BERTScope™
The Vision of a Scope, the Confidence of a BERT

The Importance of Delay Line Accuracy in Making Direct BERTScan Measurements

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Introduction

Many standards use the BERTScan, or BER Bathtub, as the compliant method for measuring jitter. These include MJSQ[i], Fibre Channel, Gigabit Ethernet and many others. Some standards specify that the operating jitter performance must be measured down to a BER of $1x10^{-12}$. Others allow some degree of extrapolation from measurements made at higher equivalent BERs, acknowledging that the accuracy will be lower. This paper will give some practical ways of quantifying the suitability of an individual instrument for making accurate and repeatable direct measurements to a specified BER level.

The Importance of Accurate Delay Control

Instruments that measure Bit Error Ratio (BER) directly, rather than estimating it, have a long history of being regarded as the final say in assessing link performance. By measuring every single bit passed by a system, they are both efficient and difficult to fool. Typically the bit by bit judgment is made with a decision circuit. The placement of the decision point within the bit period is accomplished with some kind of delay line that delays the incoming delay with respect to the reference clock being used. In legacy high speed BERTs, the aim of the delay system was to place the decision point roughly in the center of the eye, so that the instrument could count errors. The accuracy and repeatability of the delay setting was not a critical feature. This changed when people started to characterize parametric performance by exploring the boundaries of the eye diagram with measurements such as BER Contour, Q Factor and BERTScan, or Bathtub jitter. Such measurements rely on accurately mapping the position and slope of bit edges, and repeatability, small step size and accuracy are all key attributes to good measurements.

What Can Go Wrong?

Early practitioners of BERTScan jitter measurements quickly found that legacy BERT systems weren't up to the task, and instead they would use external trombone delay lines. These were slow mechanical devices unsuited to the expected speed of operation of modern measurements, prone to mechanical failure over time and often difficult to automate. Since then, modern BERT systems have emerged with greater accuracy and smaller step sizes. However, all are not equally equipped to give good measurements, and methods of verification can help users make accurate judgments.

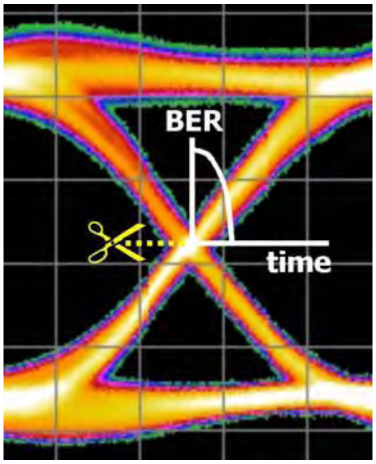

Figure 1: BERTScan measurement of jitter where the BERT decision point is scanned horizontally (in time) through the eye crossing point.

The BERTScan method of jitter measurement is widely employed, and detailed in standards such as MJSQ. Direct measurement relies on stepping the BER measuring decision point through the crossing point of the eye horizontally in time (Figure 1). It uses the measurements taken to define the jitter at a specified BER operating point, commonly 1x10^{-12}, and also to separate random and deterministic forms of jitter. Any errors in the measured points used to construct the BERTScan graph can throw the math off significantly. This is particularly true when measurements are extrapolated down to the final result when there is not enough time available for a direct measurement. As is illustrated in Figure 2, small variations in the accuracy of the points at high probability can have a big effect on any extrapolation to low probability levels such as 1x10^{-12}.

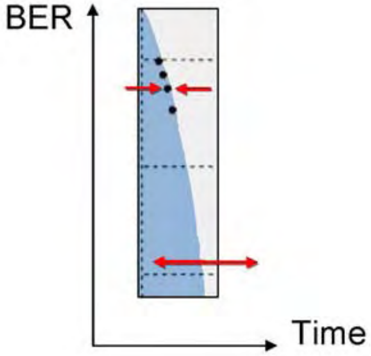

Figure 2: The small variations in points taken at high BER levels can have big effects on the answer for low BER levels such as 1x10^{-12}.

Usually the delay function in a BER instrument is accomplished with a combination of fixed length paths of different lengths that are switched in and out to get approximately the correct delay, and then fine adjustment with a variable delay element such as a varactor. The delay transfer function is a function of the sum of these delays. Ideally it should be linear, with the graph of delay requested against delay achieved being a straight line as is shown in Figure 3(a). However, this is almost impossible to achieve over all operating bit rates, temperatures etc. and is more likely to look like one of the curves in Figure 3 (b). Such responses would obviously have a major impact on any BERTScan graph and ensuing calculations.

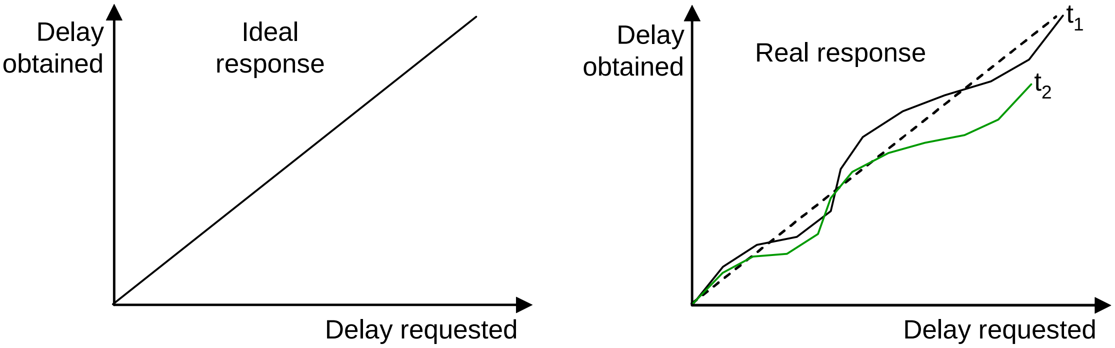

Figure 3: Delay transfer functions – (a, left) ideal, (b, right) real at two different operating temperatures.

Real responses deviate from the ideal because of:

- Non-linearity
- Hysteresis
- Variation with time
- Variation with temperature

The usual approach in engineering to this kind of problem is to calibrate the response so that a correction table can be used. Indeed, this is the approach typically taken by BERT makers to ensure that they can provide a linearized response. Where this often goes wrong is that calibration is done once, at the factory, at a single temperature. Once out in the field, the calibration can be of little value at the time, temperature and bit rate that the instrument is required to operate. This is one reason that the BERTScope family carries out fast, on the spot delay calibrations at the exact temperature and bit rate that the measurement will be made.

Methods for Validation

We are going to look at two methods of validation, one to measure the variation in delay line linearity across the delay range. The second is a way of validating the eye opening and total jitter (TJ) at the operating BER.

Method 1 – Delay Line Linearity

BER measuring instruments are usually purchased with pattern generator (PG) and error detector (ED) functions. The ability to move the clock to data delay is available on both – as discussed above, the error detector delay is now frequently used for measurements such as BERTScan and requires high accuracy. The pattern generator delay function is used much less frequently, and for much less exacting needs – usually to equalize path lengths between cables carrying clock and data. The validation method described here is going to use the PG delay as a way of exploring the ED delay response.

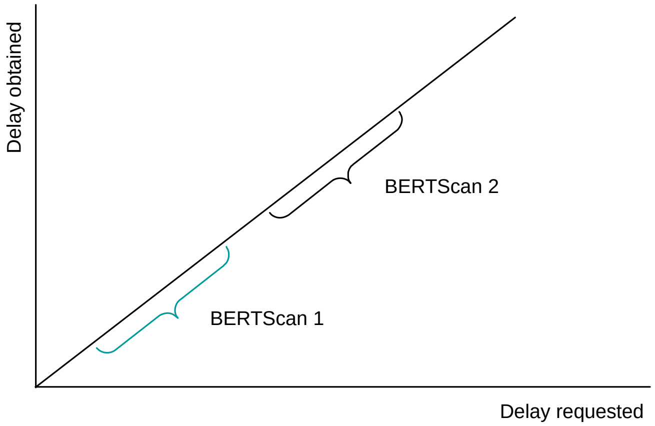

Figure 4: 'BERTScan 1' and 'BERTScan 2' are two measurements of the same device, taken using two different regions of the ED delay response. They should both give the same jitter result if the relationship is linear.

A BERTScan measurement involves moving the decision point in time through the eye crossing point. The experimental setup will have inherent physical delays that will dictate which, of potentially any, region of the ED delay response will be used in the BERTScan measurement, as shown in Figure 4. Changing cable lengths in either clock or data path of the physical setup will cause a different part of the ED delay response to be used – obviously the jitter measurement should yield the same result in every case, as the device inherent jitter has not changed significantly. Any non-linearity present will lead to different jitter results.

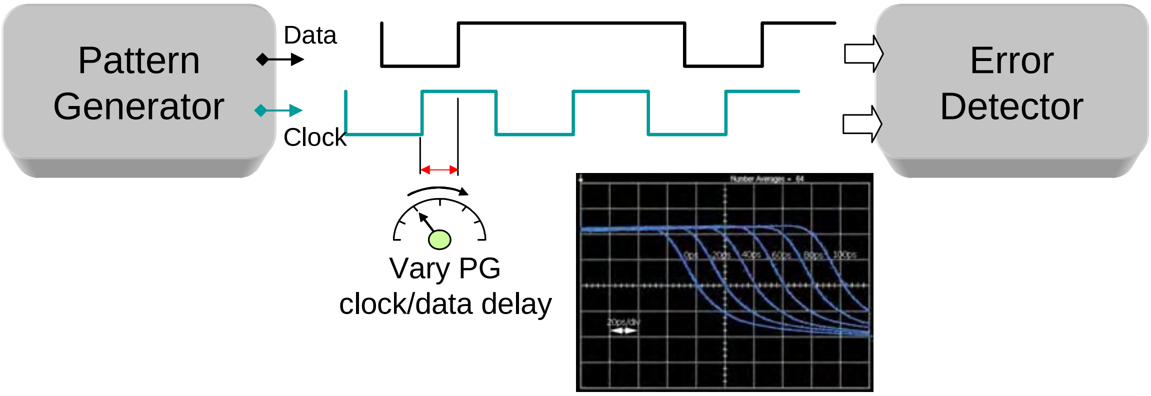

Figure 5: Using the PG delay function to explore the ED delay linearity

In reality we don't have to vary cable lengths for this experiment. Instead we can use the PG delay function to do the same job, with much greater ease, and a finer step size than could be practically achievable otherwise. As is illustrated in Figure 5, the relationship between PG clock and data is varied. At each point, the ED is used to carry out a BERTScan measurement, the results noted and then the PG delay moved again.

Measured Results

We have carried out this kind of evaluation on our own BERTScope instrument and other instruments available today. The results for a BERTScope are shown in Figure 6. In this kind of evaluation the absolute value of measured jitter is not important – it is the variation we are using to judge accuracy and repeatability. Obviously the ideal result would be a flat line. These results were taken over approximately 1 UI at the bit rate of 10.709 Gb/s. We observed significantly greater variation on other systems, with one in particular dubbed "dial-a-jitter" as it was possible to record significantly better or worse jitter results simply by choosing an appropriate point in the ED delay response to make the measurement with. This is obviously far from desirable in a measuring instrument.

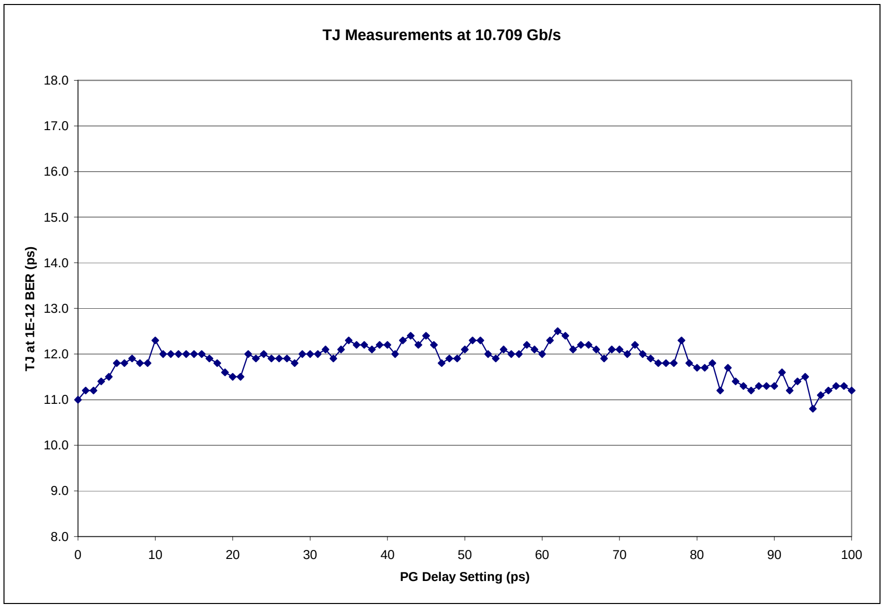

Figure 6: *Measured response variation of example BERTScope when the PG delay is varied and ED used to make Total Jitter (TJ) measurements.*

Another telltale sign of delay issues is the appearance of discontinuities in BERTScan measurements such as those shown in Figure 7.

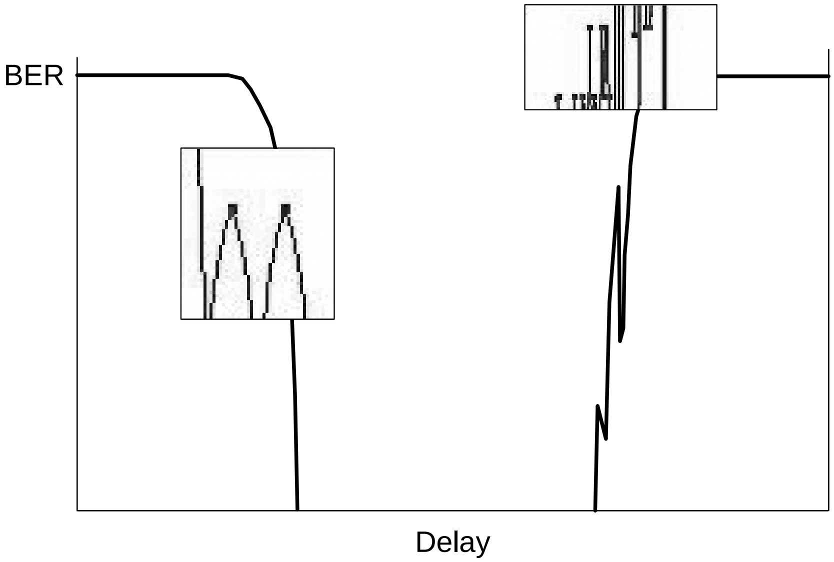

Figure 7: *Example discontinuities seen in BERTScan measurements – a sure sign that the delay line integrity of the instrument is suspect*

Method 2 – Eye Opening at Specified BER

This validation is a little different to Method 1 in its aim, and is included here mainly because it is not particularly well known. It is a way of gaining confidence in total jitter measurements through direct measurement of BER.

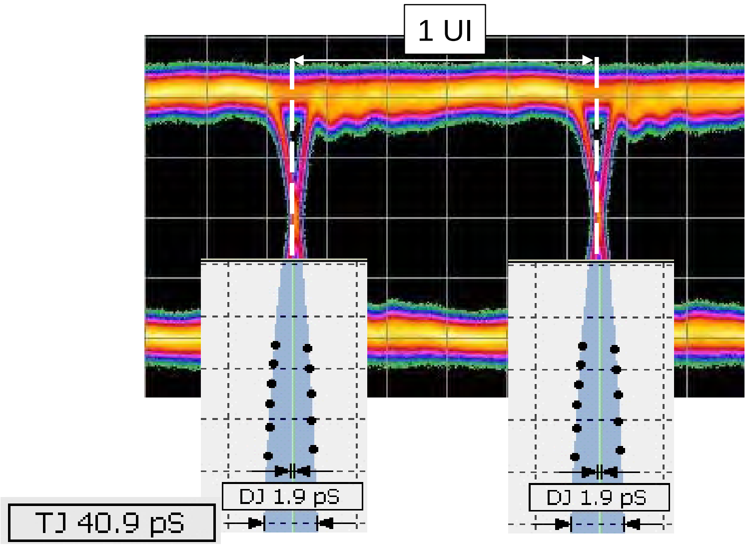

Figure 8: Relating BERTScan to the eye diagram

A BERTScan measurement, such as the BERTScope's Jitter Peak, measures the eye closure due to jitter at a BER level of 1x10^{-12}. The eye opening is therefore the period of 1 unit interval (1 UI or one bit period) minus the total jitter (TJ) figure in picoseconds. This is shown in Figure 8.

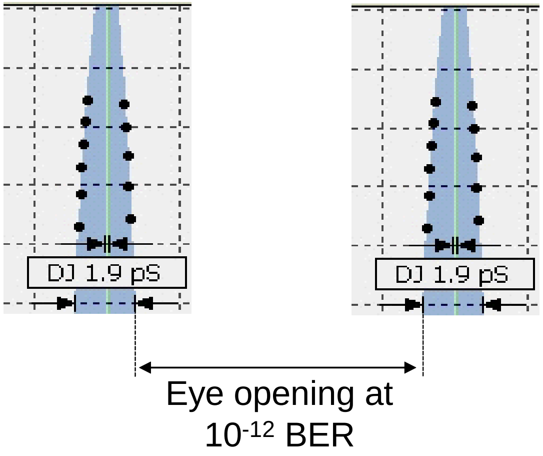

Figure 9: Relating TJ at a specified BER to the eye opening.

The BERTScan measurement gives information on the delay settings where the 10^{-12} extremes of the data edges lie (Figure 10). Using markers, it is then possible to set the BERT sampling point to one side of the jitter peak or the other, and measure BER. If this is the point that the BER measures 1x10^{-12}, then the TJ measurement is obviously correct.

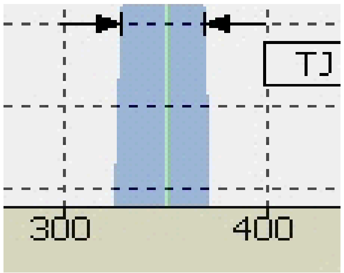

Figure 10: Delay Settings can be derived where the 1x10^{-12} edges of the data lie.

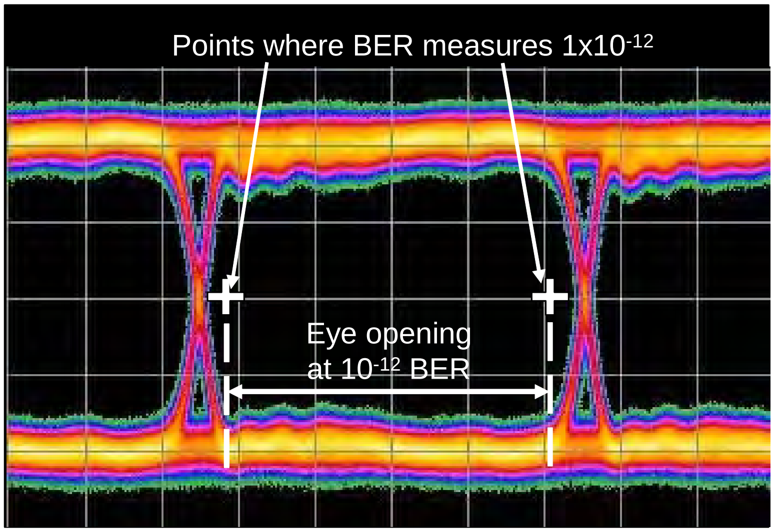

Figure 11: Moving the BERT sampling point to measure positions where BER equals 1x10^{-12}.

Validations such as this can be used to verify direct jitter measurements, and also the effectiveness of extrapolated predictions of the 1x10^{-12} level Total Jitter.

References

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