Application Note

Using Measure-Based Modeling to Analyze Backplane Deterministic Jitter

Abstract

Recently, much has been written regarding jitter analysis with an end of improving BER. Decomposition of the random and deterministic jitter components for the Active Interconnect system, which includes the PHY, is an excellent method for understanding jitter sources, but falls short when only dealing with the Passive Interconnect System. Separating the total jitter into random and deterministic components will not provide insight into the signal integrity specifics for the physical layer itself. An example of this would be how much will a single via, separate from all other physical structures, contribute to NRZ random data eye closure, timing jitter, or amplitude noise? This paper specifically deals with using measure-based modeling of deterministic jitter contributors in a concise and verifiable methodology.

Introduction

Low Bit Error Rate, low cost, and high scalable speed designs are the typical objectives of backplane design. Jitter is used as a useful methodology tool to improve BER characteristics. Engineering BER by itself is intractable, making it impossible to practically point to specific problems. Total jitter, the peak-peak jitter measured at a specified BER, is composed of random (RJ) and deterministic (DJ) components. Much has been developed in the signal integrity community regarding decomposing jitter into RJ and DJ and is very useful for evaluating system designs and PHY technology, or the Active Interconnect System. It lacks as a method, however, when dealing with the Passive Interconnect Platform. A method of relating specific physical structures to eye degradation, amplitude noise and peak-peak DJ is the method illustrated. These simple structures can be integrated into a complete model for a backplane where each jitter and AM noise contributor can be identified topologically. The driver-receiver PHY is precluded as part of this method, where the focus is only on the passive platform for this technique.

Passive Interconnect Jitter Problem

Total jitter (TJ) is composed of random and deterministic jitter described by probability density functions (PDF). Deconvolution, the mathematical process of separating these PDF's, enables for different pathologies of the active PHY to be analyzed. Unlike the PHY, the backplane does not generate RJ. However, further separation of the DJ into finer classification is advantageous for the Passive Interconnect Platform. Figure 1 shows how TJ can be further broken down and be analyzed using a topological measure-based model. Let's first illustrate the method using a simple example.

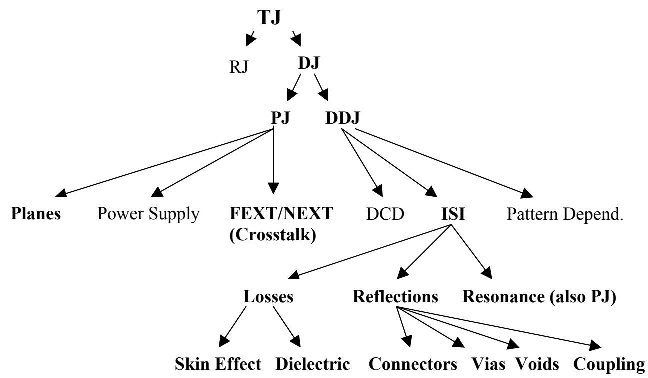

Figure 1. Total Jitter can be further separated into increasingly finer classification for Deterministic Jitter (DJ). The Passive Interconnect Platform jitter classification is in bold.

Jitter Extraction Using Selective De-Embedding

This first example consists of a simple system (except for the exclusion of a board-board connector this example represents backplane daughter card) including SMA launch, differential traces, board-board connector, differential traces, SMA launch. A typical method of analyzing this channel would be to inject a PRBS, K28.5, CJPAT type of pattern with a BERT pattern generator and observe the corresponding eye closure related to reflections due to impedance discontinuities, loss, and stubs or reflections using a DSO or sampling oscilloscope. Mask violations are recorded in pass/fail format. Although this is a valuable measurement, it does not represent a method since violations or eye degradation does not relate to the physical topology.

Figure 2 shows the reflected TDR data and accompanying reference waveform. From this data we calculate a true impedance profile, which represents our first step in analyzing the system for reflections and crosstalk. The impedance profile is used to assess impedance variations due to launches, problems with traces, connectors, etc., all jitter inducing effects

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except for lossy structures such as longer transmission lines. We will use the impedance profile to generate the model of SMA launch, and will model this as a loss-less structure, where the balance of the transmission line will be modeled as a lossy line. IConnect® is used to both calculate the true impedance profile and to extract the W-element parameters for the lossy transmission system. In Figure 3 we see the launch model simulation results and comparison against the reference and reflected TDR data.

At this point we generate a model consisting of a stimulus using the de-embedded reference TDR, SMA launch, and a lossy transmission line. Model, simulate, compare and verify against the original TDR data provides the baseline for all future deterministic jitter analysis.

Importantly, a BERT or signal pattern generator with a DSO sampling type of oscilloscope can not perform this jitter analysis since it is not a direct SMA-Circuit-SMA measurement (no transmission capability). The method relies on generating a verifiable model using only reflected TDR data, creating a simulated eye diagram, and then measuring the resulting DJ.

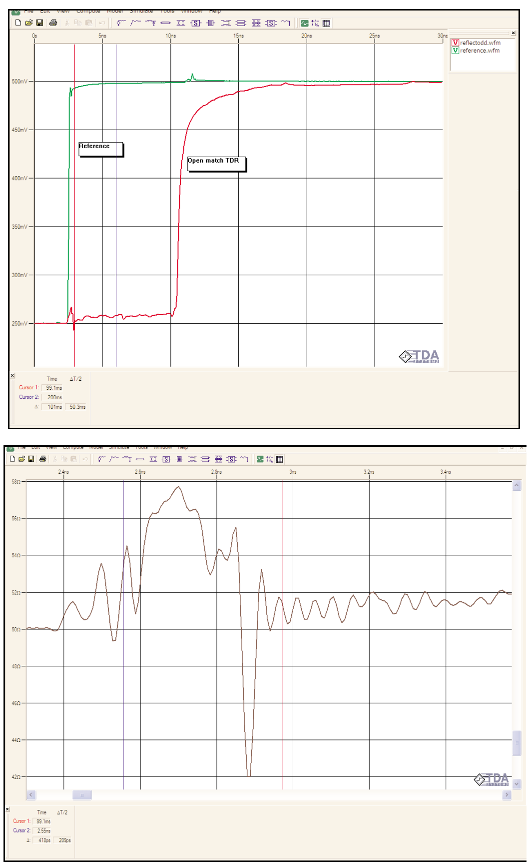


Figure 2a, b shows the TDR data collected consisting of a reference and open reflected waveform. Analysis was performed only with these 2 measurements. Figure 2b is the zoomed true impedance profile of just the launch.

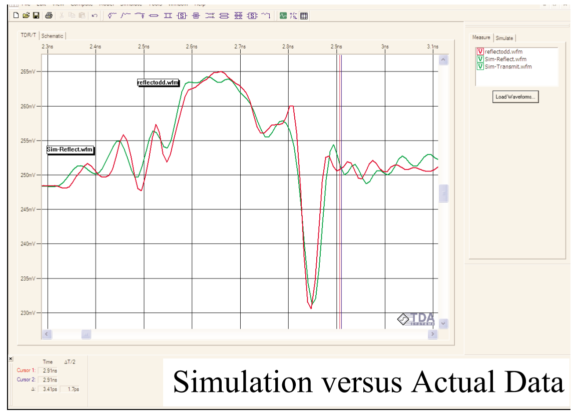


Figure 3. Simulation versus Actual data for simple example model launch.

We now have a model that we can use to explore DJ contributors throughout the system by selective de-embedding. This is done by first obtaining the DJ of the entire system via simulation, then simply de-embedding each DJ contributing element selectively to get obtain a complete jitter picture of each pathology.

Aside: An interesting example of selective de-embedding can be had with the poor impedance control of the associated launch. |S11| or Return Loss is another way of measuring launch performance. Figure 4 shows the correspondence between the de-embedded discontinuity and the simulation including it. Figure 5 shows the corresponding |S11| for each launch , as calculated by IConnect®. Interestingly, since we cannot terminate the trace into a 50ohm load both |S11| values were calculated via simulation only, where the model incorporated 50ohm load. First a model was developed, and then confirmed to match the collected data. Then the model had a characteristic (C discontinuity in this case) selectively de-embedded such that we can predict the behavior if we eliminated this specific S.I. issue.

Question still remains: How much DJ does the launch itself contribute?

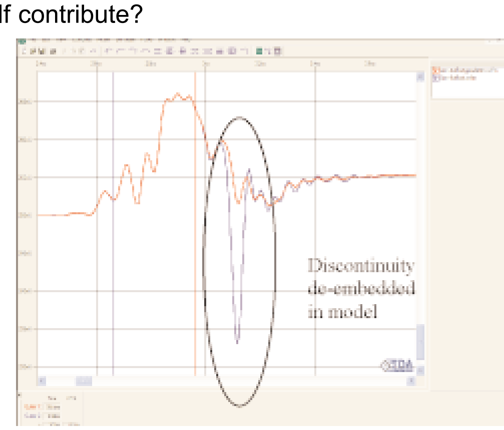


Figure 4. The large capacitive discontinuity for the launch has been removed in the model. The simulated data comparison confirms that it has been de-embedded properly.

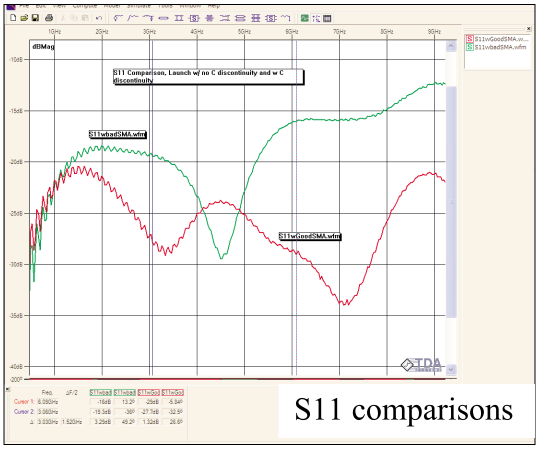


Figure 5. Selective de-embedding of launch discontinuity shows significant improvement in Return Loss characteristics. The green trace has the large capacitive-like impedance discontinuity, whereas the red |S11| does not. Both waveforms were not measured, nor could they be (|S11| for a non-load condition is meaningless) - a model was developed, verified against data, and then the model was simulated using a 50ohm load.

Summary of possible DJ contributors in the simple system:

- Launch has poor impedance control, significant region higher than 50ohms in Impedance Profile
- Large capacitive-like discontinuity of launch
- Launch has high-frequency resonance issue
- Transmission line has significant loss evident from rise-time degradation of reflected TDR

We start the jitter analysis process with no dielectric and skin effect losses for the transmission line (making it loss-less) in the composite model, and de-embedding the launch S.I. with a uniform simple transmission line of 50ohms, i.e., a perfect fictitious launch. Figure 6 shows the resulting perfect eye with no attendant DJ, as would be expected from a model that has all DJ contributors de-embedded. Recall that RJ is an issue with Active Network Platform and not part of the Passive.

Refer to Table 1 for an overview of the following figures. Essentially there are three obvious conclusions for this case:

1. Transmission losses negate effects of reflections and high-frequency resonance.

2. DJ is ISI related and tied directly to the FR-4 dielectric loss in this case

3. Although the launch can be significantly improved, the dielectric losses reduce transmission bandwidth so that significant eye degradation in jitter is not incurred by the poor launch

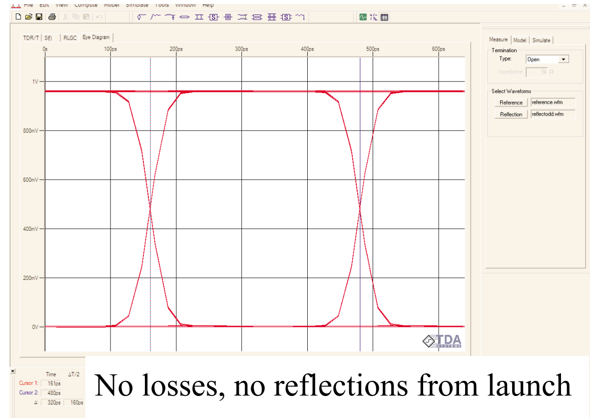


Figure 6. No Deterministic jitter since launch and losses in the transmission line are altogether de-embedded. Experiment was run at 3.125Gbps, U.I. =320psec. D.J.=0psec p-p since there are no reflections due to continuous impedance, and no transmission losses. The transmission losses, Gac and Rac, were set to zero.

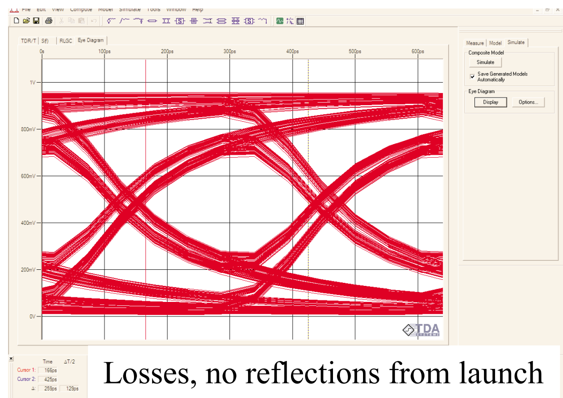


Figure 7. All losses in transmission line were not de-embedded, but launch is still de-embedded. Eye diagram reflects losses but not reflections. D.J. was measured to be 50.9psec p-p.

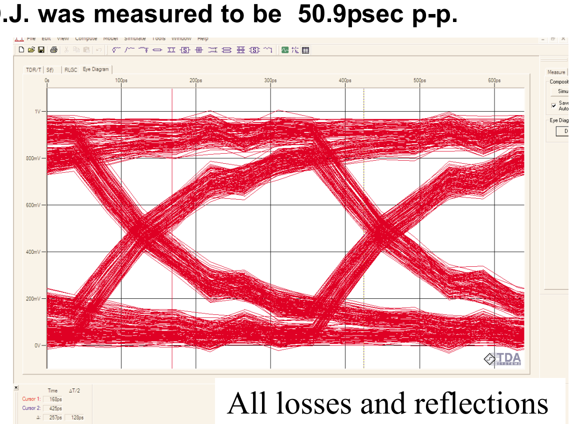


Figure 8. All losses and launch is now embedded, corresponding to all S.I. issues included in model. Deterministic jitter simulation result was D.J.=51.6psec. The launch added less than 1psec of D.J. for this 3.125Gbpsec system. Amplitude modulated noise increased noticeably.

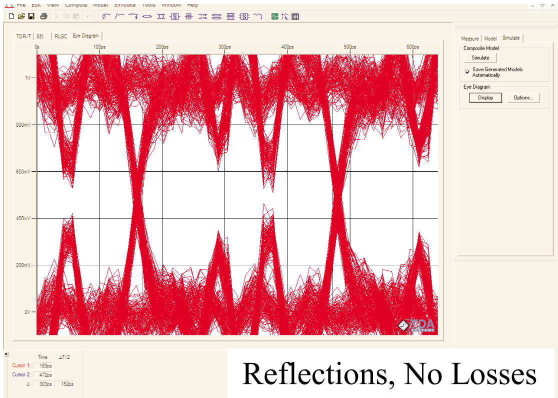
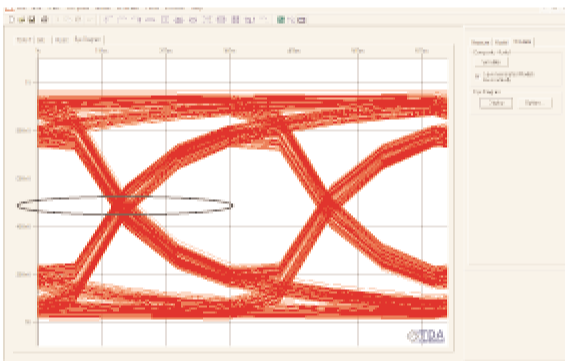


Figure 9. Simulation results of launch embedded with no losses, specifically dielectric losses (Gac) was set to zero in the model. It is evident that losses actually improve S.I. with poor impedance control such as reflections and resonance.



Reduced Gac, 10%, Reflections from launch

Figure 10. In this case the Gac, or dielectric loss was reduced 10%. The launch is embedded in the model. D.J. = 42.3psec p-p so that the simulation results suggest that D.J. is Intersymbol Interference from transmission line losses, specifically dielectric (Gac in the RLCG model).

Summary of Simple Model Simulation Experiments of D.J. p-p

Figure	Transmission Losses	Launch	DJ psec, peak-peak
6	De-embedded	De-embedded	0
7	Embedded	De-embedded	50.9
8	*Embedded*	*Embedded*	*51.6*
9	De-embedded	Embedded	Low DJ, High AM modulated noise
10	Embedded –10%	Embedded	42.3

Obviously, the dielectric losses dominate the DJ in this example, since reducing the Gac coefficient by 10% results in 9.3psec p-p jitter reduction. Further simulation between full GAC and reduced 10% comparing the insertion loss between the two cases is shown in Figure 11.

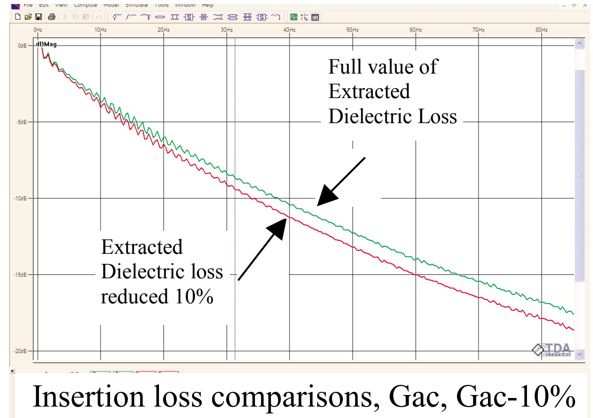


Figure 11. Simulated Insertion loss comparison of full value of Dielectric Loss versus -10% change in the loss.

Selective De-Embedding Using De-Embedding Test Structures

Connectors can be a major source of DJ in back-planes. Significant impedance control, resonance, and crosstalk, degrade connector performance. Often backplane losses and connector performance dominate Passive Interconnect Platform jitter performance. Picking out the key DJ contributors requires selective de-embedding. Evaluation boards can incorporate de-embedding structures allowing specific structures to be characterized, such as connectors. This technique however, requires de-embedding traces exactly matched to the launch traces into the connector. By de-embedding the launch and trace into the connector, we can essentially measure the contributing DJ of the connector itself. Figure 12 illustrates the difference between rise time of cable going into fixture and cable plus the calibrated trace, where the risetimes are 47psec and 239psec (10-90%), respectively. The calibrated trace exactly physically matches the trace going into the connector, such that the losses are replicated. This allows the final DJ contribution measured of the connector to be separated from the DJ de-embedded from the launches into the connector. Question: For 10Gbpsec how much does this impact the resulting DJ measurement?

Measuring and modeling are two approaches to eye diagram analysis. Measured is a direct approach incorporating a fast source using a BERT pattern generator, or alternatively using a TDR sampling head. It does not require a model, such as the last example. IConnect® software can generate a measured eye diagram using three TDR signals including reference, reflected and transmitted data. For a coupled loss type system five measurements are required, which includes reflection (TDR) and transmission (TDT) for both Odd and Even modes of signal transmission.

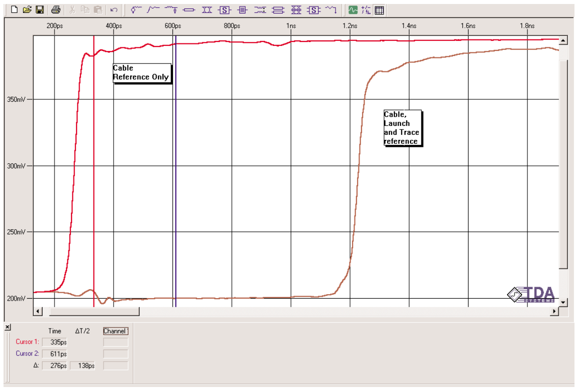


Figure 12. Rise-time degradation of launch and trace into differential connector. Significant degradation results in DJ measured error if the trace+launch is not de-embedded from the measured eye diagram.

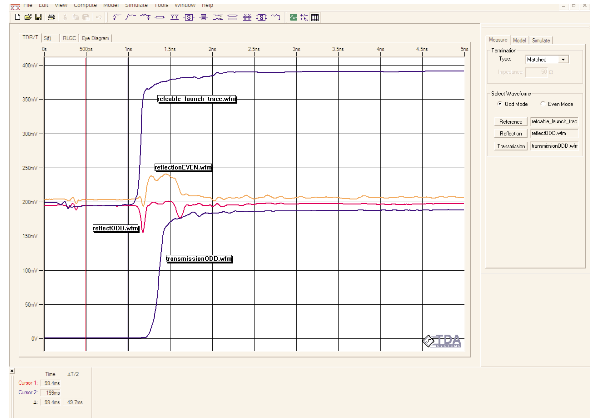


Figure 13. Data collected using the reference the SMA launch and trace de-embedded. Note that the reference waveform starts at the connector.

Comparing Figure 14 and 15 we can see there is a difference of 7.7psec p-p, all due to properly de-embedding a very good launch and an approximate 3inch coupled differential stripline trace. De-embedding using measured eye diagrams proves very useful since evaluating the DJ with a simple BERT transmission would have seriously been overstated, even with the excellent launch and relatively short trace. The data collected for ODD mode is shown in Figure 13.

Verifying De-Embedding Structures

This method assumes that the de-embedding structure matches the launch Impedance Profile for the DUT. This assumption must be tested in every case. In the connector case, half of the structure did indeed match, but the structure being differential had some glaring differences that resulted in underestimating the DJ for the de-embedded measurement case. The following will show that for differential systems, de-embedding a single line system launch is not the correct method for differential systems. It is important to note that the DJ difference between connector measurements of both trace launch de-embedded and simple cable de-embedding should have been the DJp-p measured of the simple launch and trace. This discrepancy accounts for 3.7psec p-p of DJ. In fact, the via to the connector, while being differential driven, has a dramatically different impedance profile than the single ended calibration SMA-trace via system that was single ended as can be seen in Figure 16.

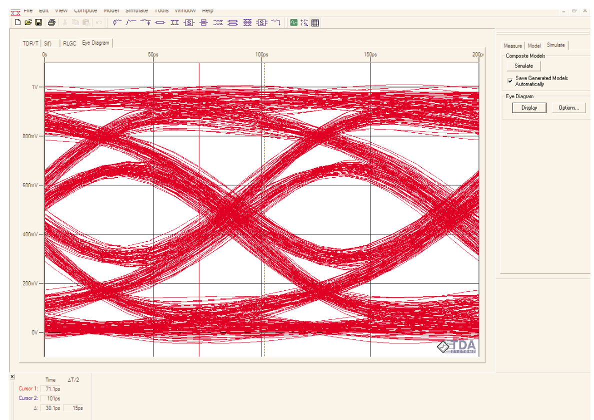


Figure 14. Measured eye diagram of SMA launch+differential trace not de-embedded from DJ measurement. DJ=30.5psec p-p.

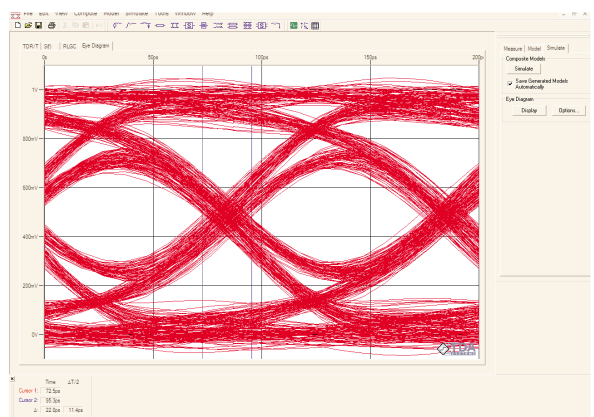


Figure 15. Measured eye diagram of SMA launch, differential trace de-embedded from DJ measurement. DJ=22.8psec p-p.

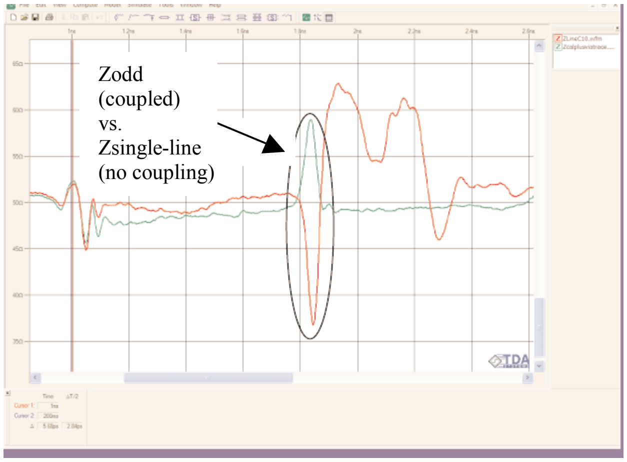


Figure 16. Two Impedance Profiles correspond to reference SMA-trace-via that is single line, no coupling, and second trace shows significant impedance difference than non-coupled system. In order for de-embedding to more exactly match the test structure launch into the DUT (connector). Interesting observation: the via on the other side of the connector is exactly the same structure, but note the apparent loss.

Simple method for checking integrity of de-embedding structures:

1. Capture a reference waveform, which is simply an open reflected TDR of the cable into the de-embedded structure
2. Capture either a matched load or open-matched TDR in both the de-embedding structure and the launch structure including the DUT. Use the same cable or probe that the reference measurement was made.
3. Using the reference waveform (this step de-embeds the cable for this particular measurement) calculate True Impedance Profiles of both reflected TDR waveforms.
4. Compare both of the generated Impedance Profiles.

Since the de-embedding structure is non-coupled, single-ended structure, the odd mode impedance is significantly different than the self-impedance of the actual structure: 37ohms versus 58ohms according to calculated Impedance Profiles, one structure is highly capacitive and the other is more inductive, as show in Figure 16. The de-embedding structure needs to be redesigned such that the odd impedance of the coupled structure matches the impedance of the launch and trace into the connector. Quite simply, the de-embedding requirement for differential systems mandates differential de-embedding structures to account for the impedance change due to coupling.

De-Embedding Mezzanine Card from Backplane:

In this example, we demonstrate the characterization of a Serial ATA backplane populated with two daughtercards. The only measurement access to the backplane was through SMA connectors on the first daughtercard. Since we assumed that the system was symmetrically differential we chose to focus characterization on odd analysis only. The equivalent composite circuit model is shown in Figure 18.

Backplane Model Methodology:
First, we extracted the lossy line model for the daughtercard, using the open reflection loss extraction technique in IConnect®. Secondly, the daughtercard-to-backplane connector model was extracted using the impedance profile (Z-line) in IConnect®. Then, we extracted the lossy line model for the backplane using the daughtercard as a reference, essentially de-embedding the daughter card. Figure 17 illustrates the correlation between the TDR collected data and the resulting simulation of the extracted model. At this point it is straightforward to simulate the generated DJ from both the daughtercard and the backplane independently, since the daughtercard DJ was selectively de-embedded from the overall system.

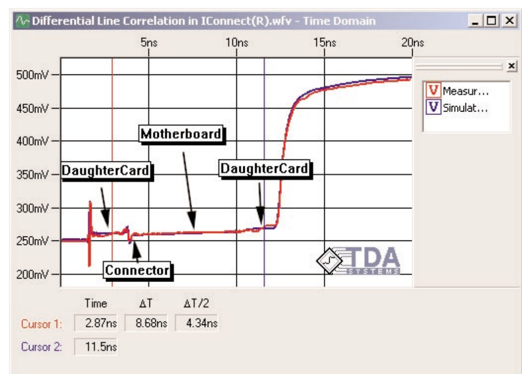


Figure 17. Example comparison of simulated versus measured data using the composite model developed in Figure 18. De-embedding the daughtercard is the key for isolating the backplane losses and developing a model that is topologically correct.

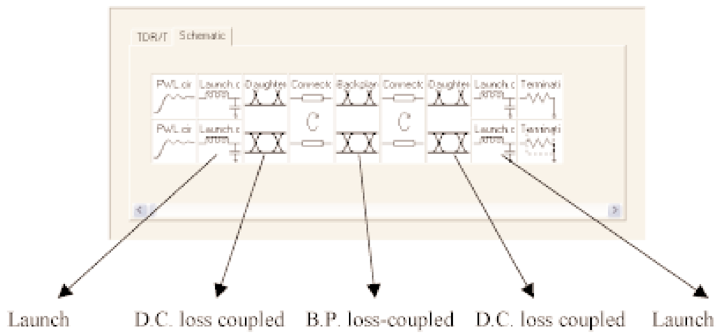


Figure 18. Generic backplane differential model, where each block represents a SPICE compatible netlist. Backplane losses were accurately modeled by de-embedding the daughter card, using it as the reference plane for the backplane model (D.C.=Daughter Card, B.P.=Backplane).

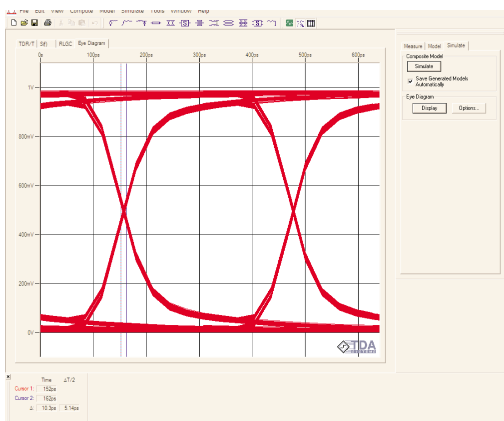


Figure 19. Simulated eye diagram of mezzanine card at 3.125Gbps. The mezzanine card reference was simply the cable from the sampling head to the SMA on the card. Generated from reference TDR and open reflected TDR of just the card. The integrity of the eye diagram depends upon corresponding the measured data to the simulated data from the model developed. Simulated jitter was 10.6psec p-p.

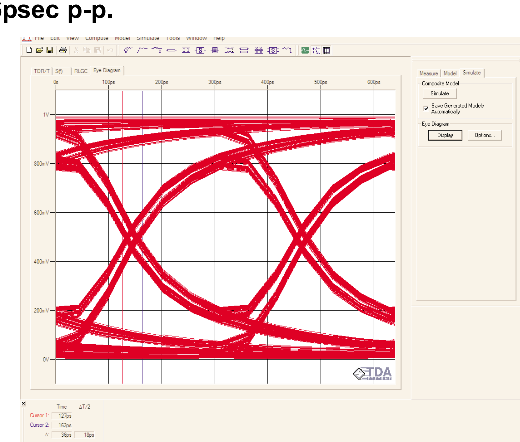


Figure 20. Eye diagram of backplane, where the mezzanine card was de-embedded by since it was used as a reference for the backplane. Simulated DJ for just the backplane is 36psec p-p.

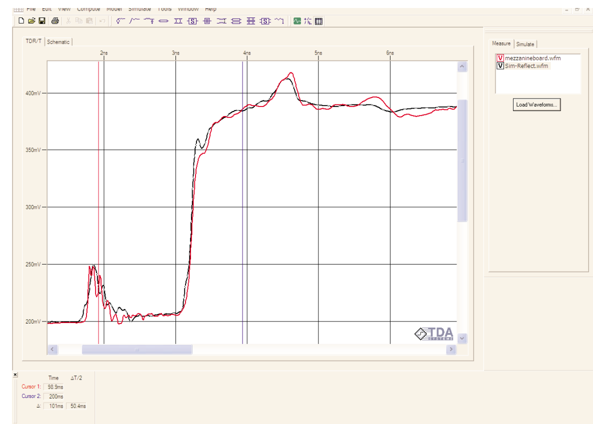


Figure 21. Correspondence of mezzanine TDR open matched data with simulation results from created model. This method of using measure-based model methods to analyze DJ relies on verification and comparison of simulation results within the bandwidth required in the system.

Summary

Essential elements to extracting DJ from a structure is to selectively de-embed, model, compare and verify model correspondence, and then simulate DJ for a specific topological physical element.

There are two methods of using measure-based methods for determining DJ for a particular structure:

1. No model required. Capture TDR reference selectively, matched TDR signal and TDT signal, and then compute eye diagram using IConnect®. The reference can be a daughter card, for example, for selectively de-embedding this structure from the backplane. Additional test structures for evaluation of connectors, for example, can be utilized to de-embed the launch into the device to be characterized.

2. Model required. Capture TDR reference selectively, matched or open TDR, and although not required TDT, or transmission. Generate model, compare, verify, and tweak model such that it corresponds to the data within the bandwidth required. In software, selectively de-embed a structure and compute the eye diagram.

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