Technical Brief

Eye Diagram Measurements Using TDR Oscilloscope Transmission Data

Introduction to TDR Eye Diagrams

Eye diagram is becoming a key figure of merit for most computer and communications system standards, including Gigabit Ethernet, Sonet, Infiniband, Rapid IO, PCI Xpress and others. Even though some designers would rightfully argue that insertion and return loss are more important and representative of the performance of the interconnect at a given speed, eye diagram provides a clear visual representation of whether the interconnect by itself would meet the eye diagram test specification for a given standard.

Because contribution of an interconnect to overall system jitter is deterministic, and is defined by the interconnect losses and pattern-dependent crosstalk-induced jitter, it can be directly derived from either transmission or transmission and crosstalk measurements. Because the complete eye diagram test setup, including a pattern generator, can be rather expensive, TDR transmission based eye diagram measurements are an attractive lower-cost alternative to the direct pattern generator eye diagram measurement.

TDR Transmission Eye Diagram Measurement in IConnect

Eye diagram based on TDR transmission data is computed in IConnect TDR software using Fourier techniques to compute the convolution of an input with the measured system response function. The modeling assumptions that are used in this type of computation, and are pretty standard for all interconnect modeling, are that the system is linear and time-invariant.

In order to obtain high-quality eye diagram, the designer has to follow normal good measurement practices when working with the 18-20 Ghz TDR oscilloscope, such as: letting the instrument warm up for 20-30 minutes before performing measurements, using good quality low loss cables and good probes with small signal-to-ground spacing, using averaging in the TDR oscilloscope to reduce noise. Two waveforms need to be acquired: the DUT transmission and the reference waveform - without changing the timebase on the TDR oscilloscope.

For the TDR-based eye diagram measurement, it is particularly important to select an acquisition window that is long enough that it allows the DUT waveforms to completely settle to its steady state DC level. We are about to start making high-frequency analysis of the DUT, and we need to allow the signal to settle to perform this analysis accurately. At the same time, the window must not be any longer than necessary, to maximize the effective dynamic range and accuracy of the measurement.

In addition, we need to make sure that a sufficient number of data points is selected in the oscilloscope acquisition window. This is particularly critical for analyzing long interconnects, such as cables. The upper frequency limit of your measurement is determined as

$$f_{upper} = \frac{1}{2t_{step}} = \frac{N}{2t_{window}} \qquad (1)$$

where N is the number of points in the acquisition window, T_{step} is the time step, and T_{window} is the acquisition window length. The accuracy of the eye diagram at a data rate F(gigabit) is determined by the accuracy of the data up to the frequency that is at least half that data rate, or F/2(Ghz). For example, to get an eye diagram at a speed of 10 Gbit for a cable that requires an acquisition window of 100ns, you need to have the frequency content of at least 5Ghz, and the number of points set to 1000 or more. When working with long cables, it is generally a good idea to keep the number of points at the maximum number allowed for a given instrument.

The user can choose between several different stimuli patterns, pattern length, signal amplitude, speed and rise time. Custom pattern can be entered as well.

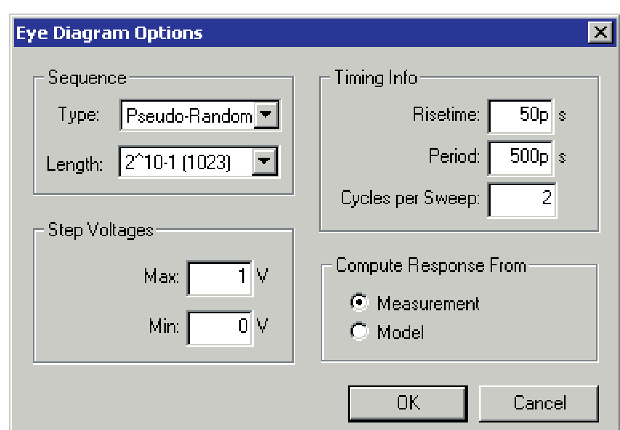

Figure 1. Eye diagram options in IConnect

Correlation of TDR-Based Eye Diagrams to Measurement Eye

Despite the simplicity of the TDR transmission eye diagram measurement process, we would like to address the accuracy questions of the eye diagram measurement in IConnect using the TDR oscilloscope transmission measurement versus the eye diagram measurements using a system based on a bit-error-rate tester or a pattern generator and a sampling oscilloscope. Since all we characterizing is the deterministic jitter due to crosstalk and losses in the passive and linear interconnect system, the TDR-based eye diagrams for the interconnects are effectively the *exact* representation of the eye diagram degradation for the given interconnect. As such, the TDR-based eye diagram computation is correct by design. To confirm this, we provide an example of correlation of the TDR-based eye diagram measurement to the directly measured eye diagram. As we stated before, as long as the TDR transmission measurement is performed with sufficient accuracy and care to characterize a given interconnect to a frequency that is at least half the desired eye diagram data rate, the eye diagram will be correct.

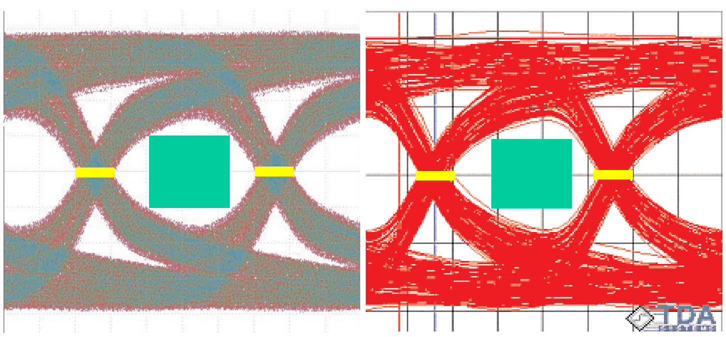

Figure 2. Eye diagram comparison: pattern generator and sampling oscilloscope (left) vs. IConnect and a TDR oscilloscope (right). Signal is PRBS 2^{10}-1, 5Gbit, 100ps rise time. Excellent correlation is observed

If the eye diagram appears "jagged" and "broken," the most likely cause is that the time step is not enough to produce frequency domain data up to required frequency. Re-acquire the data with a shorter acquisition window or larger number of points in the window.

Normally, a time domain transmission waveform through the DUT is required for TDR-based eye diagram measurement. Alternatively, the eye can be measured from TDR reflection, based on the models extracted for the interconnect. The designer can acquire the reflection, simulate the transmission through the interconnect, and use this simulated transmission data for the eye diagram prediction. However, this approach will require careful modeling of the interconnect in question.

System Level Eye Diagram

The eye diagram measured in IConnect exhibits the signal degradation due to the interconnect losses and crosstalk. In order to obtain a complete picture for the digital system eye diagram, the designer needs to extract the lossy coupled models for the interconnects in IConnect TDR software, and simulate propagation of the the signal from a real digital I/O driver into these interconnect models in a simulator that has the eye diagram display feature.

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