Measurement Brief: Examining Sampling Scope Jitter Histograms

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Eye diagrams are constructed from voltage samples taken at a rate many times lower than the data rate. The traditional method of measuring jitter on an eye diagram is to place a window around the eye diagram crossing point, and to build a histogram of the samples that were taken in that region alone. From the shape and width of the histogram, an estimate of jitter is made (Figure 1).

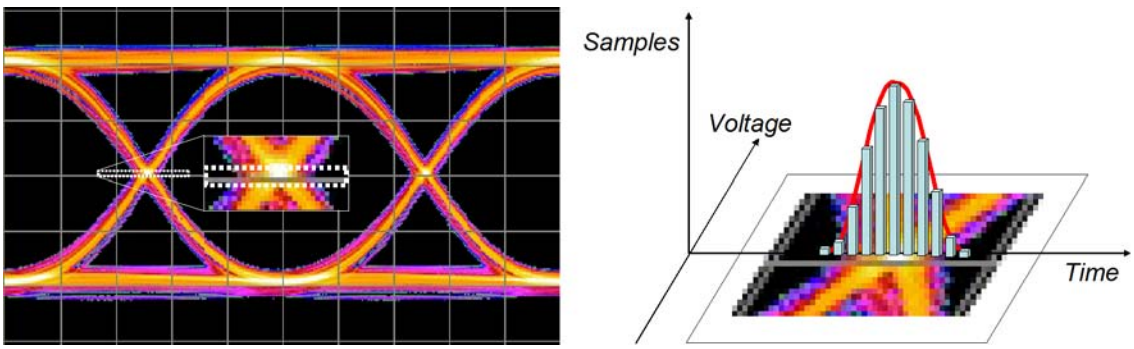

Figure 1: Taking a histogram of the eye diagram crossing point to estimate jitter. Left: Histogram window. Right: Constructing the histogram of occurrences.

There are a number of disadvantages of this approach. The biggest one is depth, or the fact that the source of data shows so little of what is really going on. Most sampling scopes take data at the rate of a hundred kilo-samples per second. The best (including the BERTScope eye diagram) are in the mega-samples per second range. The input data can be flying by at 10 Giga bits per second, meaning that there are millions of bits going past between samples that are never measured. In addition, a jitter histogram such as is shown on the right of Figure 1 is constructed from a window that encompasses only a small percentage of the samples made for each waveform. The resulting histogram is a very sparse representation of the true jitter picture.

To get a clearer picture of true system performance, it is necessary to include lower probability events in the overall picture. Many standards require the use of long patterns for test purposes, such as 2^{31}-1 PRBS, a pattern containing over 2 billion bits. The most jitter-inducing sequences in the pattern typically only repeat a few times a second, and so their effects are very likely to be missed in a shallow jitter measurement. Similarly the effects of random events such as noise are also unlikely to be observed at the maximum extent of their reach into the center of the eye. When all events are included, a picture such as shown in Figure 2 is likely to emerge. The real eye opening, including all events, will be smaller than is shown in a shallow eye diagram, but this deep measurement picture shows the real operational environment.

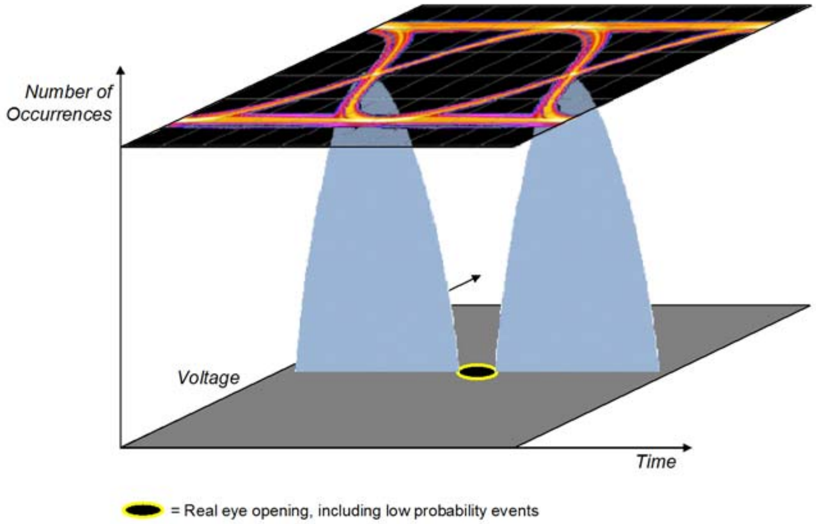

Figure 2: Viewing the eye crossing points with low probability events included. The true eye opening is smaller than is seen on a sparsely sampled eye diagram.

Viewed in this way, it becomes much easier to see why different sampling scopes yield different jitter results. For example, in Figure 3, two histograms are shown of jitter measurements, overlaid on a representation of the true underlying jitter picture. The left one is the quick shallow measurement of Figure 1. The right hand measurement might be the same instrument left to run for many hours, or might be a quick measurement taken on an instrument with more efficient sampling such as a BERTScope eye diagram. This explains why jitter measurements on scopes grow in magnitude the longer they are left to run. Jitter measurements are almost meaningless for comparison unless they have some indication of the depth associated with them. This has been recognized in many standards, and an industry accepted depth has been arrived at, as we'll see.

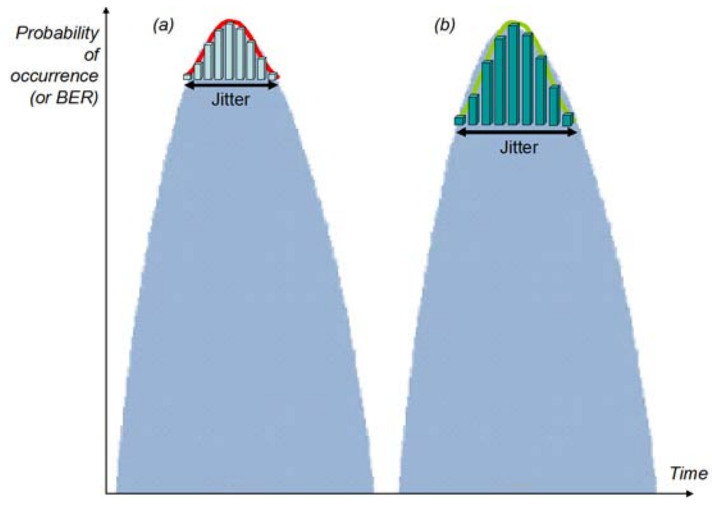

Figure 3: Two different shallow jitter histograms, overlaid on the true jitter distribution. (a) might be the measurement of Figure 1. (b) could be the same measurement left to run for many hours, or a measurement taken with a more efficient sampling regime.

In reality, component and system designers are usually required to state performance at much lower probability levels. Here, the term 'number of occurrences' and 'probability of occurrence' are proxies for

BER, or bit error ratio. Many standards require the measurement of the eye closure to assure a BER performance of $1x10^{-12}$ (i.e., at a very low frequency of occurrence).

Even for a BER based instrument measuring every bit in a data stream, measuring down to low BER levels can be time consuming. It is therefore useful sometimes to cut corners and extrapolate. Such a measurement is shown in Figure 4. Here, the total jitter (TJ) is shown at $1x10^{-12}$ level by extrapolation – however it is intuitively obvious that the smaller the extent of extrapolation, the more accurate the result. Note the estimated depth of the sampling scope histogram, and the fact that the shallowest BER-based measurement begins considerably deeper than this.

Given that usually many jitter mechanisms are at work in any given crossing point, the best way of extrapolating such a histogram has been the subject of much effort, resulting in many different algorithms and models. The most well known is probably the dual-Dirac model given by MJSQ[i]. This provides two benefits that are relevant here – a model that allows extrapolation of jitter down to low BER levels, and a method of dividing that jitter result into two sub-components, random jitter (RJ) and deterministic (DJ). Much has been written on this subject that will not be repeated here. It should be noted, however, that the most accurate measurement of jitter requires neither of these – the best result is to actually measure the eye opening at the required BER level directly using a BER-based instrument. There are no assumptions or models required – the values are read off directly.

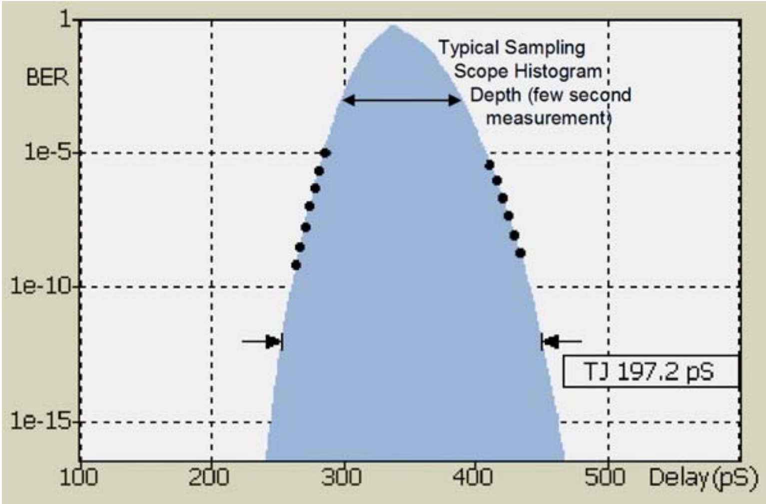

Figure 4: A BER-based jitter measurement, also known as BERTScan, bathtub jitter or Jitter Peak. Note the estimated depth of a typical scope-derived histogram. Note also that the BER-based measurements at their shallowest start considerably below the scope histogram depth.

It is easy to verify a jitter prediction such as is shown in Figure 4. The measurement gives an eye opening width at a BER level of $1x10^{-12}$. Moving the instrument's BER decision point to the time setting predicted, it is then straight forward to verify the point on either side that yields a BER of $1x10^{-12}$. An example is shown in Figure 5 (signal unrelated to example in Figure 4).

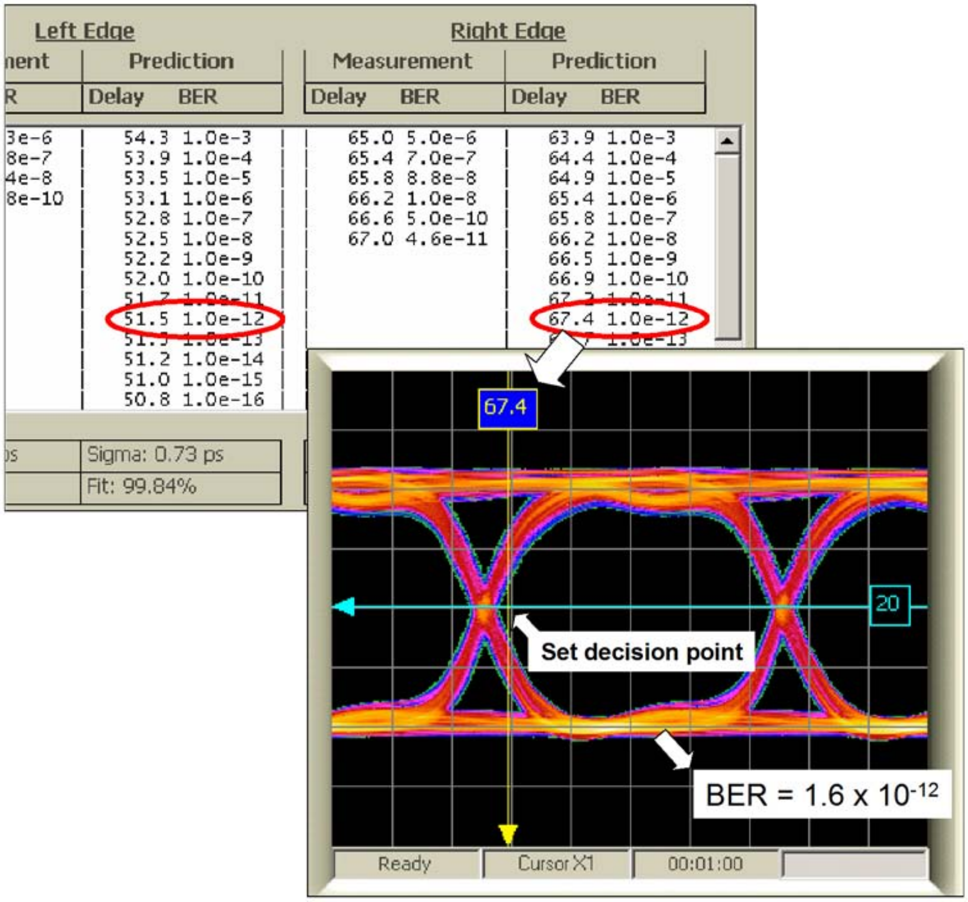

Figure 5: Verifying the $1x10^{-12}$ eye opening width by setting the BER decision point to the predicted position and measuring BER.

With a direct measurement, the main limitation on accuracy is then the input bandwidth of the BER-measuring instrument. For signals with low amounts of jitter, the intrinsic jitter floor of the measuring instrument must also be considered. It is not usually intuitively obvious which instruments have the lowest intrinsics. For example, real-time oscilloscopes tend to have relatively high amounts. Sampling scopes and BERTs tend to have lower levels, although this varies between models. Use of enhanced time bases can help. The BERTScope has an intrinsic jitter level between that of a standard sampling scope, and of one used with an enhanced time base.

It is possible to compare the result from a sampling scope histogram and fit it to the now-verified jitter curve. This gives an idea of exactly the depth of measurement achieved on the sampling scope. Figure 6 (upper) shows a manually configured jitter histogram on a sampling scope. The measurement was left to run for 1 minute, and the tab gives an idea of how many points make up the histogram. The BER-based measurement (lower) of the same signal was also run for 1 minute, and is shown with the measurements made by the scope superimposed on it. Using the BER scale it is possible to guess that the scope measurement reached down to between $1x10^{-3}$ and $1x10^{-4}$. There is a rough correlation between this and the number of data points making up the histogram (in this case $5x10^{3}$).

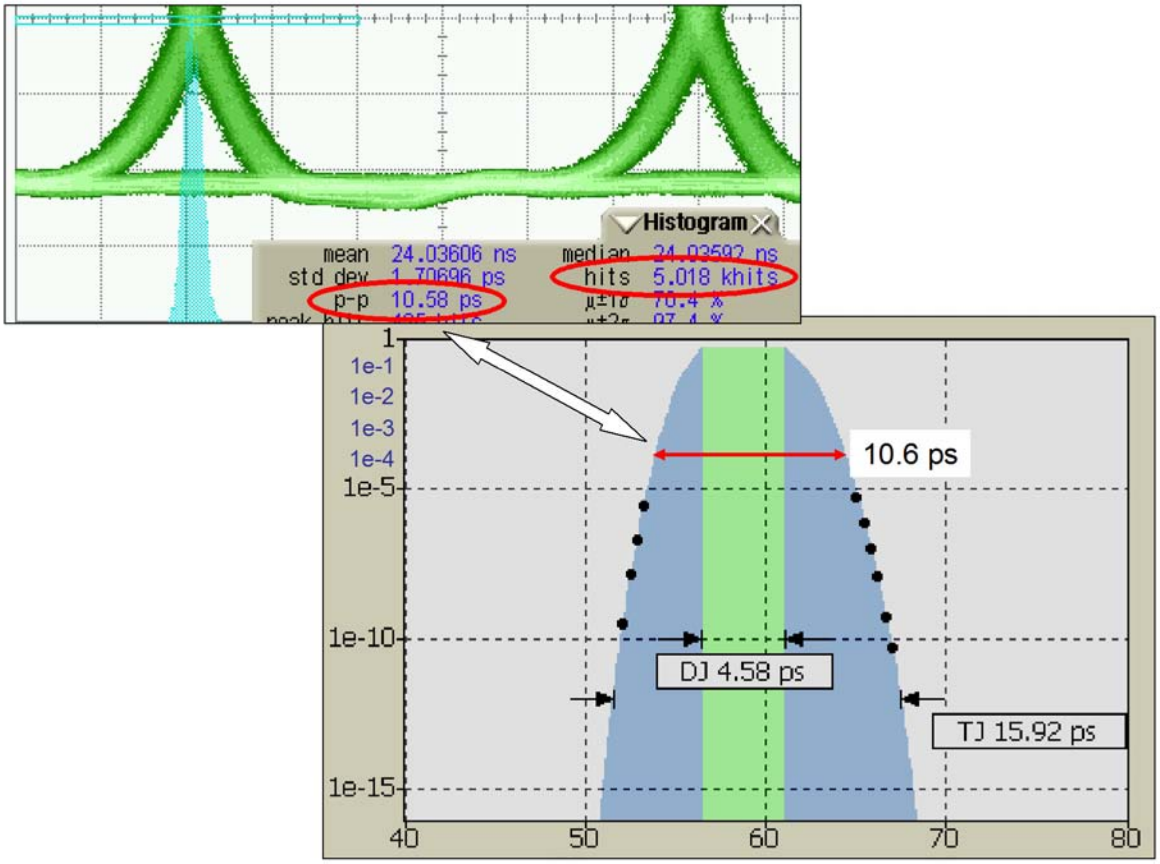

Figure 6: Correlating between a sampling scope histogram measurement measured for 1 minute (upper) and BER based jitter measurement (lower).

It should be noted that although jitter histograms are the most commonly used method of measuring jitter on sampling scopes, they are not the only method available on modern instruments. However, for standards compliance work requiring the use of medium and long patterns, they are still the only practical method on such instruments.

Summary

We've looked at jitter histograms and how they relate to the true jitter picture in an eye diagram. We've seen how the depth of measurement has a significant affect on the result, and also introduced the idea of BER-based jitter measurements.

References

i MJSQ - Methodologies for Jitter and Signal Quality Specification is a document written as part of the INCITS project T11.2. Hhttp://www.t11.org/index.htmH

ii Jitter is also discussed on the poster: 'The Anatomy of an Eye Diagram', SyntheSys Research, October 2004 – available at Hwww.bertscope.comH

iii For an introduction to BER Contour and a deeper look at the interior of an eye diagram: 'Bridging the Gap – A BER Contour Tutorial', SyntheSys Research, October 2004. Available at Hwww.bertscope.comH