Machine Learning (ML) Assisted IBIS-AMI Model for Optical Module Involved Advanced SerDes System Designs

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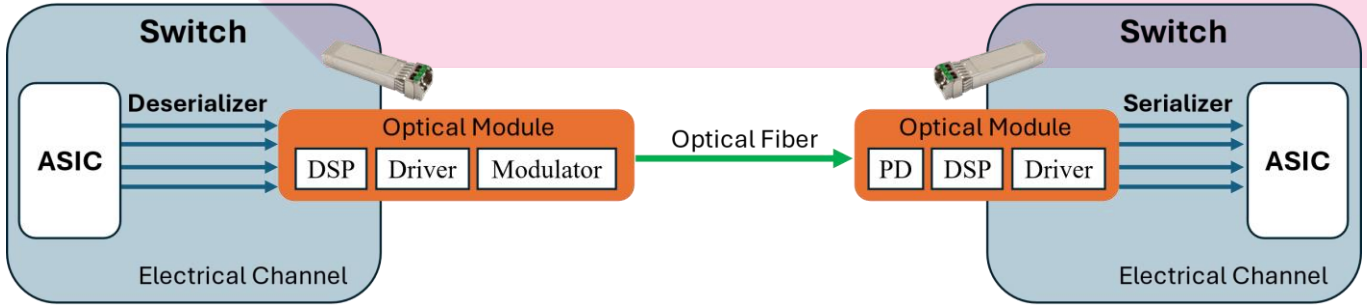
Motivation

Background:

- Optical interconnects continually replace copper connections in modern communication networks to meet demands for higher bandwidth and lower power consumption.



- Signal integrity analysis for high-speed SerDes link need to model both electrical and optical modules simultaneously, to capture behaviors of optoelectronic devices, such as nonlinearity, optical dispersion and loss.

Challenges:

- Conventional SerDes analysis solutions do not support modeling optical modules.
- Linear models, such as s-parameter, cannot accurately capture the non-linear responses of optical modules.

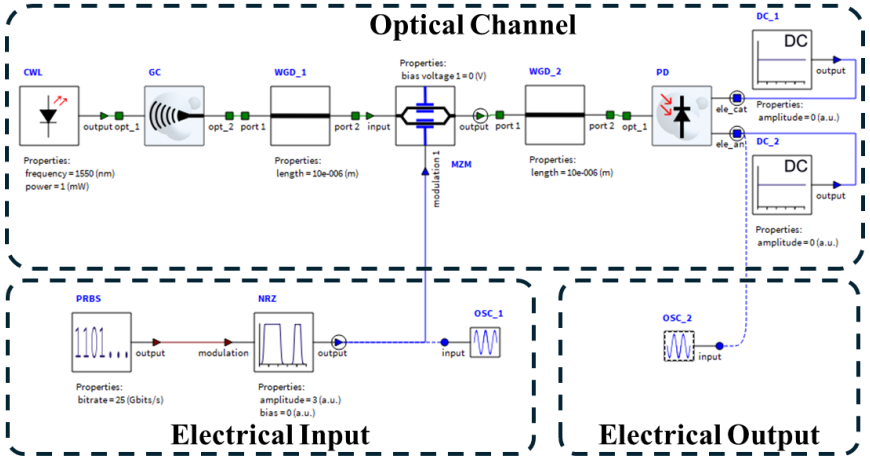
Goals:

- Create accurate optical module model through standard IBIS-AMI, to facilitate signal integrity analysis for modern high-speed SerDes link.

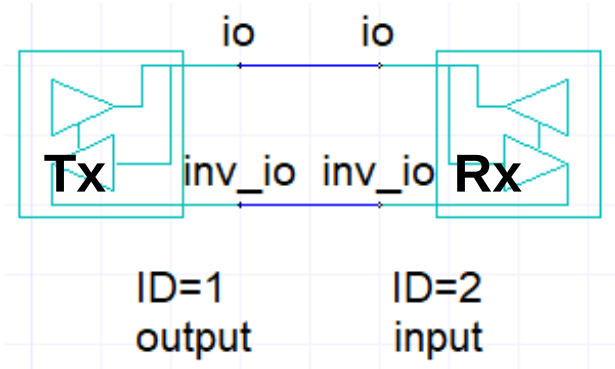
Solution Overview

Optical module data collection | Reduced order model generation | IBIS-AMI design/validation

Implement optical module design in circuit solver → Data collection → FNN training → Reduced order model extraction → Build Custom AMI model → Validate AMI model in IBIS-AMI



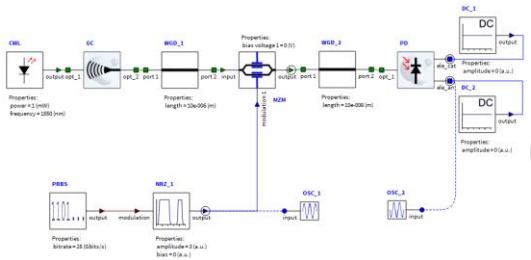
PIC design



AMI model

Automated IBIS-AMI Generation

Optical Module Designers

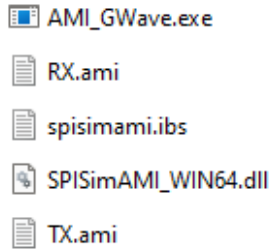


Optical module design

- Optical module designers implement and validate the optical module design in a commercially available circuit solver.

Fully Automated Model Extraction Flow

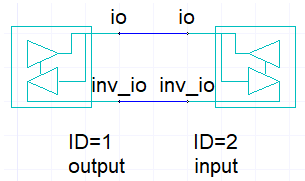
Data collection script → Reduced order model extraction script →



AMI model package

- Execute a data collection script to kick off the workflow.
- ML assisted reduced order model extraction will start automatically once data extraction is finished.
- A portable and ready-to-use AMI model package is automatically generated at the end of the workflow.

System Designers

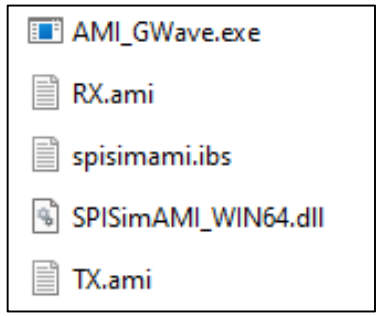


IBIS-AMI analysis

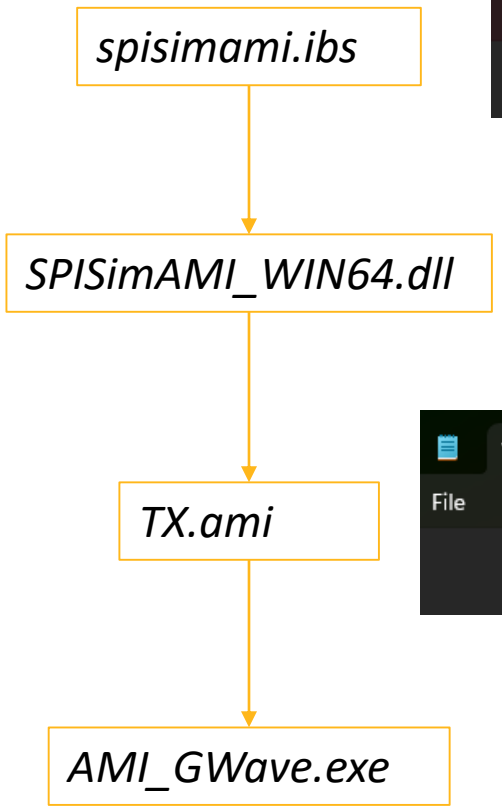
- System designers can use the AMI model to perform signal integrity analysis through standard IBIS-AMI.

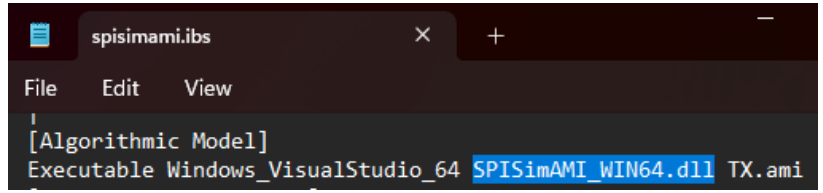
AMI model hierarchy

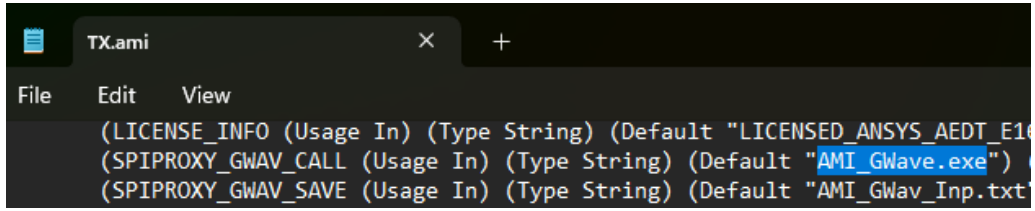
- The IBIS buffer is defined in .ibs file.
- .dll file interfaces the AMI model package with link analysis tools.
- AMI parameter definition (.ami) file is configured to execute the customized AMI_GetWave().
- Reduced order model is written in AMI_GetWave() (.exe file).



AMI model package



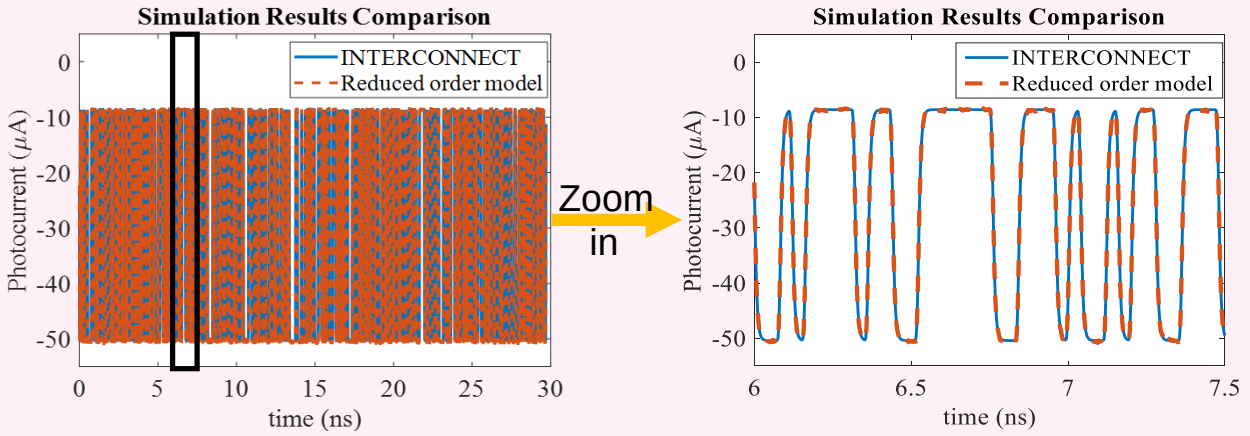




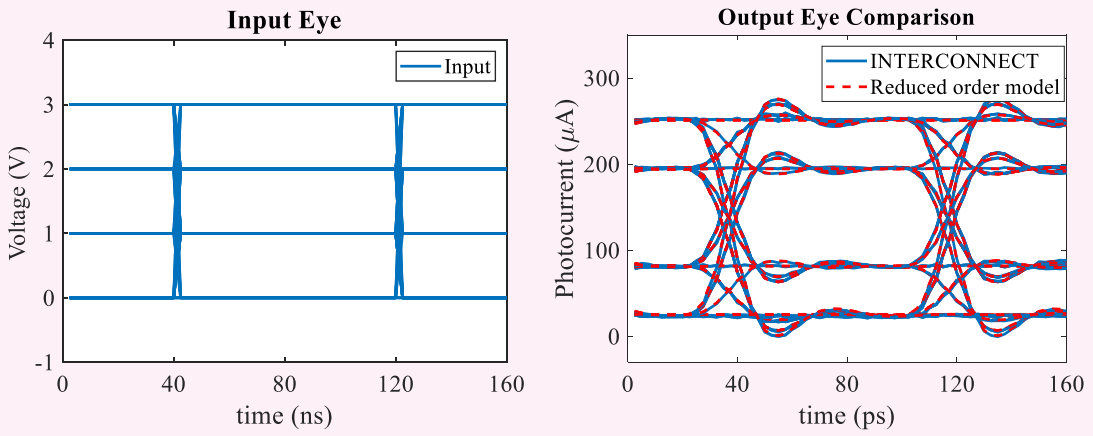
Reduced order model accuracy

- The accuracy of reduced-order model simulations is influenced by the training accuracy of the machine learning model.
- With well trained ML process, the reduced order model simulation results closely align with the results produced by a commercially available circuit simulator, INTERCONNECT.

Transient response accuracy comparison for NRZ signals



System eye distortion for PAM4 signals



Reduced order model efficiency

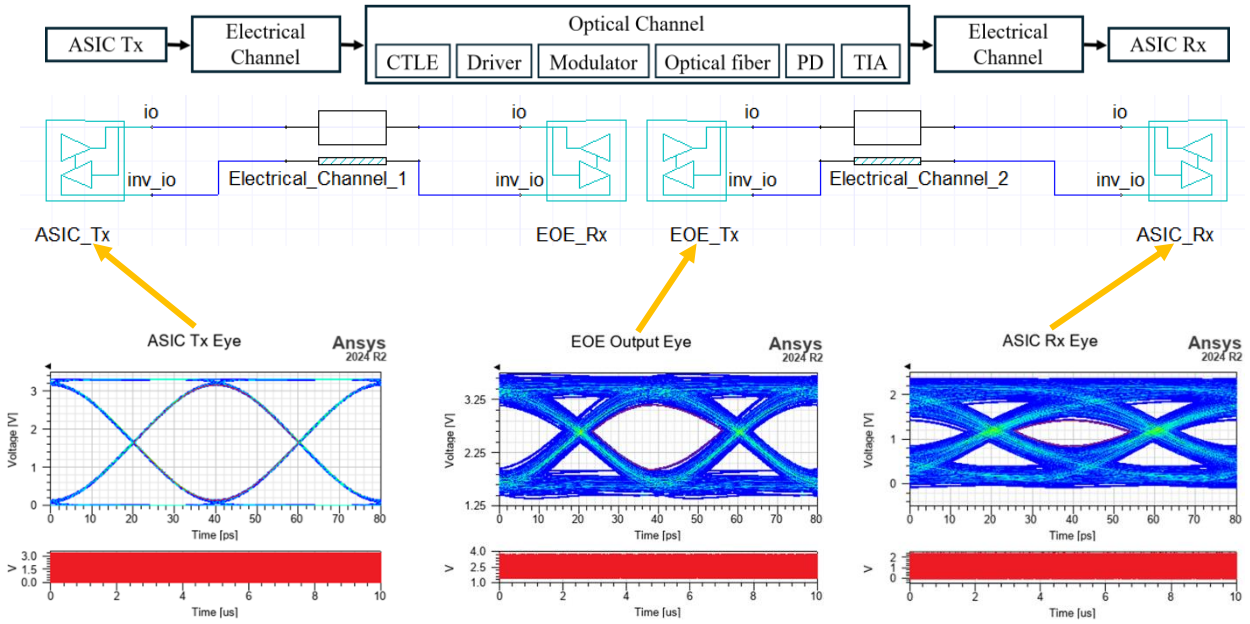
- The reduced-order model simulation runtime achieves at least a 100x speedup compared to the full optical module simulation through INTERCONNECT with optical sample rate as 10 THz.

Simulation Run Time Benchmark

Simulation Time Window		30 ns	300 ns	3000 ns
Number of Random Bits		750	7,500	75,000
Simulation Run Time	INTERCONNECT	50 s	354 s	4640 s
	Reduced-Order Model	0.448 s	3.356 s	34.513 s

IBIS-AMI simulation

- We built an AMI repeater testbench for a high-speed SerDes link, where the EOE_Rx and EOE_Tx represent for the optical module. The output of EOE_Rx is automatically passed to EOE_Tx as input, connecting the upstream and downstream links.
- AMI analysis was performed for a simulation time window of 10 *μs* at bit rate of 25 Gbit/s (for a total of 2.5x10^5 bits), and it took only 203 seconds runtime.
- The performance of optical module is well captured by the AMI model built by this flow.



Summary

- We have developed an ML assisted workflow to create IBIS-AMI models for optical modules, enabling signal integrity analysis of advanced SerDes link:
  - This workflow provides powerful tools for users to extract an optical module into an AMI model with both high accuracy and high simulation efficiency.
  - The physical design IP of the optical module is protected in the AMI model.
  - The AMI model created in this workflow satisfies the standard IBIS-AMI specification.
  - The AMI model extracted in this workflow is portable and redistributable.
  - This workflow is highly automated, easy to use, and can be customized according to the design and modelling requirements.

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