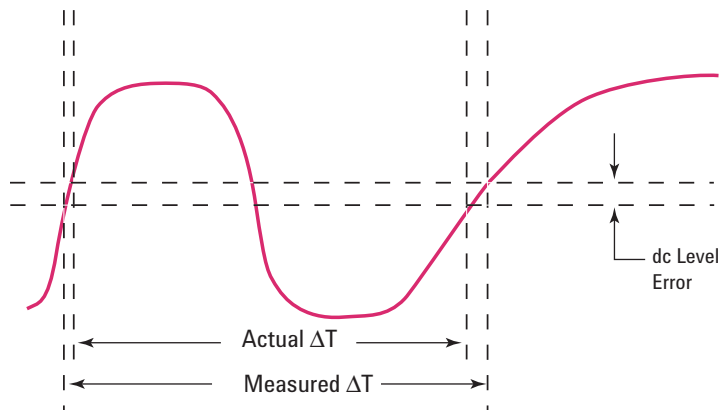


Figure 7. How vertical errors contribute to time errors

Vertical Noise

Errors in the vertical portion of the signal path including the A/D converter and preamplifier also contribute to the scope's jitter. Any misplacement of the waveform vertically will translate through the slew rate of the signal into time error (figure 7). If the slew rate of the signal at the point of measurement is steep, then the vertical error will translate into a small time jitter. If the slew rate is slow, however, this can be the most significant source of error.

Aliasing and Interpolation

From the previous section, it is clear that the signal should have a high slew rate to alleviate vertical errors. However, this can lead to signal aliasing. If the signal is not sampled sufficiently, significant time errors will be present up to the sample interval. When the scope makes measurements, it interpolates the samples above and below the measurement threshold to get the time of the level crossing. If the interpolation filter is enabled, up to 16 interpolated points may be placed between two adjacent acquisition samples. Beyond this, linear interpolation is used to determine the threshold crossing times. However, samples will only be added if the record length is less than 16K samples.

Characterizing the Scope

From the preceding discussion, figuring out if a scope can make your measurement may seem difficult. But there is a procedure that will determine how accurately the scope can make a measurement. By applying a highly stable source to the scope with a signal that resembles the signal to be measured, you can characterize the scope's jitter. Measure the amount of jitter contributed by the scope using one of the above methods. The jitter of the oscilloscope can be removed from the measured jitter,

$$J_{\text{signal}} = \sqrt{J_{\text{measured}}^2 - J_{\text{scope}}^2}$$

Where

J_{signal} is the jitter in your signal,

J_{measured} is the jitter that is measured on your signal, and

J_{scope} is the trigger jitter of the scope.

A Case Study

To illustrate how to use the jitter analysis capability of an Agilent Infiniium oscilloscope, let's examine a typical problem. You suspect that your power supply or another slower speed clock is coupling into the main clock on the board that you are designing. In order to understand how to eliminate the problem, you would like to know the frequency and wave shape of the signal that is coupling into your clock.

Traditionally, you would use an FFT magnitude spectrum and look at the side bands from the fundamental. For example, in figure 8 we have acquired a long record of a number of clock pulses and computed the FFT magnitude with a waveform math function. After we zoom in on the fundamental frequency of the clock, you can see side bands. If we take the difference in frequency from the fundamental to the nearest side band, we can determine the frequency of the coupling signal. In this example, it is measured at 198 kHz. We can also notice the odd harmonics and guess that the coupling signal would not be a sine wave. The resolution of the FFT will not give us a great deal of accuracy in determining the frequency, and we can not really see the shape of the coupling signal.

To solve this problem using the jitter analysis capability, we need to think about the problem in a different way. If a slower signal were modulating a higher frequency signal, then we would expect the period of the higher frequency signal to get slightly longer, then slightly shorter, etc., according to the slower signal (figure 8). The measurement function method described earlier in this product note could be used to plot how the period changes across the waveform.

To set up the scope, acquire the channel data with a long acquisition record in real-time acquisition mode. Put all of the waveform on screen by setting the sample rate to manual and adjusting the time per division. This will allow you to see how the period varies across the entire acquisition. In the Measurement Definitions dialog box, Jitter tab, set the control to Measure All Edges (figure 2). Now, turn on a period measurement. In the Math dialog box, turn on the Measurement function and set to the period measurement.



Figure 8. FFT of clock

A Case Study (continued)

You can now see how the period measurement varies across the signal (figure 9). Adjust the time per division until you can see several periods of the slower speed signal in the measurement function. To measure the frequency, use the markers or simply drag the frequency measurement to the measurement function. Using this technique, we measure 197 kHz and we can see that the signal is a square wave. This confirms that another signal on the board is coupling into the clock. Armed with this knowledge, we are better equipped to find a solution.

Summary

This product note presents several methods for measuring jitter with Agilent's Infiniium oscilloscopes. The following quick reference will help you choose the best method for a number of circumstances.

Infinite Persistence

- Shows absolute time or edge jitter
- Works best when the jitter to be measured is greater than the scope's jitter
- Sets up easily
- Acquires data quickly
- Measures only worst-case, peak-to-peak jitter



Figure 9. Measurement function showing coupling signal

Histograms

- Shows absolute time or edge jitter
- Works best when the jitter to be measured is greater than the scope's jitter
- Shows a distribution of the jitter
- Helps determine if the jitter is random or deterministic
- Measures worst-case, peak-to-peak jitter
- Measures RMS jitter

Measurement Statistics

- Shows worst-case, peak-to-peak delta time or measurement jitter

- Sets up easily

Measurement Functions

- Shows how measurements vary as a function of time
- Shows the shape and frequency of a jitter source
- Helps determine if the jitter is random or deterministic

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