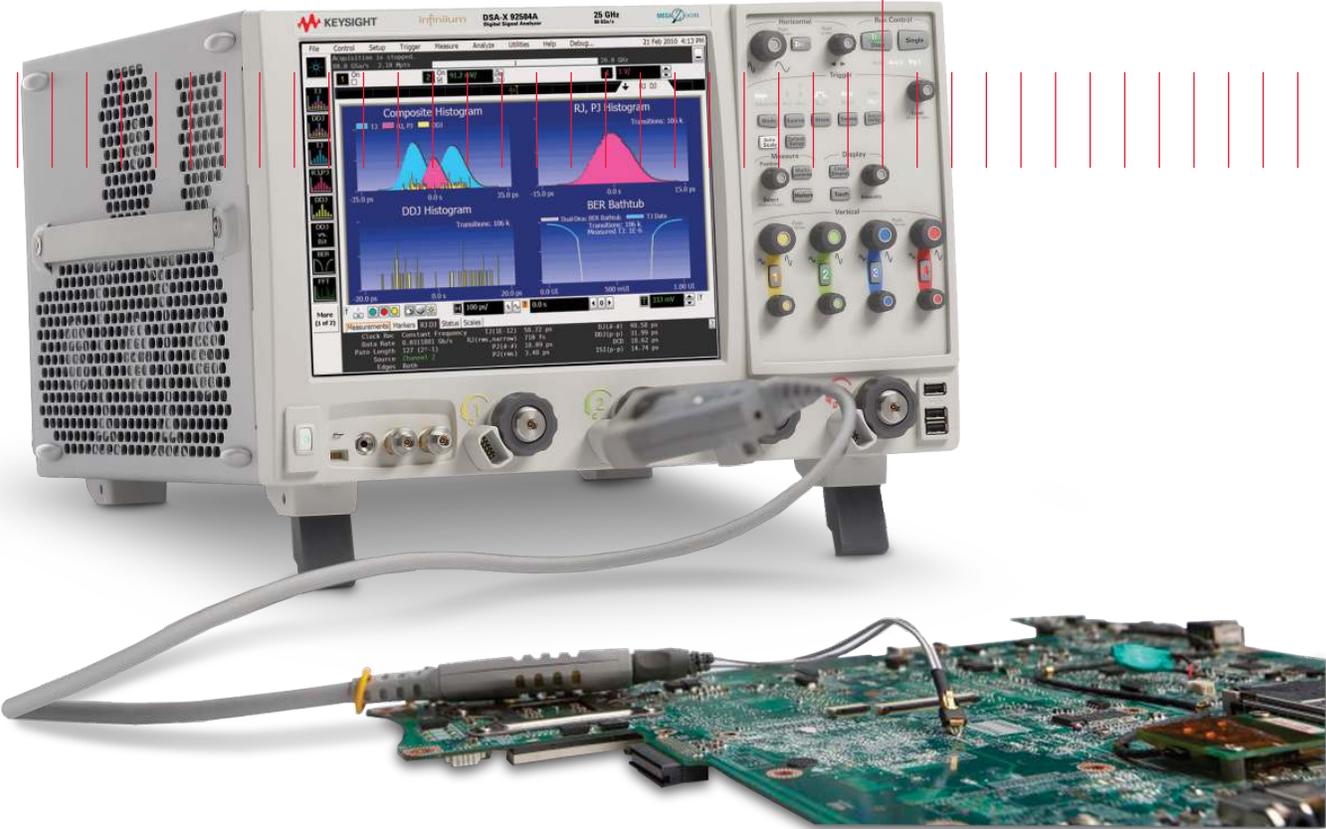


Keysight Technologies

Understanding the Oscilloscope Jitter Specification

Application Note





Introduction

Jitter is defined as the unwanted phase modulation of a digital signal, and is considered one of the most important specifications for measuring a device's quality. To better understand why jitter is so important, consider today's wireless communications devices, which rely on digital transmission to avoid cumulative noise-induced degradation. These devices should provide users with error-free communications, but this is often not the case. Instead, issues like mis-timing inside transmission equipment can result in jitter that degrades performance. As a result, today jitter performance is mandated by the various communications standard technologies, referenced by equipment specifications, and taken as a minimum requirement. Compliance requirements specify random jitter, deterministic jitter, time-interval error, and total jitter. In addition, some standard technologies specify measurements like bounded uncorrelated jitter and J2/J9 jitter. A jitter measurement that is too high can have a significant impact on a product—in some cases forcing it to be redesigned and, in the worst case scenario, keeping it from being shipped altogether.

Jitter can be precisely measured using a common, yet powerful tool like the oscilloscope. While most Windows-based oscilloscopes offer analysis software to help you measure jitter, such instruments are limited by their jitter measurement floor, which can erode crucial design margins and even cause devices to fail tests unnecessarily. If the jitter of the device-under-test (DUT) is lower than the oscilloscope's jitter measurement floor, it cannot be measured. It is incumbent on engineers, therefore, to fully understand an oscilloscope's jitter specifications before making any purchase. Doing so will not only ensure you select the right oscilloscope, but also enable more accurate measurements and faster time to market.

Understanding Jitter Specifications

In an oscilloscope, the most important jitter specification is the jitter measurement floor. This specification is a combination of the oscilloscope's sample clock jitter and noise floor, and results in random jitter within the oscilloscope that can affect its accuracy. Because oscilloscope vendors specify their instrument's jitter measurement floor in different ways, making an educated purchasing decision requires the engineer to understand what each possible specification means. These specifications include: intrinsic jitter, jitter measurement floor, and long-term jitter.

– Intrinsic Jitter

The oscilloscope's intrinsic, or sample clock jitter, is defined as the amount of jitter it transmits using internal timing. To better understand this definition, consider that real-time oscilloscopes sample data very fast, up to 120 GSa/s. Because of this, ensuring data points are in alignment is a critical task. This can be accomplished in one of two ways, either by using a chip or a time-base system that provides the necessary tight-time correlation required between the sampled input signals delivered to the analog-to-digital (A-to-D) converter and the internal clock. Like the oscilloscope, the internal clock has its own jitter specification. The internal clock also is characterized by how well it can align the oscilloscope's sample points through its time base. Consequently, the jitter specification of the entire oscilloscope time base is what is referred to as the sample clock jitter.

Intrinsic jitter is often specified differently by different oscilloscope vendors. Keysight Technologies, Inc., for example, specifies the intrinsic jitter of its Infiniium 90000 X-Series oscilloscope as 150 fs. Here, intrinsic jitter is meant to show the oscilloscope's theoretical best-case jitter measurement in the presence of no other variables. Some vendors refer to this as the oscilloscope's jitter measurement floor. Regardless, the intrinsic jitter specification alone is not sufficient to tell the engineer exactly how much jitter an oscilloscope will contribute to a measurement.

– Jitter Measurement Floor

An oscilloscope's jitter measurement floor stems from a combination of sample clock jitter and the noise influence due to slew rate. This specification is influenced by the oscilloscope's noise floor. Generally speaking, the slower the slew rate (rise time) being measured, the greater the influence from the noise floor. The jitter measurement floor specification takes into account the oscilloscope's noise floor. This is critical, because noise is one of the largest contributors to oscilloscope jitter and it is not properly accounted for with the sample clock jitter specification.

An example of an oscilloscope's jitter measurement floor comes from the 90000 X-Series oscilloscope data sheet:

$$\sqrt{\left(\frac{\text{Noise}}{\text{Slew rate}}\right)^2 + \text{Sample Clock Jitter}^2}$$

Here, the jitter measurement floor specification is comprised of three components: sample clock jitter, noise and slew rate, each of which play an important contributing role. Some vendor data sheets only specify one number (e.g., 200 fs). By doing so, the vendors are essentially specifying only their oscilloscope's best-case jitter or sample clock jitter, rather than properly representing its jitter measurement floor.

In contrast, having sample clock jitter, noise, and slew rate each represented provides a much more thorough and accurate representation of an oscilloscope's jitter measurement floor. That is because noise influences oscilloscope jitter, a phenomenon that can be observed by looking at the time-interval error of different sine wave frequencies.

Understanding Jitter Specifications

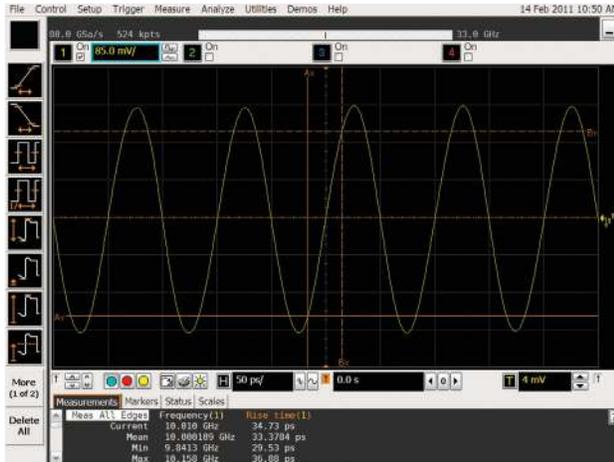


Figure 1. Noise influences oscilloscope jitter, as seen by looking at the time-interval error for various sine-wave frequencies.

Figure 1 illustrates the influence of noise on oscilloscope jitter. The figure shows that for a 20-GHz sine wave, the oscilloscope has a time-interval error of 190 fs. When the sine wave slows to 5 GHz, the time-interval error is 400 fs (Figure 2). Figure 3 shows an entire jitter-versus-frequency curve for the 90000 X-Series oscilloscope. Note that as the sine wave frequency increases to above 30 GHz, the jitter measurement floor approaches the sample clock jitter specification of 150 fs. Sine wave frequencies' slew rates become faster as the frequency increases. When the sine wave frequency is 30 GHz, the slew rate is over ten times faster than that for a sine wave running at 5 GHz. As a consequence, significantly less oscilloscope noise contributes to the time-interval error of the measurement.



Figure 2. When the sine-wave frequency decreases, the time-interval error increases.

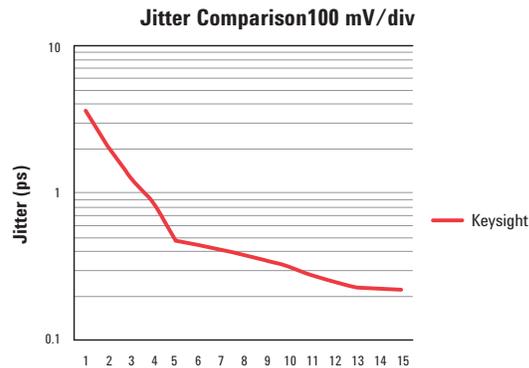


Figure 3. This curve illustrates jitter vs. frequency for the 90000 X-Series oscilloscope.

– Long-term Jitter

The long-term jitter specification measures the maximum change in a clock's output transition from its ideal over a large number of data points. As an oscilloscope's memory increases, the time base is forced to align more sample points at extremely fast rates. With the deep memory today's oscilloscopes offer, this problem will only get worse. Keysight's 90000 X-Series now offer up to 2 Gpts of data, putting extreme stress on the oscilloscope's time base. In addition to the deeper memory, chip manufacturers now separate jitter on longer patterns (e.g., PRBS23 and PRBS31). Properly separating random jitter from deterministic jitter on one of these patterns, for instance the PRBS23, requires up to 500 Mpts of data and beyond. At such deep memory depths, an oscilloscope's long-term jitter becomes vitally important.

Because long-term jitter takes into account the effects of an oscilloscope's drift in its time base, a time base that was not designed for deep memory will experience significant drift and result in very large jitter measurements. This drift can have an unexpected result: For example, a jitter measurement taken with 2 Mpts of data may produce a completely different answer than one taken with 100 Mpts of data.

Verifying Jitter

Regardless of how an oscilloscope's jitter is specified, it can be verified using the following process:

Step 1. Find a very low-jitter sine-wave source with as much or more bandwidth than the oscilloscope (e.g., Keysight's E8267D PSG vector signal generator, which has greater than 30 GHz of bandwidth and very low jitter).

Step 2. Connect the sine wave generator to an input on the oscilloscope (Figure 4).

Step 3. Starting with 1 GHz on the sine wave generator, input the sine wave into the oscilloscope.

Step 4. Activate the oscilloscope's time-interval error measurement and record the measurement result. Note that the clock recovery can be set to the oscilloscope's constant clock recovery setting.

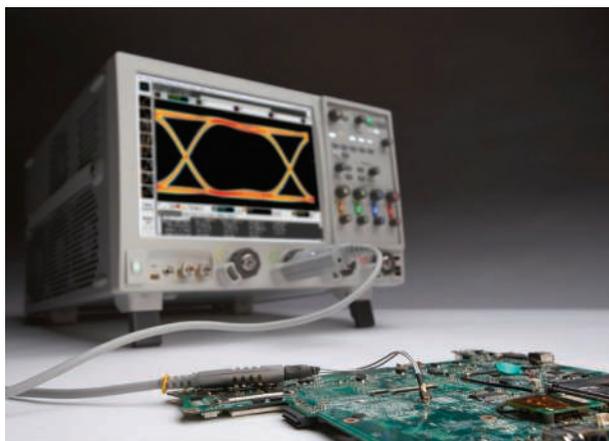


Figure 4. The 90000 X-Series oscilloscope displays an entire jitter-versus-frequency curve.

These four steps represent the first measurement of the jitter measurement floor curve. To complete the curve, repeat Steps 2 through 4 in either 1-GHz or 500-MHz steps up to the bandwidth of the oscilloscope.

Although these steps are fairly straightforward and easy to perform, you need to keep in mind a number of additional issues. To begin with, the jitter measurement floor will decrease as the bandwidth of the sine wave increases. This occurs because as the rise time gets faster, less noise contributes to the jitter measurement floor. In fact, when measuring rise times slower than 30 ps, the noise contributes more to the jitter measurement floor than the oscilloscope's actual sample clock jitter.

Another factor that must be considered is that as the amplitude and offset of the sine wave change, so too do the results provided by the oscilloscope. As an example, consider that one vendor's oscilloscope may be very sensitive to offset changes and its jitters may significantly worsen when offset is added. Another vendor's oscilloscope may be optimized with 75 percent of the scale input (Figure 5). Increasing the scale input above 90 percent increases the jitter measurement floor.

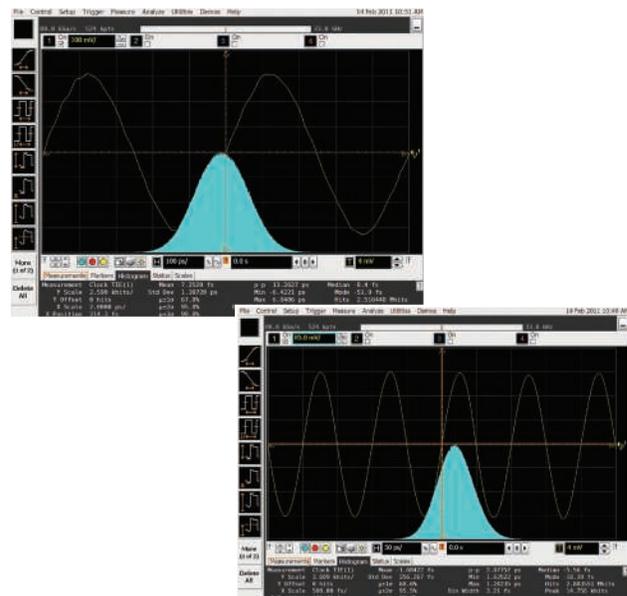


Figure 5. The jitter measurement increases as the frequency decreases.

Verifying Jitter

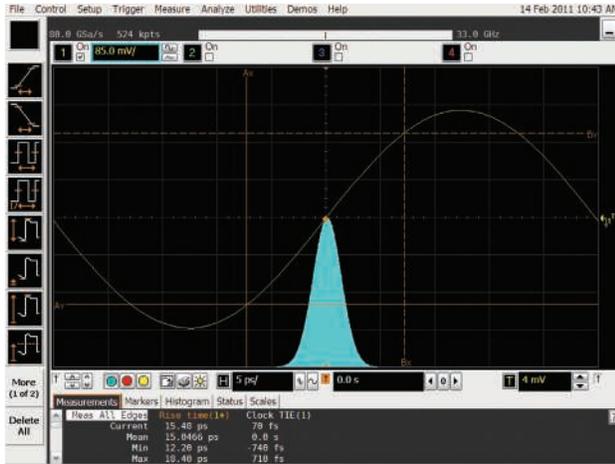


Figure 6. The oscilloscope's noise contribution to jitter measurement increases as rise times increase, as shown for this 90000 X-Series scope.

When time permits, it may be useful to change key measurement variables (e.g., amplitude, offset and percentage of screen of input) and measure the same jitter measurement floor curve. Performing this exercise illustrates another consideration: rise times increase as frequencies decrease. As a result, the oscilloscope's noise contribution to the jitter measurement increases. This fact is illustrated in Figure 6, which depicts the jitter measurement floor of the 90000 X-Series oscilloscope. Notice that at sine wave frequencies of greater than 20 GHz, the 90000 X-Series nears its intrinsic jitter of 150 fs.

One additional consideration that you should be aware of pertains to the oscilloscope's jitter being close to the jitter of the measurement. When this occurs, the oscilloscope will contribute more jitter to any measurements that are made. Although it is possible to see the lowest theoretical jitter of the oscilloscope, doing so requires that the device have significantly lower jitter. Consider, for example, a device with 150 fs of jitter and an oscilloscope whose lowest jitter measurement floor is also 150 fs. In this case, an error of roughly 30 percent to 40 percent would be added to the jitter measurement. In other words, at best, the real-time oscilloscope would realize a jitter measurement of 200 fs.

Summary

By far, one of the most important specifications of an oscilloscope is its jitter. That is because obtaining an accurate picture of what a design looks like, as opposed to just looking at oscilloscope noise and jitter, requires the oscilloscope to have a low jitter measurement floor. Unfortunately—simply reading a data sheet jitter measurement is not enough to determine if this requirement is met. The engineer needs to understand what the oscilloscope vendor is actually specifying. Is the jitter specification really just the sample clock jitter or is the vendor confusing best-case sample clock jitter with jitter measurement floor?

The jitter measurement floor ultimately determines the oscilloscope's true jitter by combining sample clock jitter and noise floor with a slew rate component. Because this specification varies by slew rate, it is important to find the needed slew rate and actually test the specification at that point. This may take additional time when evaluating an oscilloscope, but the benefit to the engineer using the instrument is invaluable: more accurate measurements with a lower total jitter measurement and, in turn, the ability to deliver products to market faster.



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