Application Note

Modeling of Infiniband Cable Assembly From Measurements

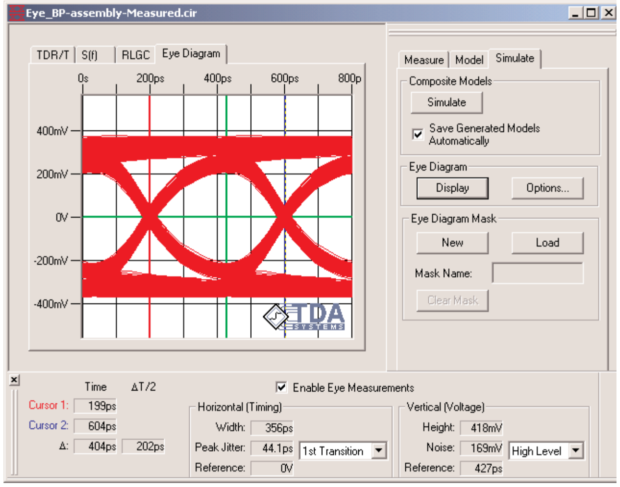
Introduction

In past few years, there is an increased demand in communication and computer industries for accurate SPICE and IBIS models that are able to predict signal propagation at gigabit speed range. At these speeds, interconnects are complex and distributed structures and require careful design and analysis techniques. Signal integrity becomes a key factor in achieving reliable performance of the digital system design. The signal integrity issues such as frequency dependent transmission and reflection losses, crosstalk, coupling, and signal dispersion become greatly pronounced especially when the interconnect structure is electrically long. The modeling challenges of the cable structure are evident from the designer's point of view and need to be addressed in order to achieve accurate simulation and a reliable digital system operation. This paper presents a detailed procedure for generation of the Infiniband cable model from measurements with IConnect® signal integrity software.

Challenges of Infiniband Cable Modeling

It is well known that even at low frequencies, the interconnect structure is not a simple conductor. It has characteristics and could exhibit resistive, inductive, or capacitive behavior. When the signal enters a gigabit range, interconnect becomes a distributed structure with certain time delay. The differential signaling scheme is commonly used to improve the performance of the high speed interconnects.

One of the main benefits of using the differential coupled lines in the Infiniband cable design is increased immunity to the common noise and reduced electromagnetic interference (EMI) between devices [1]. A coupled structure could be fully described by two modes of propagation: even and odd. When signaling is performed with one of these modes for two-signal-line differential pair, the signal propagates undistorted [2]. Since the system's noise has common component, the odd mode signal is used to transmit the data. Each line in the odd mode of propagation carries a single bit of data of the same amplitude but opposite polarity. When the signals subtracted at the receiver's side, the common noise components ideally are canceled out.



	Time	ΔT/2
Cursor 1:	199ps	
Cursor 2:	604ps	
Δ:	404ps	202ps

☑ Enable Eye Measurements

Horizontal (Timing)
Width: 356ps
Peak Jitter: 44.1ps 1st Transition
Reference: 0V

Vertical (Voltage)
Height: 418mV
Noise: 169mV High Level
Reference: 427ps

Figure 1. Eye diagram generated at 2.5 Gbit/s and 100ps 20-80% rise time for the Infiniband cable assembly. Eye opening is 418 mV and 356 ps, and peak-to-peak jitter is 44.1 ps.

The physical world however is not ideal. Since a typical Infiniband cable test structure contains such elements as connectors, board traces, bends and other discontinuities, the signal integrity issues arise even when the differential signaling scheme is used. In the Figure 1, we observe eye diagram closure for a typical cable assembly operating at Infiniband speed. This eye closure occurs primarily because of high-frequency losses in the cable assembly. A digital designer has to be able to accurately predict and model the effects of these signal integrity issues.

When a cable-connector assembly is manufactured, it is critical to analyze its performance as a part of the whole system. That is where the measurement - based models provide most of the benefits. The circuit element values that model discontinuities and physical features of a typical Infiniband cable assembly shown in Figure 2, could be determined from the time domain measured data making interconnect modeling software to be indispensable tool for every digital designer. A TDR oscilloscope or a Vector Network Analyzer (VNA) combined with TDA Systems's IConnect software allows effectively generate accurate SPICE and IBIS models based on the real life measurements helping to achieve success in the rapidly changing high-tech industry.

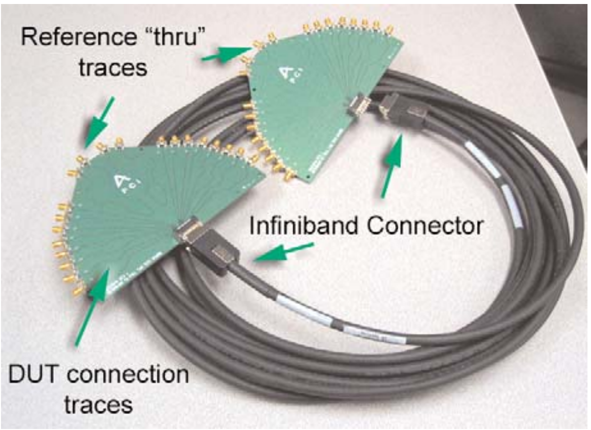


Figure 2. 4X Infiniband cable assembly, courtesy Meritec. Test fixture courtesy FCI/Tektronix.

Topological Models

The modeling approaches that could be used to model the Infiniband cable test structures could be sub divided in two major categories: behavioral and topological (Table 1). Behavioral or data driven model replicates the behavior of the measured device based on the mathematical behavior of the measured waveform. The IConnect's MeasureXtractor modeling technology allows automatic model extraction of two-port or four-port models, which corresponds to single-line and coupled-line circuit [3]. The topological models represent real geometrical features of the measured structures. The greatest benefit of using the topological models to model Infiniband cables is the ability of a designer to look at each individual component and tweak them to achieve desired performance.

Depending on the application requirements the topological models for Infiniband cable assembly could be single ended or coupled. For example, if the primary interest is an odd mode of propagation the model just for differential impedance could be built to analyze the device's behavior. Such model will have 2 ports; one for input another for output. However, if it were desired to analyze common mode noise rejection then the fully coupled model would be the best choice. Since any signal traveling a differential line could be decomposed in even and odd components, the fully coupled model provides a complete description of the system assuming negligible crosstalk from the adjacent lines. The resulting model will have effectively 4-ports: two ports for input signal and two for the output. Moreover, the fully coupled model could be modified to be used with a differential driver, by multiplication series impedances and dividing shunt admittances of the model by two and doubling the termination impedance.

A typical Infiniband cable test system includes the test cards with connectors followed by the uncoupled traces, coupled latching connector, and the cable itself (Figure 2). As a differential signal propagates through the device under test (DUT) it sees the discontinuities due to all transitions. Therefore it would be reasonable to consider the effects of each component when a topological model is constructed. IConnect software allows obtaining the circuit models for each individual part, and then combining them in one assembly.

Table 1. Comparison of behavioral and topological modeling approaches.

	Behavioral	Topological
Measurement requirements	Requires full-port measurement	Just TDR (reflection) is sufficient
Topology selection	Automatic, no user intervention	User-controlled (easy and intuitive from TDR measurements)
Model extraction	Automatic, no user intervention	User-driven; more labor intensive and require more skill
Type of models	"Black-box," no internal changes allowed	Intuitive, topology correlates to model
Limitation	Large model size for long interconnects (backplanes, cable assemblies)	Efficient model extraction processes exist for large interconnects
Application	Quick inclusion of S-parameter or TDR/T measurements into simulation; the "do-it-all" Modeling Tool	Comprehensive modeling, "what-if" scenarios analysis, signal integrity troubleshooting and fault-finding

Data Acquisition

Given that the modeling is performed on the measured data it is critical to obtain reliable measurement of the cable assembly. The TDR oscilloscope that provides high bandwidth of approximately 20 GHz is preferable to use. It is also important to follow good measurement practices while working with high precision instrument, such as:

- Let the instrument warm up for at least 20-30 minutes before performing the measurements
- Perform the required calibrations
- Use good quality low loss cables and probes
- Use a lot of averaging to reduce noise
- Use a maximum number of acquisition points
- De-skew the channels in the TDR-oscilloscope, as specified by your oscilloscope manual.

As it was mentioned before, the fully coupled model is a four-port structure, and in order to fully characterize it the instrument with four channels is desired, two for reflection and two for transmission measurements. Nevertheless, in some cases it is not possible to obtain the measurements of all four ports and IConnect could be very handy here proving a possibility to build a model based only on TDR reflection measurement. Table 2 lists the waveforms that are recommended to have to build a typical Infiniband cable model.

When modeling the test card and the cable losses, the time domain acquisition window must be long enough to capture all the transitions corresponding to the DUT. In view of the fact that the cable assembly is electrically long structure, several panoramic screen shots might be needed to capture the data. However, when modeling a high-speed connector, it is preferable to keep the window relatively short, in order to achieve sufficient resolution and resolve the connector details.

Modeling Process

Creating a model using the data that was acquired with exceedingly fast rise times will result in unnecessary complexity. Hence, before starting the modeling process it is good to determine the range of validity in terms of measurement rise time or equivalent bandwidth. Then the waveforms could be filtered with IConnect to meet the required specifications. For the example considered in this paper the measured waveforms were filtered to 100ps 20-80% rise time. Given that the cable assembly consists of the cable itself and the test cards, the modeling process could be split in two general stages: the cable loss modeling and the test card modeling. The high-speed connectors interconnecting the test card and the Infiniband cable are modeled as a part of the process.

Table 2. Waveforms recommended to build a typical Infiniband cable model with connected test cards ** For identical test cards only one needs to be measured

Structure	IConnect Model	Waveforms	Termination	Comments
Infiniband Cable testing assembly	Coupled Lossy Line	Odd reference	Open	Acquired at the end of connecting cable
		Odd Reflection Even Reflection	Matched* or Open	* When it is difficult to measure the transmission, the coupled lossy line model could be built using just reflection waveforms.
		Odd Transmission* Even Transmission*		
Test Card**	Single Line Model for uncoupled connectors and traces Lossy line for lossy traces	Odd Reference	Open	Acquired at the end of connecting cable
		Odd Reflection	Open	Acquired with test card detached from the cable
	Symmetric Coupled Lines for coupled latching connector and coupled lossy line for coupled test card traces	Odd Reference	Open	Acquired at the end of connecting cable
		Odd Reflection Even Reflection	Cable Connected	The instrument's window is adjusted to capture the behavior of the latching connector

Cable Loss modeling

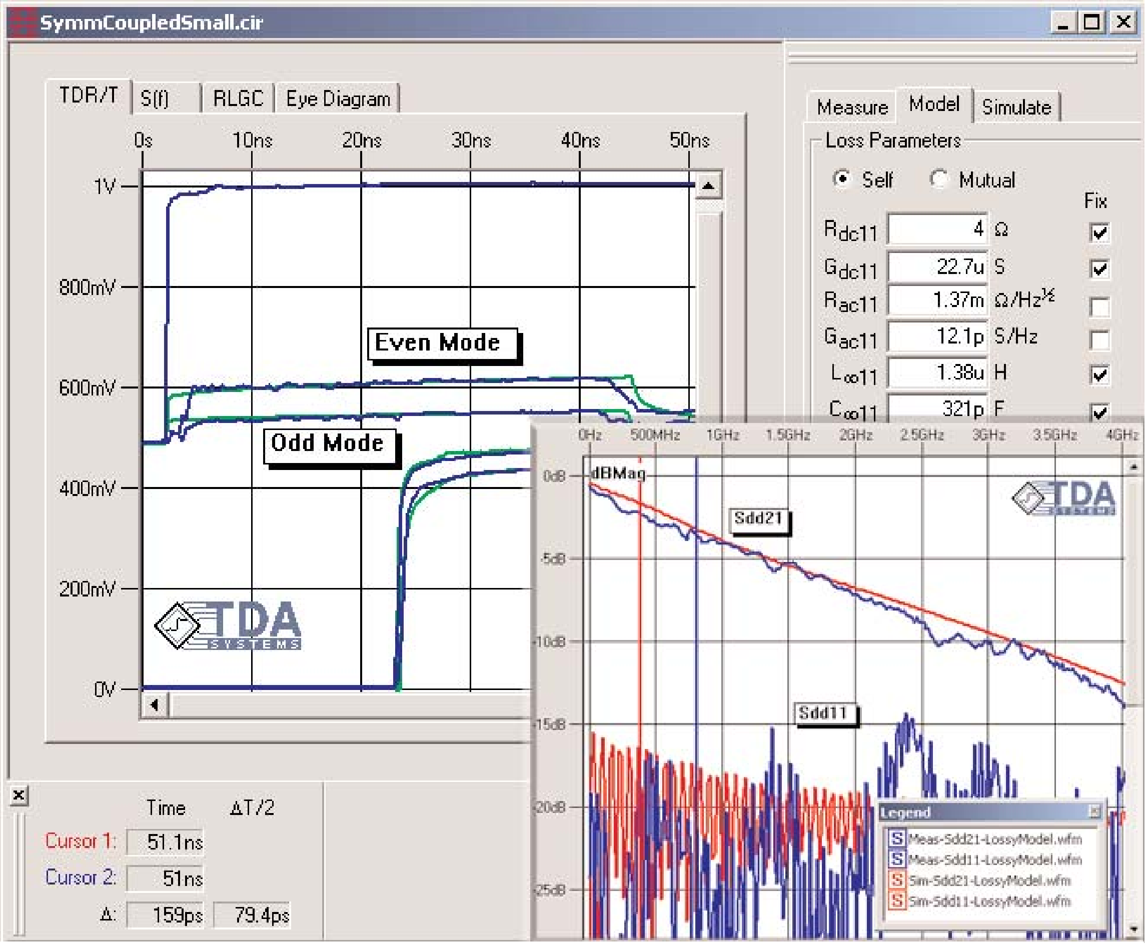
The step response of the cable assembly is dominated by the frequency dependent transmission line losses. Skin effect and dielectric loss are two major contributors to the rise time and amplitude degradation of the signal [4] making the symmetric coupled lossy line to be a perfect candidate for the cable loss modeling, with the skin effect typically being the more dominant factor for the cable assemblies.

After the required waveforms are loaded to the IConnect modeling window the lossy line model could be optimized to a very high degree of accuracy. Moreover, IConnect allows for the manual user input, and the models parameters could be adjusted to get an excellent correlation in time and frequency domains (Figure 3). To provide a good starting point, the DC circuit values could be simply measured with a digital voltmeter and then fixed with "fix" feature of IConnect for further optimization process. When the symmetrical coupled lossy line model is verified with linked simulator of choice it could be saved for the final assembly. To properly scale the interconnect length, the user can use the scaling function in IConnect lossy line model.

Test Card Modeling

To decide what models are best suitable to simulate the test card's behavior it is practical to analyze the true impedance profile generated with IConnect. For this purpose coupled line modeling feature of IConnect was used. (Figure 4). There are three main regions exist in the impedance profile for the test card. As the signal propagates it sees the SMA's connector area, then it enters to the trace region. These two regions represent uncoupled lines and could be modeled with single line feature. When signal comes to the latching connector it becomes coupled with the adjacent trace, here the symmetric coupled model is most suitable.

The SMA connector and the latching connector areas could be easily partitioned to obtain a better fit. The partitions are placed at each impedance change and represent different circuit element in SPICE or IBIS model (Figure 5).



Loss Parameters

● Self ○ Mutual

			Fix
R_{dc11}	4	Ω	☑
G_{dc11}	22.7u	S	☑
R_{ac11}	1.37m	Ω/Hz½	☐
G_{ac11}	12.1p	S/Hz	☐
$L_{\infty 11}$	1.38u	H	☑
$C_{\infty 11}$	321p	F	☑

	Time	ΔT/2
Cursor 1:	51.1ns	
Cursor 2:	51ns	
Δ:	159ps	79.4ps

S Meas-Sdd21-LossyModel.wfm
S Meas-Sdd11-LossyModel.wfm
S Sim-Sdd21-LossyModel.wfm
S Sim-Sdd11-LossyModel.wfm

Figure 3. Coupled lossy line, correlation between modeled and measured values. The only significant difference in time domain data is observed for the test card area, which ought to be modeled in separately.

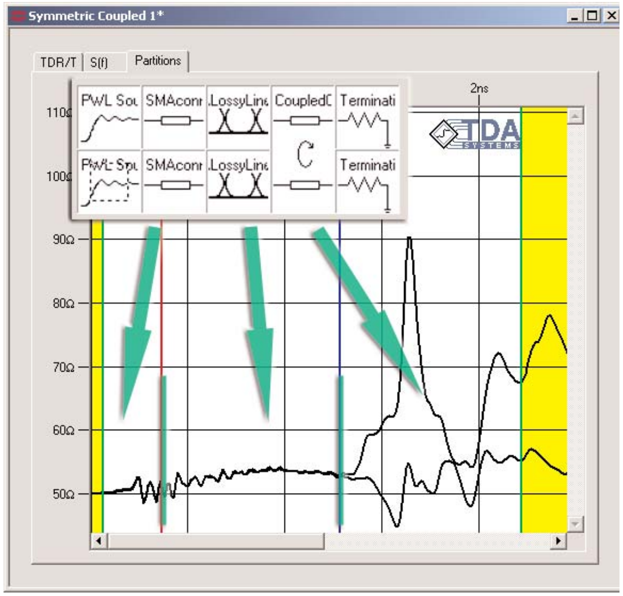


Figure 4. True impedance profile of the test card structure and model topology. Uncoupled regions are modeled with partitioned transmission lines and lossy line, whereas the 4x Infiniband latching connector is modeled with symmetric coupled lines

After all pieces of the test card's circuit model are put together the HSPICE simulation reveals excellent correlation shown in Figure 6. If the second daughter card is same as the one that was just generated, the circuit model could be reused by interchanging the port numbers in a netlist.

Infiniband Cable Assembly

After the models obtained for the test card and the cable are verified with the circuit simulator of choice the models could be assembled in one composite. During the assembly process the length of the symmetric coupled lossy line model needs to be scaled down to account for the length of elements inserted in the circuit model. Figure 7 shows the resulting circuit model topology for a complete Infiniband cable assembly and the correlation between measured and modeled data. Each box represents thesub-circuit of the composite model.

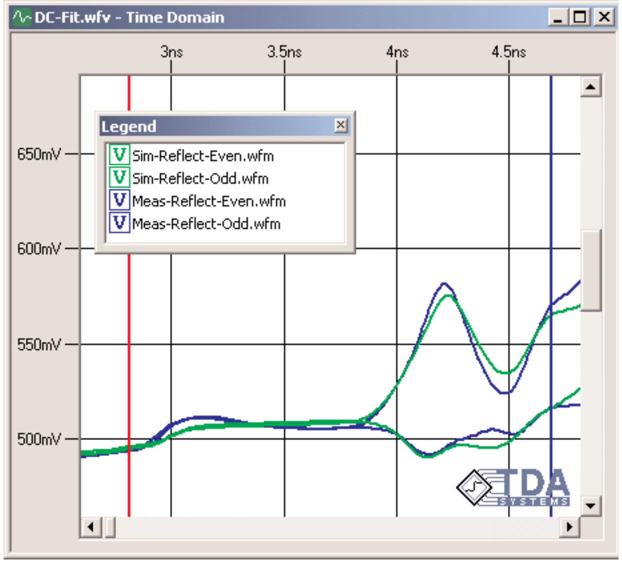


Figure 6. Correlation between simulated and measured waveforms for the test card assembly.

The model simulation reveals excellent time and frequency domain correlation between measured and modeled values for both even and odd modes of excitation.

Model Analysis with an Eye Diagram

It is often desired to analyze the effects of different parts of the Infiniband cable assembly on the eye diagram. The topological model is perfectly suitable for such analysis because it allows acquiring transmission waveforms at the different stages of the circuit topology. Once a good approximation of the actual measurement is obtained, we can remove or add different design components. For example to approximate the eye diagrams for the test card and the cable, we simulate one

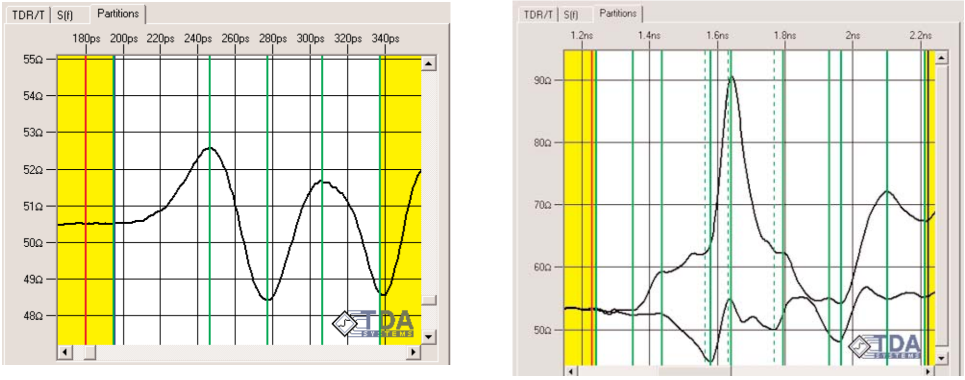


Figure 5. Partitions performed for uncoupled (L) and coupled (R) regions of the test card. Green lines represent partitions, which were placed at the beginning of each impedance change.

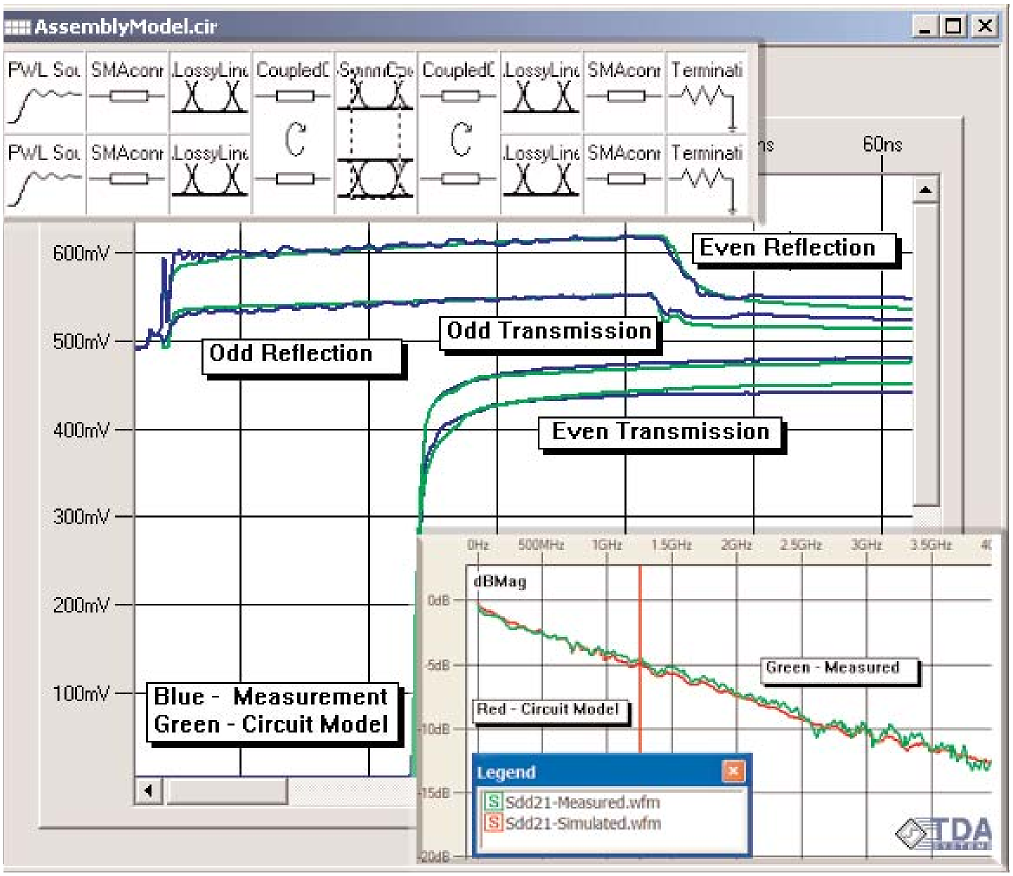
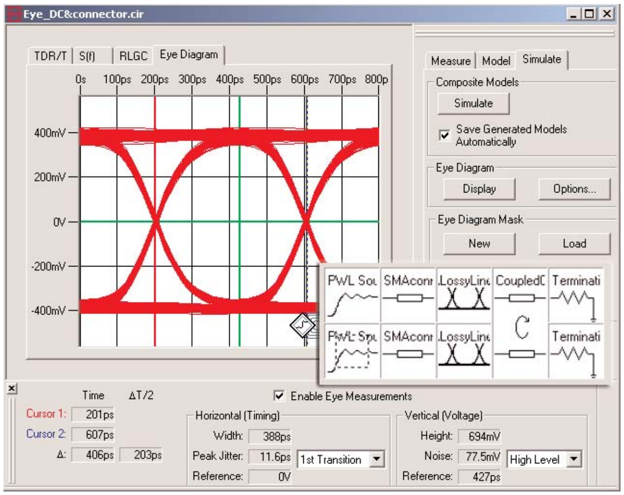


Figure 7. Complete model topology for the 4X Infiniband cable assembly and correlation between measured and modeled data. Each box represents a sub-circuit of the composite model.

transmission waveform for the test card and the connector, and the other with only the cable and two connectors at the ends. Then the saved waveforms could be used to generate eye diagrams.

Eye diagram generated with this approach shown in Figure 8 and Figure 9 indicates a significant contribution of the test card to the eye diagram closure. The test card alone produces an eye opening of 694mV and 388ps, and peak-to-peak jitter is 11.6ps for the eye diagram generated at 2.5Gbit/s and 100ps 20-80% rise time, while the cable-connectors model generates an eye opening of 484 mV and 367 ps, and peak-to-peak jitter is 32.7 ps for the same conditions.



☑ Save Generated Models Automatically

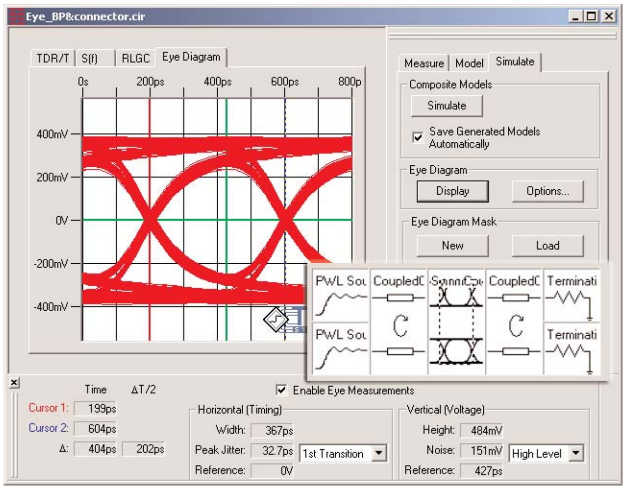
☑ Enable Eye Measurements

Time ΔT/2
Cursor 1: 201ps
Cursor 2: 607ps
Δ: 406ps 203ps

Horizontal (Timing)
Width: 388ps
Peak Jitter: 11.6ps 1st Transition
Reference: 0V

Vertical (Voltage)
Height: 694mV
Noise: 77.5mV High Level
Reference: 427ps

Figure 8. Eye diagram generated at 2.5 Gbit/s and 100ps 20-80% rise time for the for the test card model only. Eye opening is 694mV and 388ps, and peak-to-peak jitter is 11.6ps.



☑ Save Generated Models Automatically

☑ Enable Eye Measurements

	Time	ΔT/2
Cursor 1:	199ps	
Cursor 2:	604ps	
Δ:	404ps	202ps

Horizontal (Timing)

Width: 367ps

Peak Jitter: 32.7ps 1st Transition

Reference: 0V

Vertical (Voltage)

Height: 484mV

Noise: 151mV High Level

Reference: 427ps

Figure 10. Eye diagram generated at 2.5 Gbit/s and 100ps 20-80% rise time for the cable assembly model. Eye opening is 484mV and 367ps, and peak-to-peak jitter is 32.7ps.

Summary

A complete modeling methodology for 4x Infiniband cable is presented. With the TDR-based measurements and analysis techniques a designer can produce accurate and reliable models for the gigabit system interconnect.

Bibliography

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MICA-0205