Jitter Analysis:

Correlation

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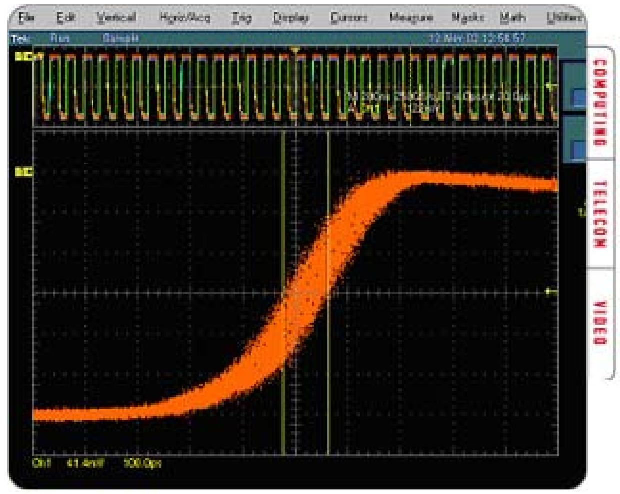
- Comparing Results



Jitter Analysis

Jitter can be described as unwanted timing variation in any series of clock or data pulses. There are a variety of methods that are useful to measure jitter. A few common oscilloscope methods are discussed here, as well as reasons why the answers from any one method may or may not agree with another method. This becomes a serious matter when someone wants to verify your results.

Measurement Techniques – A Cornucopia of Variation

There are three basic types of parametric measurements of jitter made using oscilloscopes. Most common, because it has been around longest, is a simple edge width measurement made after some set delay. Depending on the delay chosen, the measurement can include one or many cycles of accumulated jitter.

An example is shown in Figure 1. The time between a trigger event and the edge is used as a reference. A waveform is built up using several triggers, overlaying each trace on top the previous traces. On older analog oscilloscopes, this process required dark rooms and viewing hoods to see the display with enough detail to make an accurate measurement of the trace versus the graticule lines. On today's digital storage oscilloscopes, the measurement is made much easier using infinite persistent display modes and cursors. The time of interest, the jitter, is measured between the first overlaid edge of waveform to the last overlaid edge of the waveform, the area highlighted with the cursors in Figure 1. The cursors show a result of 1.05ns.

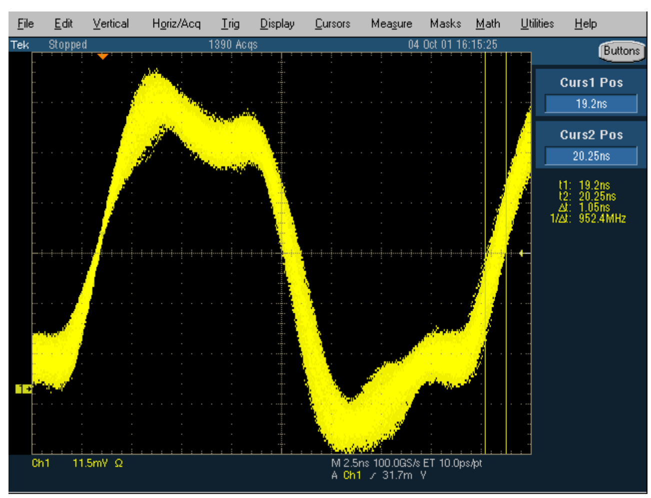


Figure 1

Jitter measured this way is simply called jitter.
A result measured this way is always a peak-to-peak value since nothing is known about the content of

data between the cursors.

A second common method of measuring jitter is to extend the first method and utilize some way of counting the number of waveforms that make up the display. This adds the advantage of enabling statistical analysis of the results. Figure 2 shows an example of measuring jitter using a histogram. With a histogram, the number of waveforms (the locations of hits) can be used to compute the mean and standard deviation values. From this example we can see the peak-to-peak value of 1.05ns, and we can also know the standard deviation of 153ps. This method has one other advantage: you can easily count the number waveforms that make up the data. This leads us to several key points.

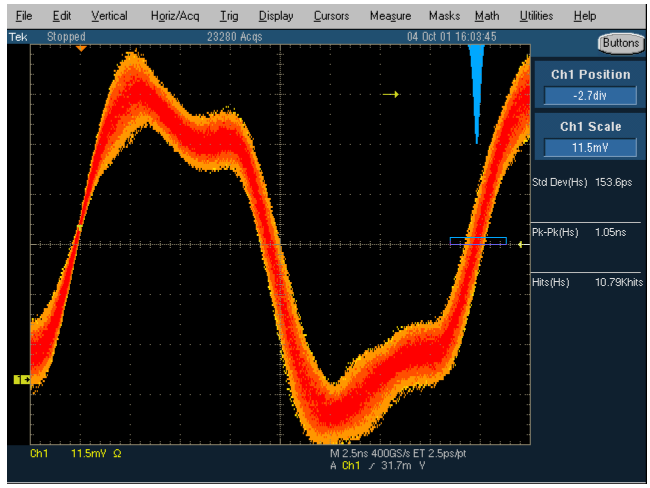


Figure 2

In Figure 1, we really don't know how long data was acquired to get a result or, with analog oscilloscopes, how many waveforms make up the data. Even knowing the number of waveforms displayed doesn't really tell us much. Data might have been taken in a few seconds, or over several days. We just can't tell. Figure two shows more information on the display. A standard deviation is a first step to providing results that can be meaningful to others you want to share data with. But again, we really do not have any idea the time period over which the data was acquired. Why is that important? If waveforms are captured over several seconds then we will also be measuring wander along with the jitter. This is because wander is jitter that is between DC and 10Hz. Because waveforms are captured a second apart, 1Hz effects can be captured. There are many factors in the setup that can affect this, but the fact remains; unless you treat the measurement and setup properly, various unwanted components can creep into the results.

In Figure 1 and Figure 2, it isn't obvious where the trigger point is (unless you are familiar with Tek oscilloscopes). In these examples the trigger point is on the first edge in the display. These two measurements are being made with little delay between the trigger and the edge of interest. If you had only passed the results to another colleague, he might choose a different reference point to measure from and your results may not agree with his.

When the reference point for a jitter measurement is not within the same cycle as the measurement, you begin to accumulate jitter. Jitter can accumulate in a variety of ways. The simplest is summing, where adjacent cycles are slowly changing period. Measuring over a several cycle delay will give a different jitter result, a result that is the sum of the jitter on all the cycles. Figure 3 and Figure 4 show two representative waveform measurements, Figure 3 measuring jitter on the first cycle, Figure 4 measuring jitter on the eighth cycle. Notice how the jitter in Figure 3 is 54ps peak-to-peak, and the jitter in Figure 4 is 85ps peak-to-peak.

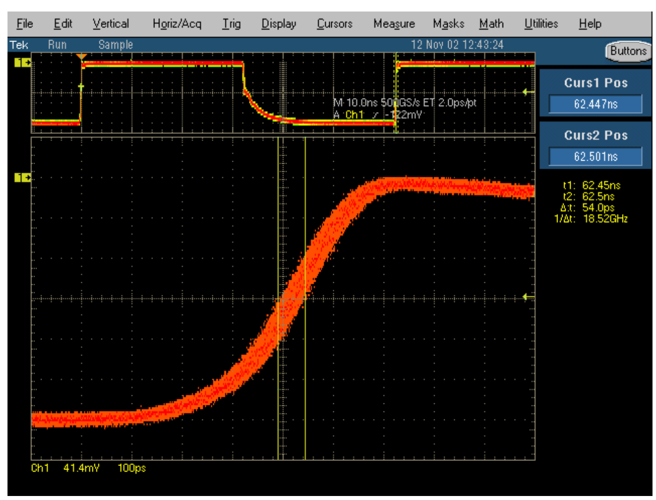


Figure 3

Some measurement references require a set delay be used to measure jitter. A common point of reference is 20us. Figure 5 shows the same signal, but with a 20.44us delay. It shows about 88ps peak-to-peak jitter.

Measurement Methods

By now it should be clear that there are many ways to measure jitter. They can be very similar, yet yield different results. Operator technique even plays a role. For example, where you place the cursors makes a difference in these examples. So, correlation of measurements takes some personal patience and understanding of the variables involved.

The preceding examples are all correctly measuring jitter – just differently. To design tests and expect different individuals to get similar results across different vendor's equipment, you need to be specific and exact about what and how jitter is measured. The essential items to specify are:

- Reference (if applicable)
- Measurement type (period, TIE, etc.)
- Threshold or reference level (and how it is found)
- Measurement rate (measurements per second)
- Measurement duration (acquisition period)

The three basic types of jitter measurements are period, cycle-to-cycle, and time interval error.

Period and cycle-to-cycle measurements are often the easiest measurements to correlate. Variation in period measurements can be caused by reference level, measurement rate (delay or spacing between measurements), measurement sample size (how many periods were measured), and total measurement time (how long between the first period measured and the last period measured). Correlation is improved when a standard specifies the reference level, measurement rate and sample size.

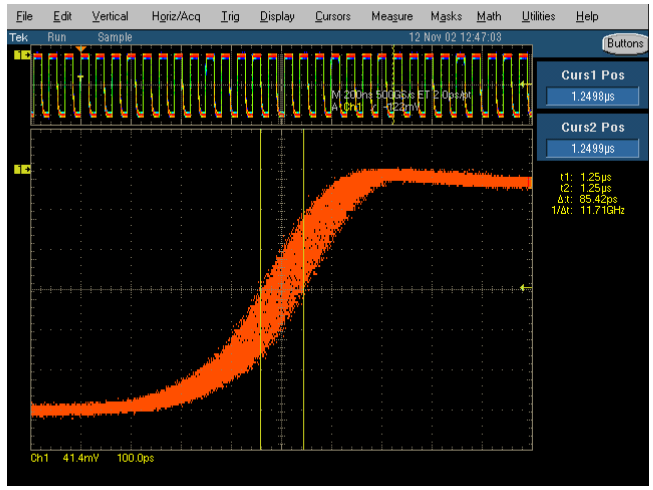


Figure 4

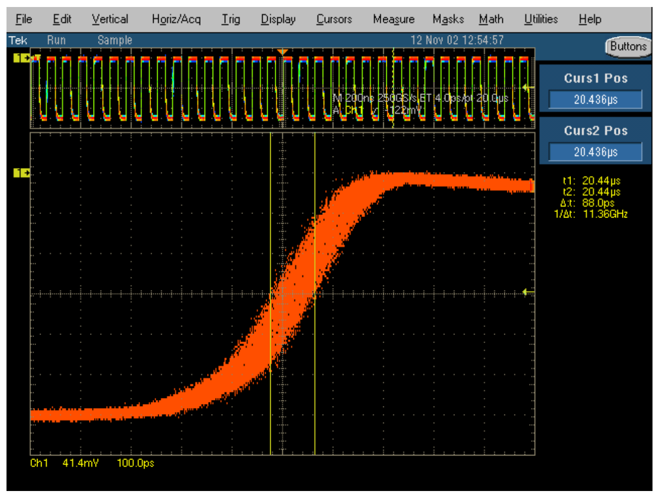


Figure 5

If several engineers were asked to measure the jitter of a 1GHz clock and given the requirements – detect only rising edges at the 50% of average peak-to-peak level; measure every 1000th cycle; measure for 10 seconds – they would all get very similar results.

Correlation becomes easier with the following requirement: measure the jitter of a 1GHz clock: detect only rising edges at the 0.0v crossing level; measure every cycle; measure for 1,000,000 cycles. This is also nearly a specification for a cycle-to-cycle measurement, which changes the displayed results from the period value to the change in period value.

Time interval error (TIE) is different from period measurements in that it requires a reference to compare detected edges against. TIE is a good measurement to use because it can be easily correlated across most types of equipment used to measure jitter, perhaps with the exception of spectrum analyzers.

In the simplest model, TIE is the difference between where an edge is in time and where the reference says it should be. This is also the classic definition of jitter. To measure TIE of a 1GHz clock, you would measure the time of occurrence of every edge in the clock and compare it to a reference. An easy reference to visualize is a simple ruler. If we let every inch or cm equal 1ns, and laid our measured waveform edges on it, we could measure how far from the ruler marks our measured edges are. This difference is TIE.

Due to the analog nature of most signals, most timing measurements require a reference level to properly determine where an edge occurs. A typical reference is the 50% point on a signal. But what is the 50% relative to? Is it the highest positive and negative peak amplitudes or the average positive and negative levels? Most oscilloscopes have the capability to choose how reference points are determined. You must specify your choices otherwise your colleague may use the other one.

Measurement rate and duration are probably the most abused of all measurement specifics. You use your oscilloscope and measure the period statistics using the automated measurements, tell your colleague in Sao Paulo your results and he laughs and says he gets 50% better results using the same oscilloscope make and model. Is the oscilloscope power line rejection better at 50Hz? What I find as a common error when engineers try correlating results is they ignore the acquisition period – the time over which data is accumulated. Measuring a signal for 1 second will yield a result that is different from measuring for 10 seconds. That is the nature of analog signals and jitter. Even two 1us measurement periods will be different because of the random and unique events that make up noise.

Before going into comparing results, we need to understand the basic similarities of equipment we use to make some of these measurements.

Measurement Equipment

TIE is a good method for measuring jitter because it can be used across several different types of equipment: bit error rate testers (BERT), analog oscilloscopes, equivalent-time sampling oscilloscopes, real-time sampling oscilloscopes, and time interval analyzers (TIA).

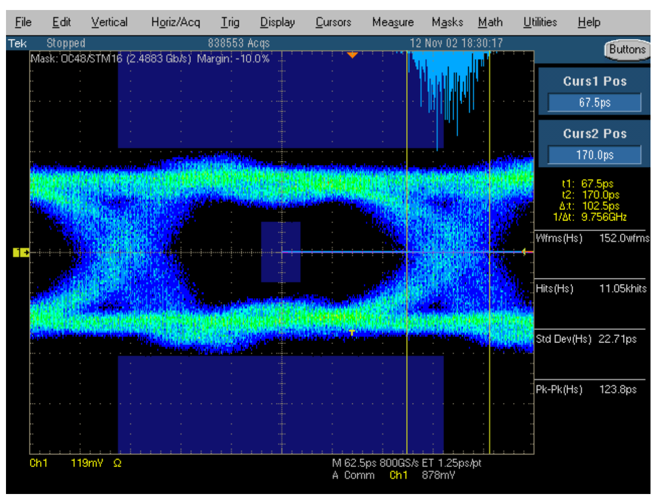


Figure 6

TIA (SIA3000): A time interval analyzer measures the time between a reference edge and the when signal under test transitions. The results are analyzed and statistical variation reported. The reference is usually a clock at the frequency of the applied signal.

ET oscilloscope (CSA8000): An ET oscilloscope uses an external reference to trigger every sample. Sample timing is randomized and recorded with the sample value. The samples are then arranged into a time correlated waveform display. From the displayed or raw waveform data, measurements are made of the signal and statistical results displayed. Again, the reference is usually a clock at the frequency of the applied signal.

RT oscilloscope (CSA7000): A RT oscilloscope can acquire a signal using two methods. The first is similar to the ET oscilloscope using an external reference. The second method is to acquire a series of sequential samples at a very fast sample rate and display a waveform. In the RT method, for efficiency, the reference is often computed rather than directly measured. Measurements are made of the signal and statistical results displayed.

BERT (70843A): A BERT acquires data using an external reference clock to trigger when a sample occurs. The sample is tested for state information (high/low). By varying when the sample occurs relative to the reference-induced trigger, a BERT can find where transitions occur. A BERT then measures where transitions actually occur and statistical results displayed.

The common theme here is that in all cases a reference is used to measure against.

Mask Testing

We'll start with a mask test, or eye diagram. A typical mask test uses an external clock to sample a signal and provide voltage and timing information. It is important to note that while a TIA can produce similar timing information, the voltage information is typically lost. When a mask test is used to measure the width of an eye opening or amount of eye closure, they are directly comparable to TIE. This is because the signal edges are positioned relative to a reference clock edge that is the center of the mask eye.

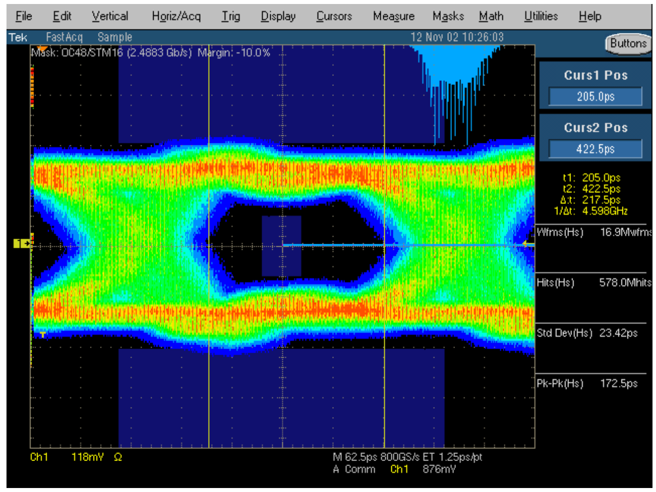


Figure 7

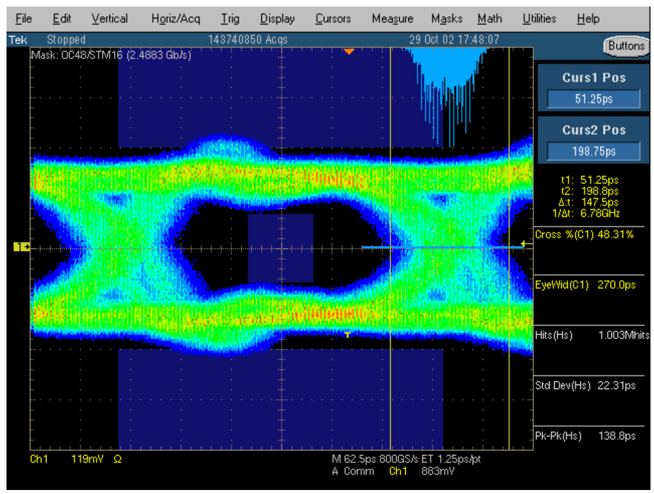


Figure 8

Figure 6 shows a 2.5Gbps data signal being measured on a RT oscilloscope (CSA7404). The eye measurements are made up of about 100 edges sampled over about 0.1 second (as fast as I could start and stop the oscilloscope when it was in slow mode). Contrast this with Figure 7 showing the same signal, but with 578 million edges (several days of FastAcq/DPX data accumulation at greater than 200,000 waveforms per second). The important feature of these two figures is that while the standard deviation remains constant (22.8ps vs. 23.4ps respectively), the peak-to-peak jitter increases with the number of sampled edges (100.0ps vs. 172.5ps).

Since most standards require measuring jitter over a predetermined number of bits (1E12 for Fibre Channel), these tests take a great deal of time to perform directly, so often standards don't require testing to reasonable levels like 1E12 (though most of us use a BERT or oscilloscope to characterize at least a few devices to this level).

Comparing Results

Enter real-time jitter analysis introduced in TDSJIT3. By acquiring a continuous stream of samples at very fast sample rates, thousands to millions of edges can be captured in a single moment. Analyzing this acquired data for frequency content, a reference clock can be mathematically derived and used to enable a measurement of TIE.

In Figure 8, about 1 million edges are being measured, with a result of 138.8ps peak-to-peak. In Figure 9, TDSJIT3 has been used to measure the signal over 4us, about 50,000 edges, and estimate what the peak-to-peak value would be for 1 million edges: the estimate is 136.9ps peak-to-peak. This is a 99% correlation. This is derived from the random and deterministic decomposition within TDSJIT3 producing eye opening result of 0.657 unit intervals (UI). This 2.5Gbps data signal has a 400ps UI. Jitter, in seconds, is equal to eye closure multiplied by the unit interval. Tj = UI * (1 – EyeOpen).

So we can see that a real-time measurement can correlate with traditional methods for moderate bit error ratios. What about smaller or larger measurement periods? Acquiring 1E12 edges is too long a mask test for an oscilloscope. However using FastAcq on a CSA7404, we can acquire enough data in a reasonable time to have comparable data for 578E6 edges. That test resulted in 172.5ps peak-to-peak jitter. Using TDSJIT3, the estimate for 1E9 edges is 0.586UI. That equates to 165.4ps peak-to-peak, a 97% correlation. The test time difference is phenomenal: five days versus five seconds.

Tektronix has also tested TDSJIT3 performance against BERTs and found results accurate within 2.5% at 1E12 BER. With this data, it becomes clear that using TDSJIT3 is a viable solution to estimate jitter in place of longer tests.

The table below shows data from testing a data signal with TDSJIT3 and standard mask testing, similar to the above examples. It shows that there is correlation between the various jitter measurement methods once all the various and variable factors are understood.

Jitter Correlation	MASK				TDSJIT3				
	Hits	Eye (UI)	Jitter (ps)	Time (s)	Edges	Eye (UI)	Jitter (ps)	Time (s)	Correlation
1E6	1.0E+6	0.653	138.8	78	50398	0.658	136.9	4	98.6%
500E6 (fast acq)	578.0E+6	0.569	172.5	432,000	50392	0.581	167.6	4	97.2%

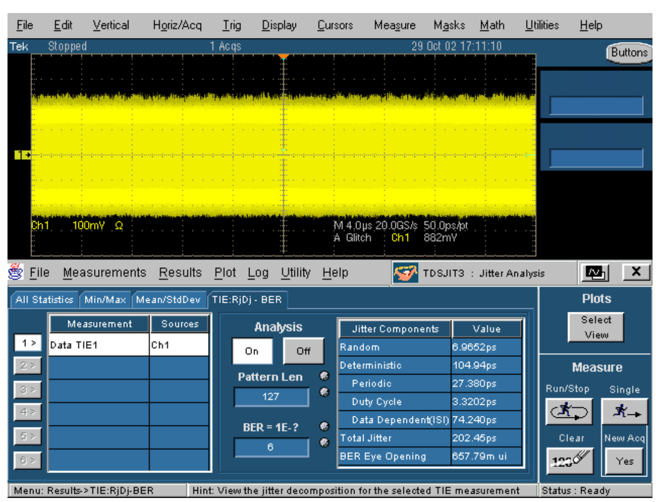


Figure 9

Conclusion

The ability to correlate results must be designed into the test methodology. Without that intrinsic design step, precise correlation will be difficult to achieve, no matter how hard you try. If you must try to correlate with colleagues regarding non-standard tests, then be as specific as you can about your test conditions, including as much information as you know about how a measurement was made.

The three key variables in any jitter measurement are:

- Edge Threshold or Reference Level
- Measurement Interval or Sample Size
- Measurement Duration

Other variables that can influence results are:

- System Bandwidth – jitter happens from DC to light though most jitter is lower frequencies.
- Jitter Noise Floor – how much noise does the measurement system introduce?
- Probing – probes and cable lengths are important test considerations.

Be able to answer this question:

Where did you measure and how many edges are in your sample set?

Contact Tektronix:
ASEAN / Australasia / Pakistan (65) 6356 3900

Austria +43 2236 8092 262

Belgium +32 (2) 715 89 70

Brazil & South America 55 (11) 3741-8360

Canada 1 (800) 661-5625

Central Europe & Greece +43 2236 8092 301

Denmark +45 44 850 700

Finland +358 (9) 4783 400

France & North Africa +33 (0) 1 69 86 80 34

Germany +49 (221) 94 77 400

Hong Kong (852) 2585-6688

India (91) 80-2275577

Italy +39 (02) 25086 1

Japan 81 (3) 3448-3010

Mexico, Central America & Caribbean 52 (55) 56666-333

The Netherlands +31 (0) 23 569 5555

Norway +47 22 07 07 00

People's Republic of China 86 (10) 6235 1230

Poland +48 (0) 22 521 53 40

Republic of Korea 82 (2) 528-5299

Russia, CIS& The Baltics +358 (9) 4783 400

South Africa +27 11 254 8360

Spain +34 (91) 372 6055

Sweden +46 8 477 6503/4

Taiwan 886 (2) 2722-9622

United Kingdom & Eire +44 (0) 1344 392400

USA 1 (800) 426-2200

USA (Export Sales) 1 (503) 627-1916

For other areas contact Tektronix, Inc. at: 1 (503) 627-7111

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