1 Annex 48B (Jitter Test Methods)

This annex specifies the definitions, measurement requirements for the jitter specification of the XGXS, XAUI described in Clause 47 and the 10GBASE-LX4 PMD described in Clause 53. These measurement methods and specifications are intended to be used for jitter and wander compliance testing, but are not definative.

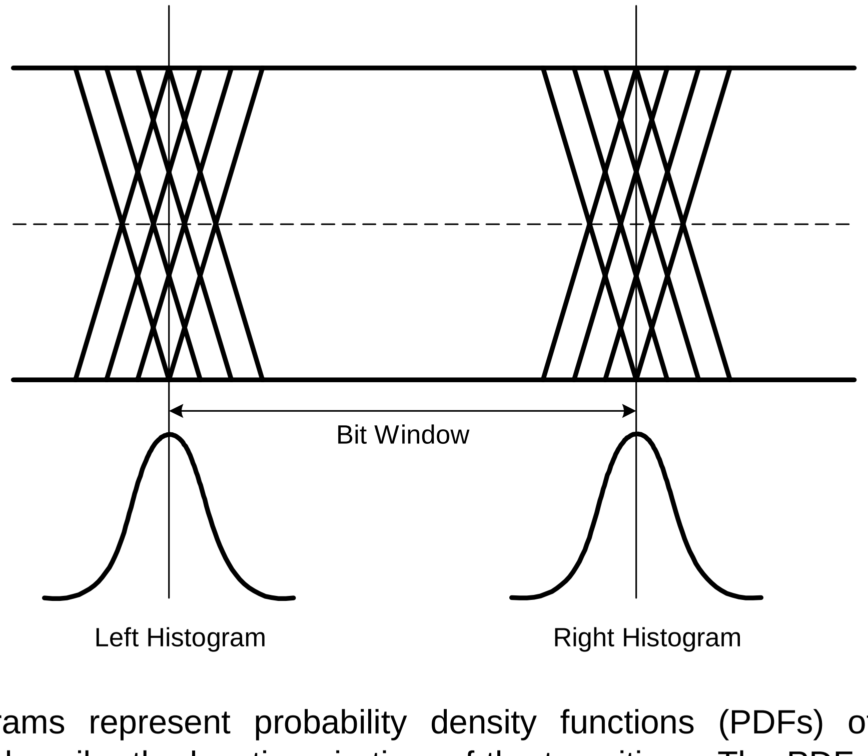
1.1 Bit error rate and jitter model

Measurement of bit error rate within a data eye is a valuable tool to infer jitter properties. Insight into the relationship between jitter, eye opening and error rate can be gained through mathematical modeling.

1.1.1 Description of Dual Dirac Mathematical Model

Figure 1, considers a typical eye diagram that may be seen on an oscilloscope. For the purpose of discussion, assume that an ideal trigger source is used so that the eye is accurately depicted. Jitter is indicated by distributed transitions (crossings) of the threshold as the data toggles between logic states. Histograms of transition regions can be taken at the threshold level. The width of the histograms can then be estimated, including standard deviation, etc.

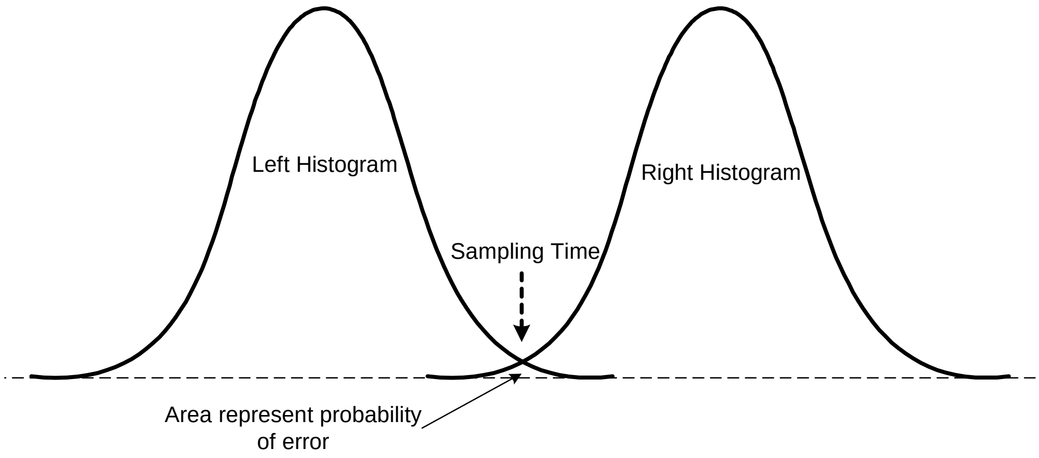
Figure 1 Eye Diagram Sketch



The histograms represent probability density functions (PDFs) of the jitter and statistically describe the locations in time of the transitions. The PDFs are placed with their means at the ideal transition times of the logic states. To simplify matters, the time scale is given in terms of unit intervals (UI) with 0.5 located at the exact center of the eye. The means of the two PDFs are at 0 and +1 UI.

Ideally, the receiver samples the eye at the center where the tails of the transition histograms are small, as shown in **Figure 2**. To calculate the probability of either transition causing an error due to jitter, the area under its PDF tail on the errored side of the sample point (time) must be calculated. This is the complementary cumulative distribution function, or CDF. For the left hand PDF, the tail is integrated from to the sample point to $+\infty$; the right hand PDF's tail is integrated from $-\infty$ to the sample point. The overall probability of transition error is the sum of the two CDFs. It is assumed tha the tails of the neighboring bits do not contribute to the probability of error.

Figure 2 Eye Sampling and Probability of Error



To determine the bit error rate (BER), the probability of a transition-caused error must be multiplied by the probability of a transition occurring. Nominally, the latter may be seen as the average transition density. This model assumes typical data streams have a transition density of 50%.

To demonstrate these concepts, define a general jitter PDF, $JT(\tau, W, \sigma)$, centered at 0, where τ is time, W is the pk-pk value of deterministic jitter, and σ is the rms value of random jitter. The left PDF histogram (centered @ 0) causes bit errors as

$$BER_{left}(\tau_{sample}, W, \sigma) = \Gamma_{transistion} \cdot \int_{\infty}^{\tau_{sample}} JT(\tau, W, \sigma)\delta\tau$$

where τ_{sample} is the sampling instant in time, and $\Gamma_{transistion}$ is the transition density. Similarly, the right PDF histogram (shifted and centered @ 1 UI) causes bit errors as

$$BER_{right}(\tau_{sample}, W, \sigma) = \Gamma_{transistion} \cdot \int_{\infty}^{\tau_{sample}} TJ(\tau - UI, W, \sigma)\delta\tau$$

The sum of these two functions provides the total bit error rate (BER) due to jitter,

$$BER_{total}(\tau_{sample}, W, \sigma) = BER_{left}(\tau_{sample}, W, \sigma) + BER_{right}(\tau_{sample}, W, \sigma)$$

In the BERT scan, BER is measured as the sample point, τ_{sample}, is swept between the two eye crossings. The probability of error as a function of the sample point is commonly known as a BER bathtub curve.

1.1.2 Random Jitter

For random or Gaussian jitter (RJ) only the standard deviation, σ, is neccessary to define the PDF

$$RT(\tau, \sigma) = \frac{1}{\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot e^{-\left(\frac{\tau^2}{2\sigma^2}\right)}$$

The CDF for this Gaussian PDF function is the complementary error function (erfc).

1.1.3 Addition of Deterministic Jitter

Total jitter is comprised of both random and deterministic components. The DJ component can be defined, as for RJ, by a PDF, where the combined total jitter PDF is a convolution of the DJ and RJ PDFs.

For purposes of simplification of the dual dirac model, it is assumed that the DJ PDF is comprised only of a pair of delta functions. Other PDFs are certainly possible, however, in the prediction of low BERs, this simplication is sufficient.

The pair of delta functions can be visualised as a pure duty cycle distortion (DCD). Which when convolved with RJ results in two Gaussian functions, each one centered at the delta function of DJ pdf.

The magnitude of the DJ, is given as peak-to-peak amplitude, W. Therefore, each delta function is offset from the mean crossing position by the peak value of DJ, W/2. The PDF for deterministic jitter, centered at 0, is therefore defined as

$$JT(\tau, W, \sigma) = \frac{\delta\left(\tau, -\frac{W}{2}\right)}{2} + \frac{\delta\left(\tau, \frac{W}{2}\right)}{2}$$

When convolved with random jitter, the PDF, centered at 0, becomes

$$JT(\tau, W, \sigma) = \frac{1}{2\sqrt{2\pi}} \cdot \frac{1}{\sigma} \cdot \left(e^{-\left(\frac{\left(\tau - \frac{W}{2}\right)^2}{2\sigma^2}\right)} + e^{-\left(\frac{\left(\tau + \frac{W}{2}\right)^2}{2\sigma^2}\right)} \right)$$

1.1.4 Approximate curve-fitting for BERT scan

Section 1.3.1.3 describes a technique for using a BERT scan to determine eye opening and jitter. For highest accuracy, the bathtub curve should be measured over a high number points at low BER and curve-fitted with a least-squares method to estimate equivalent DJ, RJ, and TJ values. However, a simple and fast method for estimating these values may be applied using only 2 measurement points.

The following steps describe a process for estimating equivalent RJ, DJ, and TJ values from a 2 point BERT scan measurement:

a) Measure the eye opening at 2 different bit error rate, $BER_0 @ \tau_0$ and $BER_1 @ \tau_1$ (e.g 10^{-9} and 10^{-5}).

b) For each BER_n, determine the associated Q_n from the inverse normal cumulative probability distribution. e.g. $Q = 3.99$ for $BER = 10^{-5}$

c) Calculate the individual jitter components using **Equation [1]**, and **Equation [2]**. The total jitter for the given $BER = 10^{-12}$, is then given by **Equation [3]**

Random Jitter [1]

$$RJ_{RMS} = 0.5\left|\frac{t_1 - t_0}{Q_1 - Q_0}\right|$$

Deterministic Jitter [2]

$$DJ = UI - t_0 - (2Q_0 RJ_{RMS})$$

Total Jitter [3]

$$TJ = DJ + 13.73 \cdot RJ_{RMS}$$

Note: The minimum value for measured BER is constrained by test time (10 errors are suggested as an absolute minimum to get reasonable statistical confidence); the maximum value is constrained by potential de-parture of actual results from the assumed curve fit shape ($BER = 10^{-6}$ *should be maximum value used).*

1.1.5 Effective deterministic jitter

Simple pk-pk is insufficient as the requirement for DJ. An overall weighting function that captures not only the pk-pk but the shape of the density function is required for DJ. This may be known as "effective DJ" and can be determined or derived from the bathtub curve. Effective DJ is based on a Dual-Dirac function, as explained above. Therefore, all references in Clauses 47 and 53 to DJ should be understood as effective DJ.

1.1.6 Effects of jitter high-pass filtering and CJPAT on deterministic jitter

It is understood that CDRs track low frequency jitter, and that including this effect in the specifications could ease requirements on clock oscillators (lower cost designs tend to exhibit low frequency RJ), serializer (SERDES, same advantage) designs and switching power supplies, layouts, bypassing, etc. All jitter output specifications include the effects of a high-pass filter (to suppress the significance of low frequency jitter) to emulate CDR tracking.

It is also realized that, due to frequency content, long complex patterns cause phenomena that are not observed with short patterns - data dependent jitter (DDJ, a form of DJ) can have extreme ranges of frequency content from well below to well above the CDR corner frequency. Effects are usually seen in both transmitters and receivers. Jitter test patterns are specified in Annex 48A.

1.2 Jitter tolerance test methodologies

An important measurement in determining link integrity is the characterization of a receiver's (i.e. CDR's) ability to tolerate jittery inputs yet recover error-free data. This is accomplished by inputting a well controlled, jittery signal to a CDR while measuring the BER at the output of the CDR. As the source signal is modified in amplitude and spectral content, the change in BER is measured. This section describes some useful test methodologies for testing a receiver's jitter tolerance.

1.2.1 Calibration of a signal source using the BERT scan technique

The jitter model described in **Section 1.1** can be used to calibrate the signal source for tolerance measurements as well as to provide a method for extrapolating lower bit error rates. In this approach curve fitting of the dual dirac model onto bathtub curves derived from BERT Scans give the jitter content.

Figure 3 BERT Jitter Tolerance Source

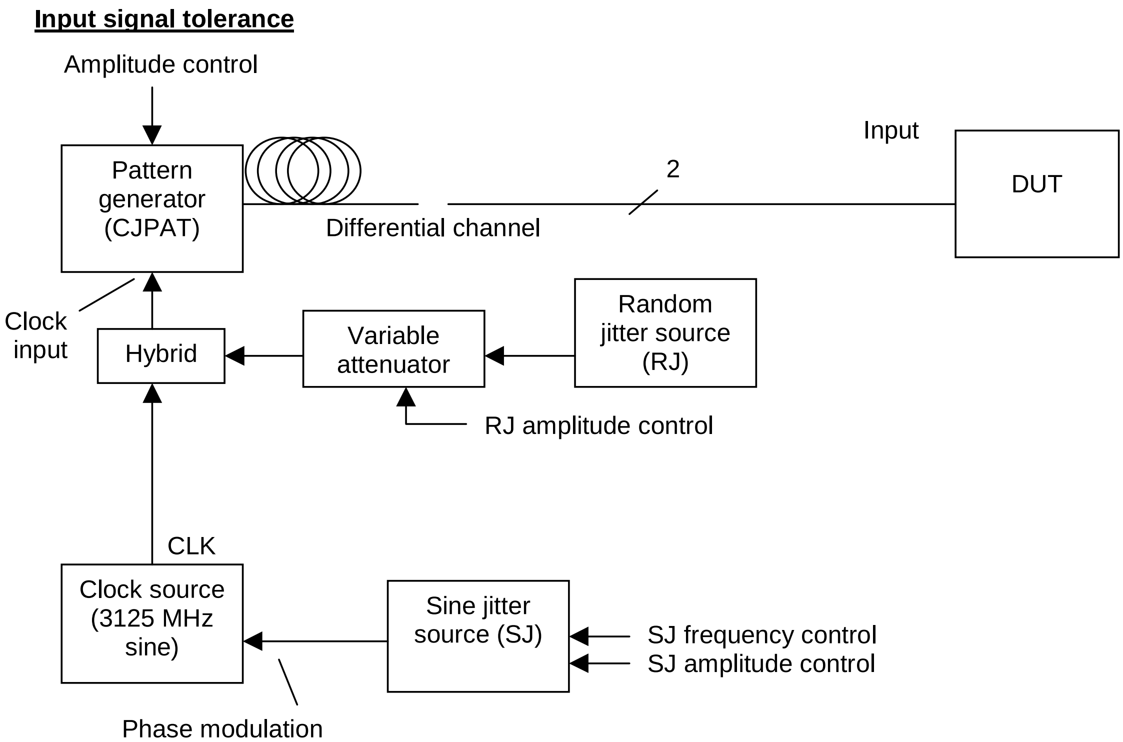


Figure 3 shows an example of how to generate controlled amounts of jitter in a signal to be used for tolerance measurement[1]. Three sources of jitter are provided: Deterministic (DDJ and sinusoidal (SINE)) and Gaussian (RJ). Each of these is added to the serial signal generated by a BERT Pattern Generator. A sinewave generator modulates the clock to the Pattern Generator to provide Sinusoidal jitter modulation from 10 Hz to 5 MHz. A filter or cable adds deterministic jitter. A white noise source[2] with a bandwidth between 500 and 1000 MHz[3] is added to the signal to provide random jitter. Amplitude calibration is not possible on a scope due to the low probability of the pk-pk RJ effects.

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1) Beware of calibrating instrument noise floors and data dependencies, as these may lead to test signals with less stress than intended.

2) RJ must be Gaussian and not clipped out to >BER being tested (spec is 1E-12). Simply measuring the rms value does not guarantee that the tails exist and that the Rx will be sufficiently stressed as specified.

3) The spectrum of the portion of RJ that is calibrated must be from greater than 20MHz. The sketch as shown assumes the pattern generator passes clock input jitter through to the data with >>20 MHz BW. This may not be the case. The RJ spectrum need not be white above 20 MHz, but a wider spectrum is preferred.

For better visibility for amplitude calibration, the RJ portion should be replaced with an equivalent amount of pk-pk SJ to bring TJ up to the same specified output jitter level, allowing, the desired amplitude value to be met[1) 2)]. The output of the setup has controlled amounts of the three types of jitter which can then be used for receiver tolerance testing. If the clock data recovery circuit has a corner frequency above the maximum sine wave generator frequency, be sure to increase the amount of the applied deterministic jitter by the amount of the expected sinusoidal jitter.

When calibrating the jitter source, care should be taken to High Pass Filter the time jitter in the trigger path to calibrate out any jitter with frequency content below the specified corner frequency.[3)]

It should be notes that the XAUI is a differential input and calibration of the test signal must be performed using the differential signal. Where test equipment only provides single ended possibilities, care should be taken to use balan to convert differential signals to single ended signals. Single ended signals should not be directly used due to asymetric characteristics.

1.3 Jitter output test methodologies

Three viable methodologies for measuring jitter output are described in this section.

1. Time domain measurement using an oscilloscope to characterise the data eye.
2. Time domain measurement using BERT scan by moving of the data sampling point within the data eye.
3. Time interval analysis based on accurate measurement of the time interval between threshold crossings of the transmitter waveform;

1.3.1 Time Domain Measurement - Scope and BERT Scan

The advantage of time domain measurement is its ease of understanding and its coverage of both voltage amplitude and time eye closure. It is easy to grasp that if the eye is larger than the eye mask, it must be ok. This is not necessarily true. Given the probabilistic nature of random jitter, it is necessary either to test for an extended amount of time to reach a high confidence level for achieving 1×10^{-12} bit error rate or to perform some kind of statistical extrapolation.

The following technique can be used to measure the total jitter for achieving 1×10^{-12} bit error rate. Total jitter includes the deterministic jitter and the random jitter. This technique uses the basic assumption that only the tails of the jitter distribution are truly Gaussian and that all other sources are bounded and deterministic.

1) Amplitude calibration should be done before addition of SJ, as SJ is designed to add margin into the design.
2) It may be required to add an amplifiction stage to achieve the required test signal amplitude.
3) Beware of autocorrelation effects.

In this approach, a jitter histogram is collected by any means (sampling scope, time interval analyzer, BERT, etc.). The best-fit Gaussian distributions for each tail are then determined. Because this total jitter histogram is assumed to be the convolution of some tailless deterministic jitter distribution with a single Gaussian random component of jitter, the σ of each tail is assumed to be equal. However, since the deterministic component is, in general, not symmetrical, the μ of each tail will not be equal. DJ is defined to be the distance between the μ of each tail and RJ is defined to be 14σ.

1.3.1.1 Jitter High Pass Filtering (using Golden PLL)

Due to the issues mentioned in **Section 1.1.6** when testing either at the component level or the system level, the test clock should be derived from the data with a given high pass filter function of the jitter using, for example, a golden PLL.

Given a typical test setup, the serial bit pattern is transmitted to the input of a BERT and a golden PLL. The golden PLL extracts a reference clock to trigger the sampling scope. The golden PLL tracks low frequency jitter from the unit under test and triggers the scope correspondingly such that the only data collected is in the desired frequency range. For the most adverse testing conditions, the unit under test should operate its receive port asynchronously from its transmitter port under test. The test then also accounts for any interaction which may occur between the receiver and the transmitter.

1.3.1.2 Time Domain Scope Measurement

Time domain measurement uses the high speed sampling scopes to view the jitter output data eye. Most high speed sampling scopes today provides features to collect and present data on the output jitter. Some oscilloscopes provide a feature to compare the measured data to an “eye mask.” An eye mask is a specification for allowed eye opening. The advantage of an eye mask is that it tests for amplitude as well as timing compliance. The general physical media transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram at any of the compliance measurement points. These characteristics include rise time, fall time, pulse overshoot, pulse undershoot, and ringing, all of which prevent excessive degradation of the receiver sensitivity. For the purpose of an assessment of the transmit signal, it is important to not only consider the eye opening, but also the overshoot and undershoot limitations. The parameters specifying the mask of the transmitter diagram (eye mask) can be found in the clause of the applicable physical layer specification whether it be copper or fiber physical media. The eye mask through its use of a specified time range in which the transmit signal can change state from the logic low to logic high levels is also specifying a measure of the allowed jitter.

The eye pattern measurement procedure is valid only when the data clock can be derived or accessed and the total jitter is less than one unit interval. Thus, generally, the eye pattern test using the eye mask is valid for evaluating jitter when the jitter frequencies of interest are restricted to values above the response corner frequency of the clock recovery circuit as defined by the jitter tolerance mask.

It is strongly advised not to use the eye mask to verify that total jitter is within specification because of the nature of the test. The eye mask test is generally a short test and thus the eye diagram is not captured for a sufficient time to capture the full extent of the random jitter's peak to peak value. It is necessary to capture the eye pattern for a sufficient period to insure the full extent of the deterministic jitter is captured by the test instrument. Since the peak to peak of the random jitter for a BER of 1×10^{-12} is 14 times the sigma, it is not possible to measure the full peak to peak value of the RJ. The effective sampling rate of the oscillascope must be calculated and the width of the eye mask adjusted accordingly.

1.3.1.3 BERT Scan

A BERT Scan can be used to characterize the interconnect as it relates to bit error rates. In doing so, it obviates the need for determining the quantity of RJ and DJ components.

The BERT Scan approach when used in conjunction with the jitter model of Annex A can provide random and deterministic jitter components and provides a mechanism to extrapolate to lower Bit Error Rates (less than 1×10^{-12}) without impossibly long test times.

1.3.2 Time Interval Analysis

No text available.