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Proposal for Automated E-O-E IBIS-AMI Modeling

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SPEAKERS

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Focused on modeling high speed digital (HSD) integrated circuits (ICs) based on the industry Input/Output Buffer Information Specification (IBIS) Algorithmic Model Interface (AMI) standard. Principal engineer and architect for the SerDesDesign.com web site, channel simulation, modeling tools and technology. Has provided custom NRZ/PAM4 Tx/Rx IBIS-AMI models and modeling training for over 40 high speed digital IC semiconductor companies

Outline

- Introduction
- Brief Overview of Optical E-O-E Repeaters
- Modeling the VCSEL Module
- Proposal for E-O-E IBIS-AMI Model Development
- Automated IBIS-AMI E-O-E Model Generation
- Testing the IBIS-AMI E-O-E Model
- Engineering Trade-offs
- Conclusions

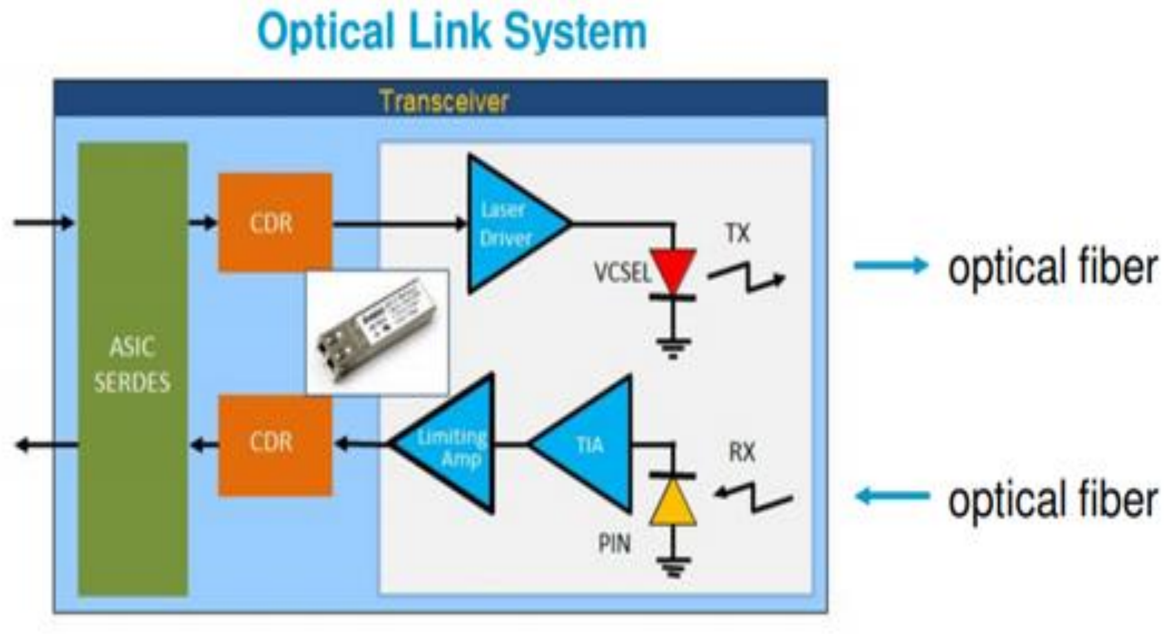
Introduction

- EOE systems typically represent repeaters and must be converted to IBIS-AMI models to be used in SerDes Channel Simulators.
- IBIS-AMI modeling has matured; processes can be automated.
- The EOE device developer can focus on extracting data.
  - Electrical: S-parameters or time domain waveforms.
  - Optical: time domain power waveforms.
- Proposal for automated EOE IBIS-AMI modeling.

Brief Overview of Optical E-O-E Repeaters

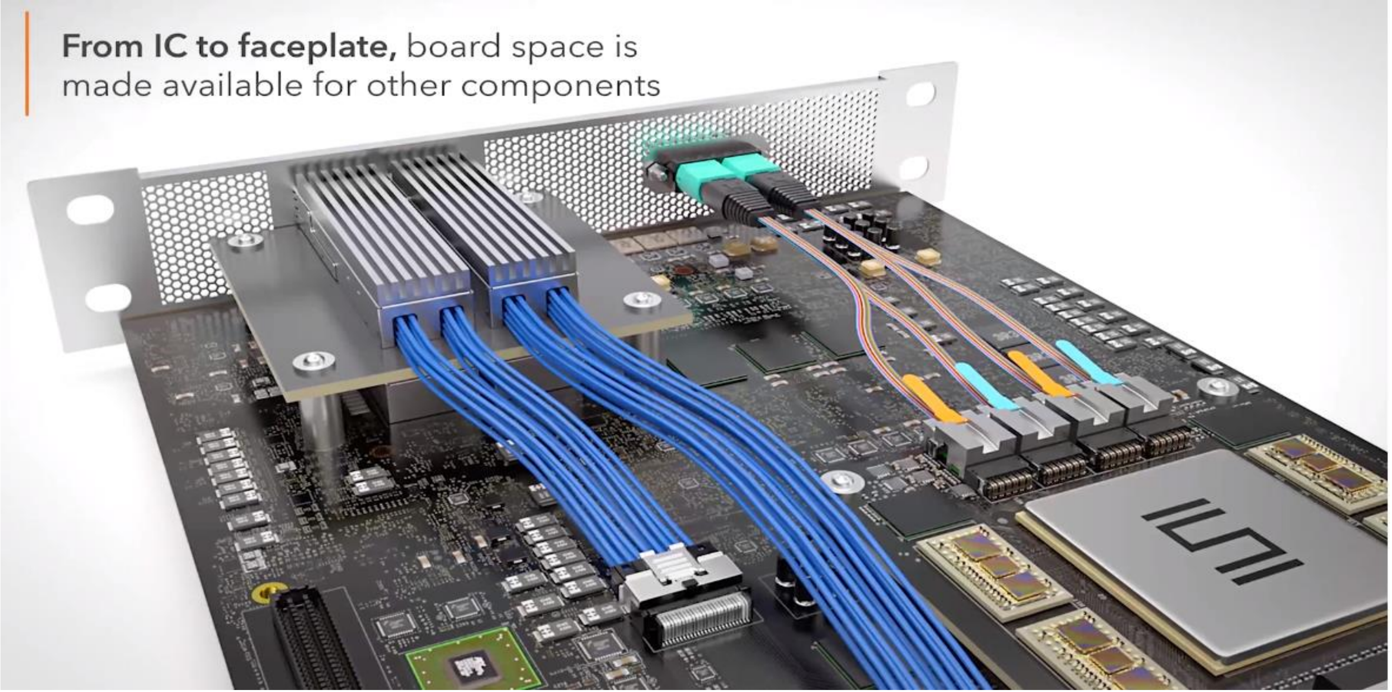
- **What are E-O-E repeaters**
- **How are E-O-E repeaters used in system simulations**

Brief Overview of Optical E-O-E Repeaters



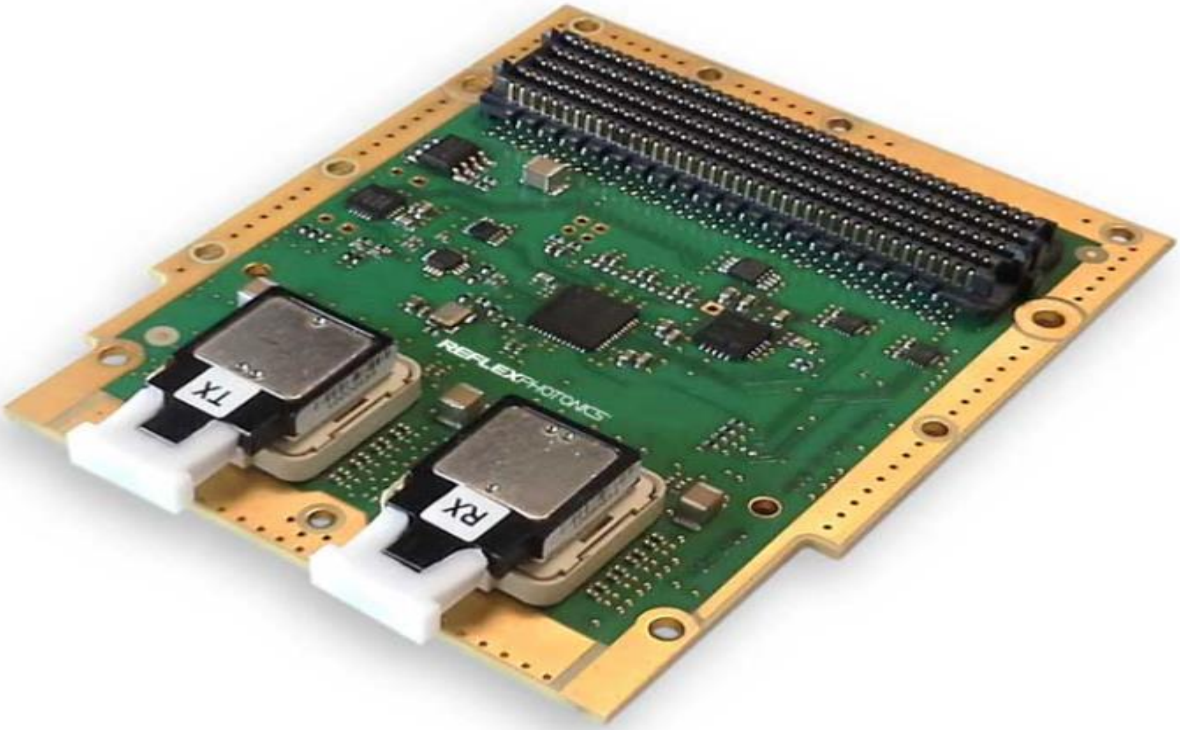
Brief Overview of Optical E-O-E Repeaters

- **Samtec Firefly EOE system**



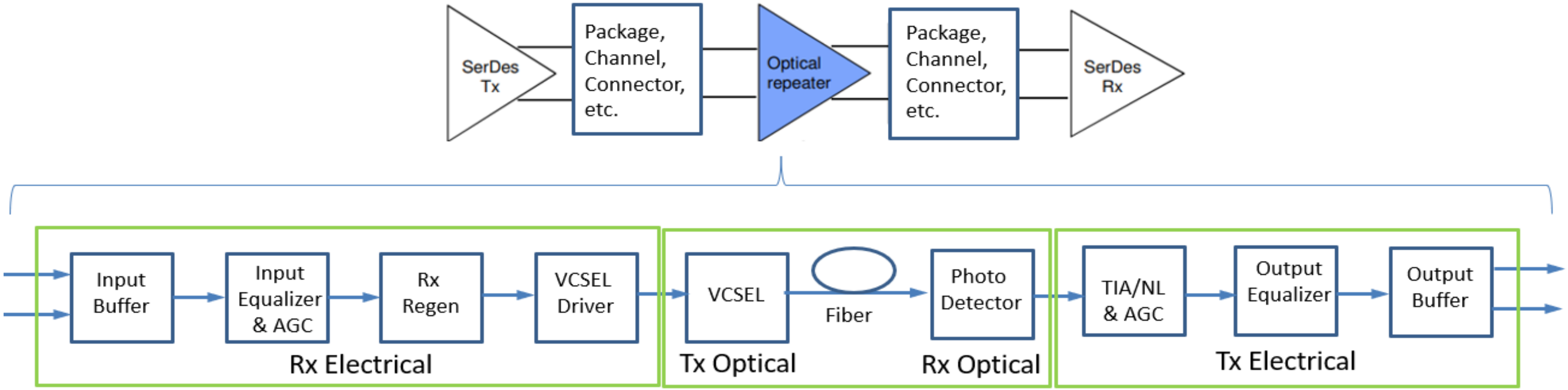
Brief Overview of Optical E-O-E Repeaters

- **Reflex Photonics Lightable EOE system**



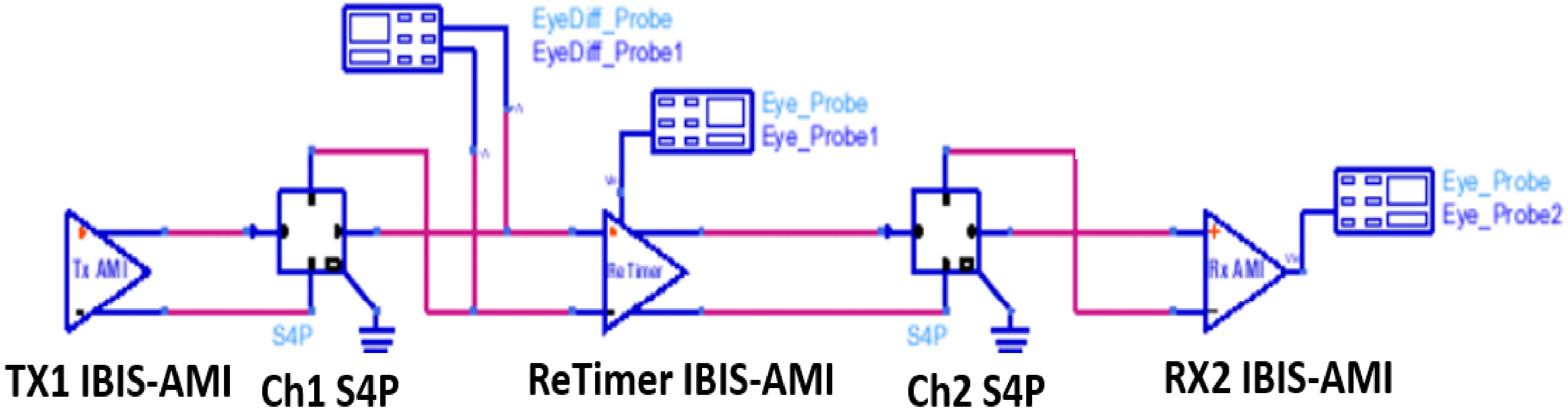
Brief Overview of Optical E-O-E Repeaters

Typical SerDes system EOE retimer block diagram



Brief Overview of Optical E-O-E Repeaters

Typical EOE system simulated using Keysight ADS Channel Simulator

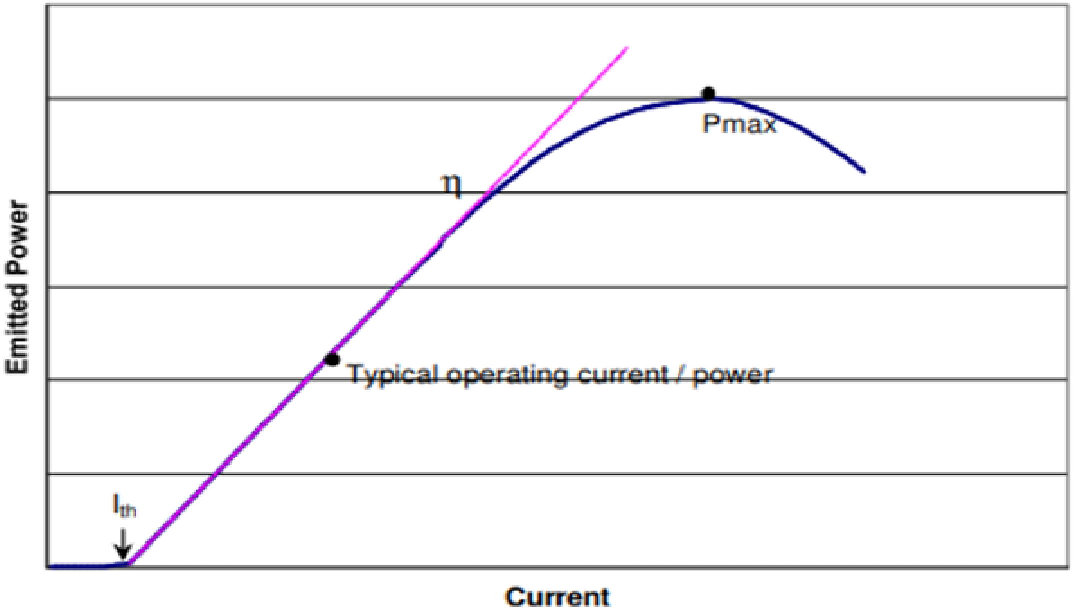


Modeling the VCSEL Module

- Typical VCSEL emitted power vs current
- VCSEL output power vs driver current and modulation current
- Approaches for modeling the VCSEL
- Measurement based VCSEL model
- VCSEL compensation

Modeling the VCSEL Module

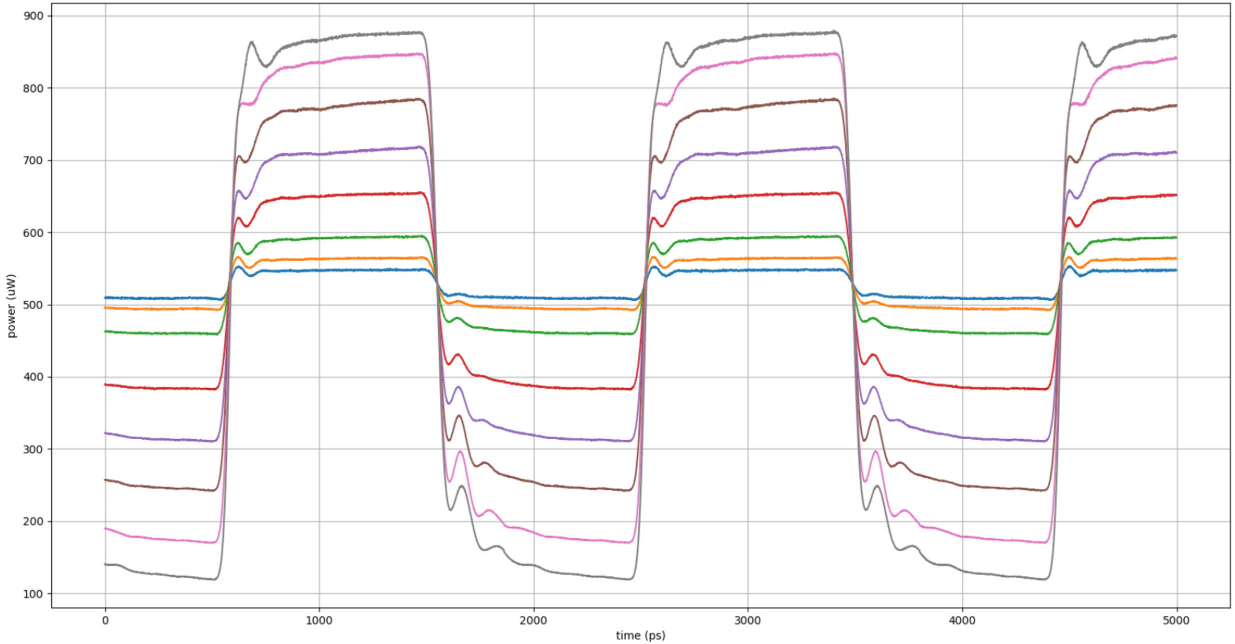
- **Emitted VCSEL optical power vs current**



Emitted power vs current

Modeling the VCSEL Module

- **VCSEL optical power waveform vs modulation current**



Modeling the VCSEL Module

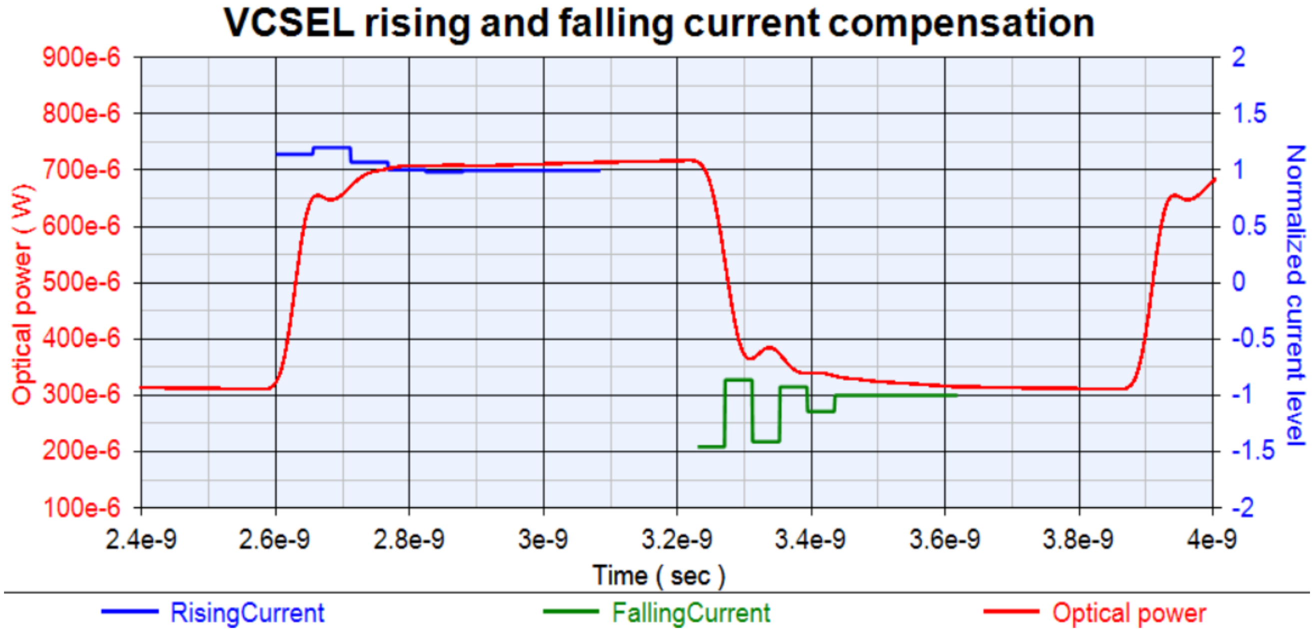
- Possible VCSEL modeling approaches
  - Simple nonlinear model based only on the optical output power versus drive current.
  - Keysight Physics-Based VCSEL Model introduced in 2013.
  - VPI Photonics software for modeling photonic systems.
  - Keysight Electrical-Optical-Electrical System Design Workflow which integrates the VPI Optical Link

Modeling the VCSEL Module

- **VCSEL modeling approach used in this proposal**
  - **“black box” model using VCSEL stimulus/response waveforms**
  - **Include modeling options**
  - **Include automated compensation for rising and falling waveforms**
  - **Include automated common-mode compensation**

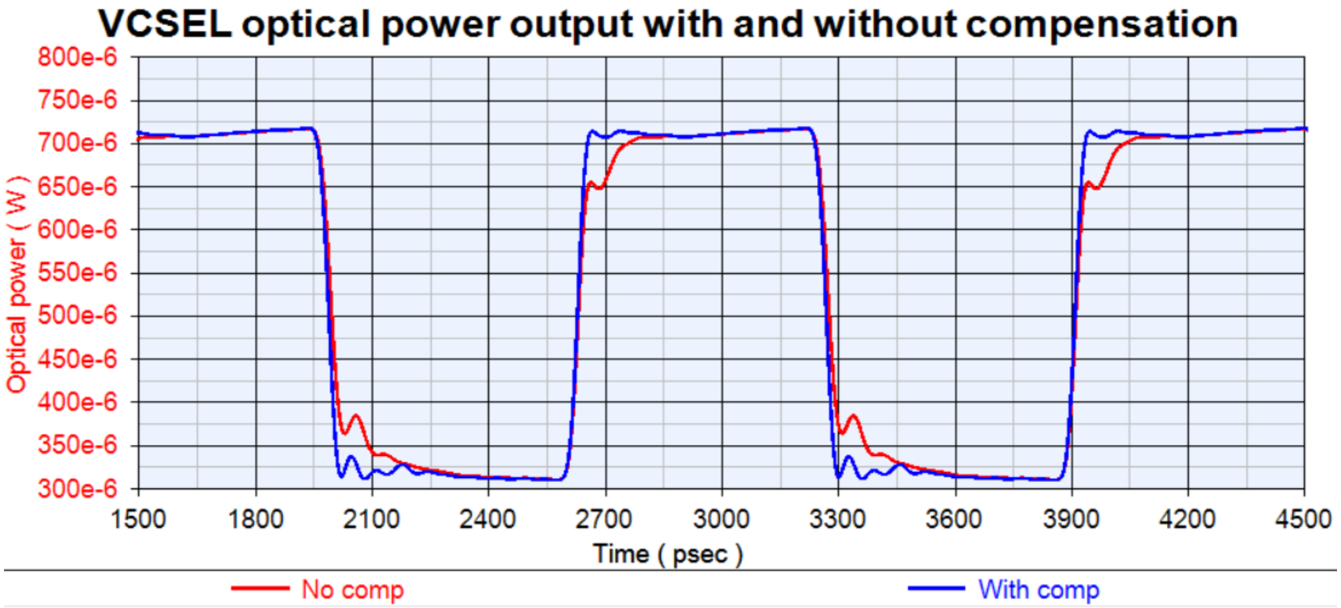
Modeling the VCSEL Module

- **Use current steps to compensate for rising and falling edges**

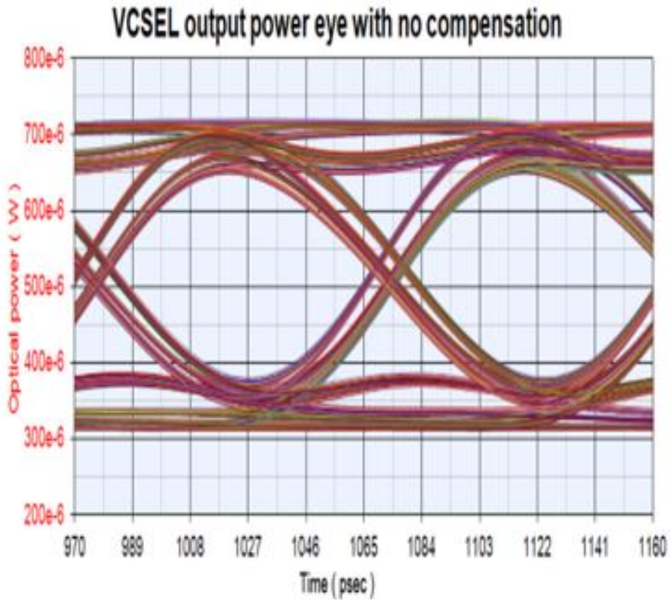


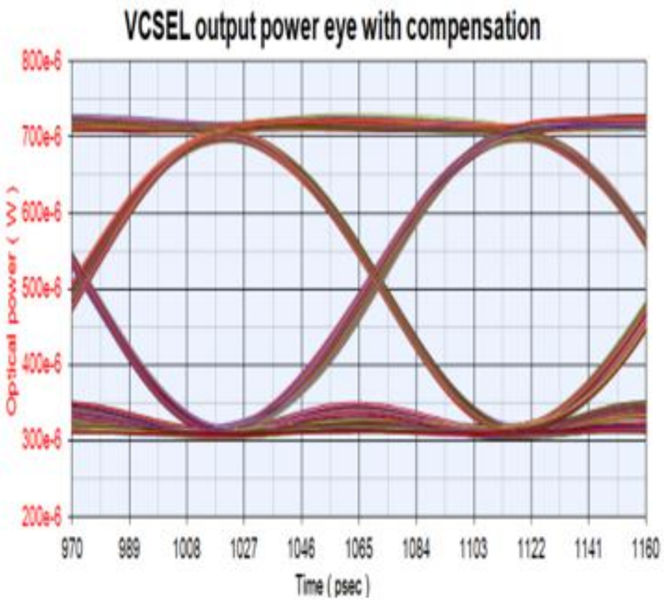
Modeling the VCSEL Module

- **The blue waveform is the optical power with compensation**



Modeling the VCSEL Module

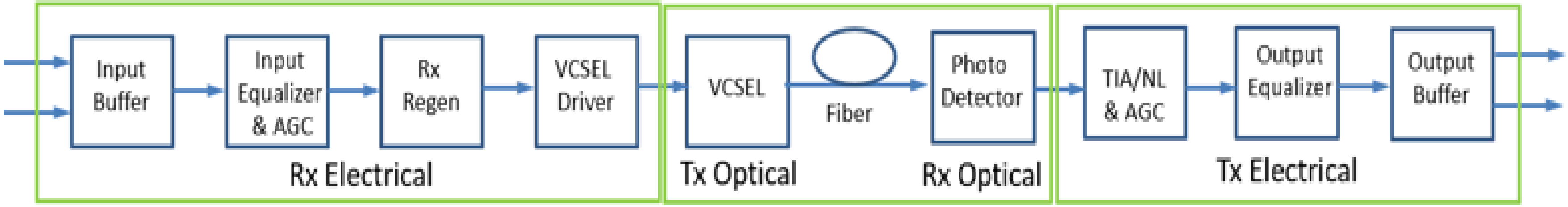




- The VCSEL output eye without and with compensation

Proposal for EOE IBIS-AMI Model Development

- **Many blocks in addition to the VCSEL model**



- **Use circuit stimulus and response measurements (hardware or simulations) in time domain or frequency domain for the various blocks in this block diagram**

Proposal for EOE IBIS-AMI Model Development

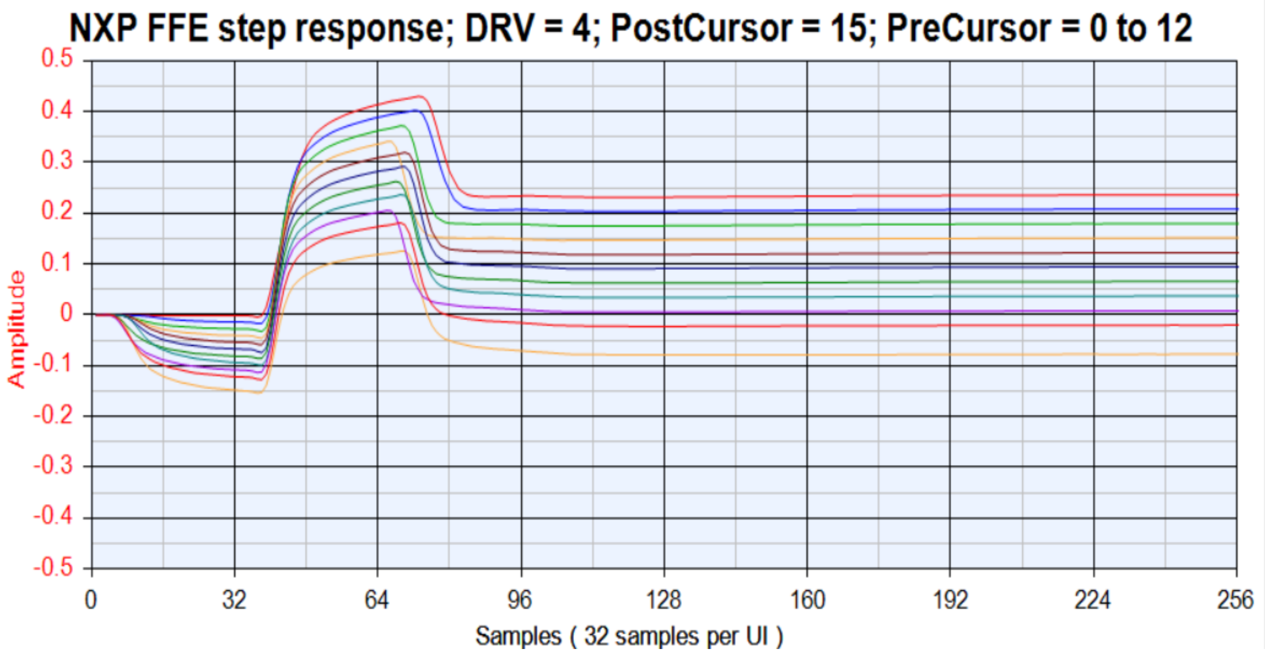
- **Input Rx IBIS Buffer and Output Tx IBIS Buffer models**
  - **Based on measured 4-port S-parameter files provided by NXP Semiconductor**
  - **IBIS 7.0 standard supports S-parameter use for IBIS buffers**
  - **Prior to the 7.0 standard, the IBIS buffer could only be simplistic RLC circuits**
  - **Using S-parameter files gives the IBIS buffer higher fidelity**

Proposal for EOE IBIS-AMI Model Development

- **Input Rx Equalizer model**
  - **Based on "black box" stimulus/response waveforms provided by NXP Semiconductor**
  - **FFE with 1 pre-cursor, 1 post-cursor**
    - ***14 Drive level states***
    - ***25 PreCursor states (12 negative, 0, 12 positive)***
    - ***33 PostCursor states (16 negative, 0, 16 positive)***
  - **The model must de-embed the IBIS buffer characteristic**

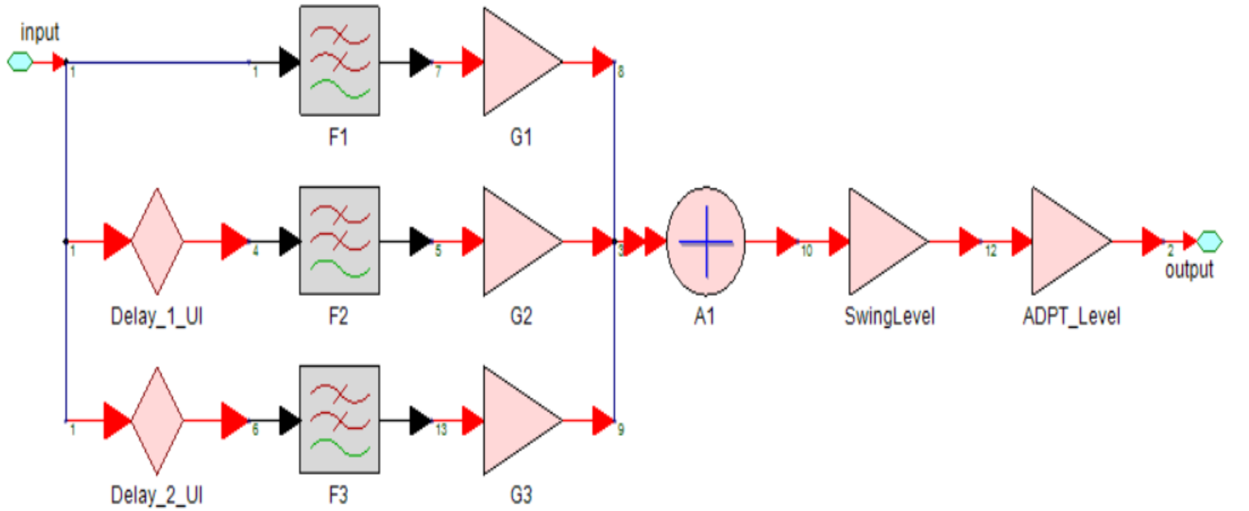
Proposal for EOE IBIS-AMI Model Development

- **Input Rx Equalizer model; example data**



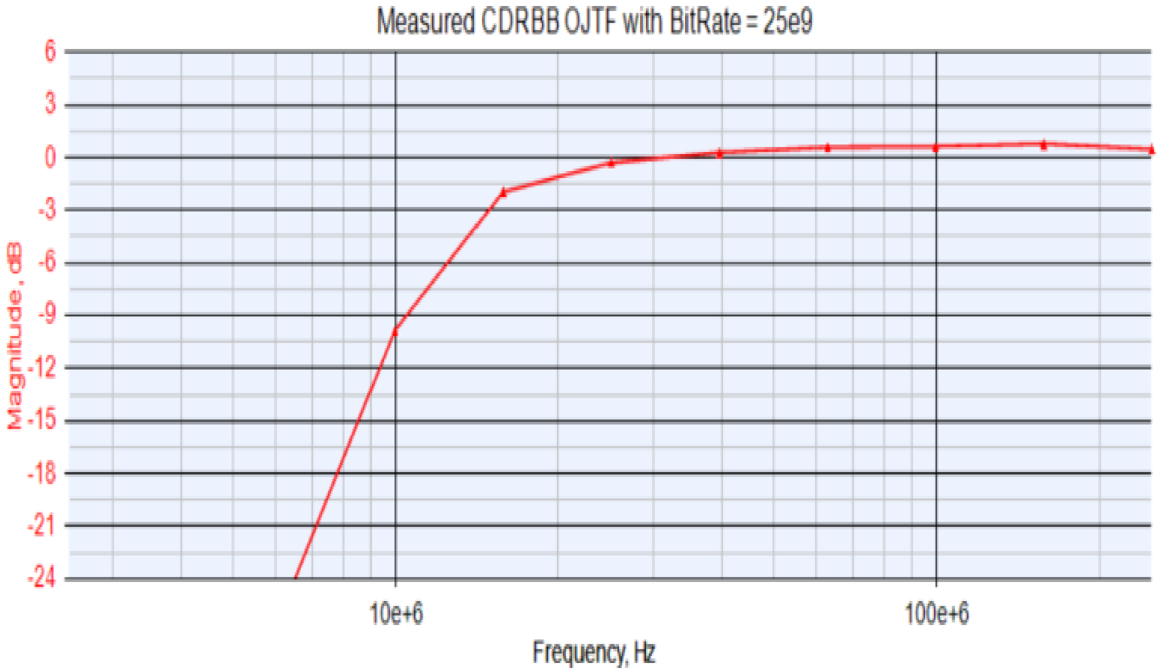
Proposal for EOE IBIS-AMI Model Development

- Input Rx Equalizer model; model processing
- The model derives the FFE tap gains and filters from the waveform data



Proposal for EOE IBIS-AMI Model Development

- **Rx Regenerator**
- **Based on a bang-bang type of CDR**
- **Use an OJTF characteristic**
- **Include additional jitter and AWGN as desired**



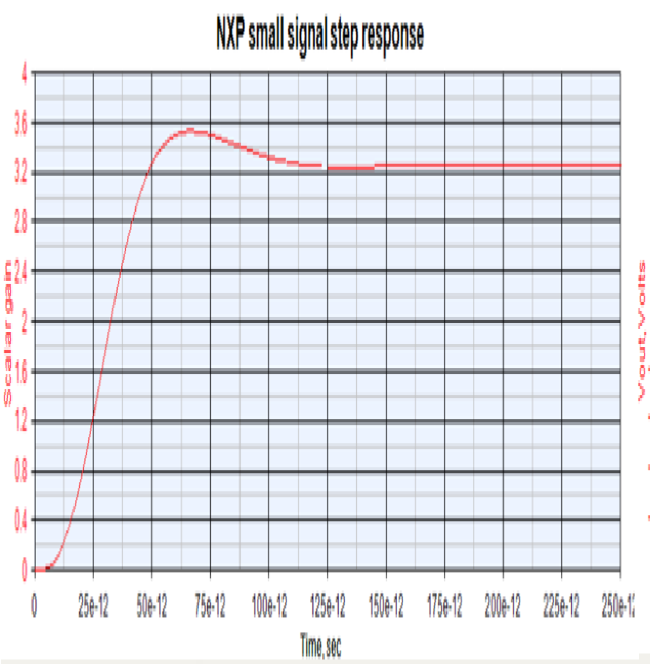
Proposal for EOE IBIS-AMI Model Development

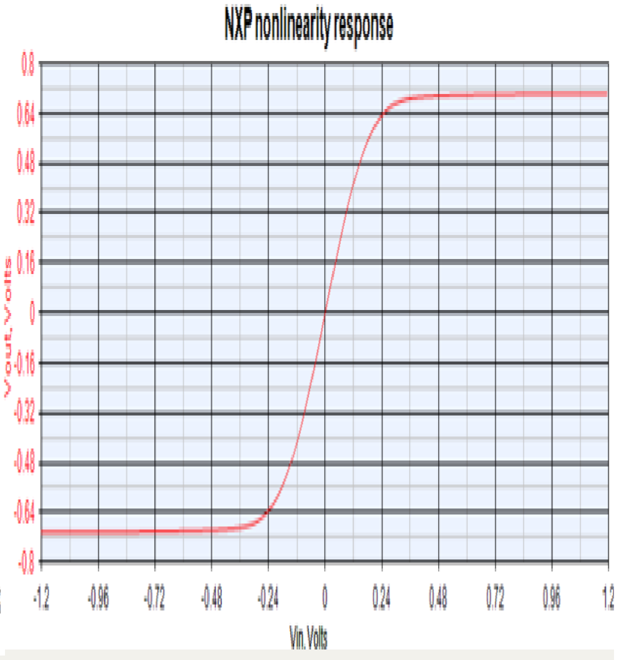
- Optical fiber model has these settable parameters
  - FiberLoss = Optical cable loss per unit length in dB/km
  - FiberLength = Optical cable length in meters
  - FiberConnectorLoss = Optical cable connector loss in dB
  - FiberCouplingLoss = Optical cable coupling loss in dB
  - FiberLossBW = Optical cable bandwidth-loss product (GHz * m)

Proposal for EOE IBIS-AMI Model Development

- **Optical PIN and TIA has these settable parameters**
  - **Photo-diode responsitivity, mA / mW**
  - **Photo-diode capacitance, uF**
  - **Trans-impedance resistance, V / A**
    - **This capacitance and resistance results in a low pass filter (RC time constant) at the photodiode output**
  - **Option to enable an automatic gain control at the TIA output**

Proposal for EOE IBIS-AMI Model Development





- **TIA nonlinearity defined from its small and large signal characteristics provided by NXP Semiconductor**

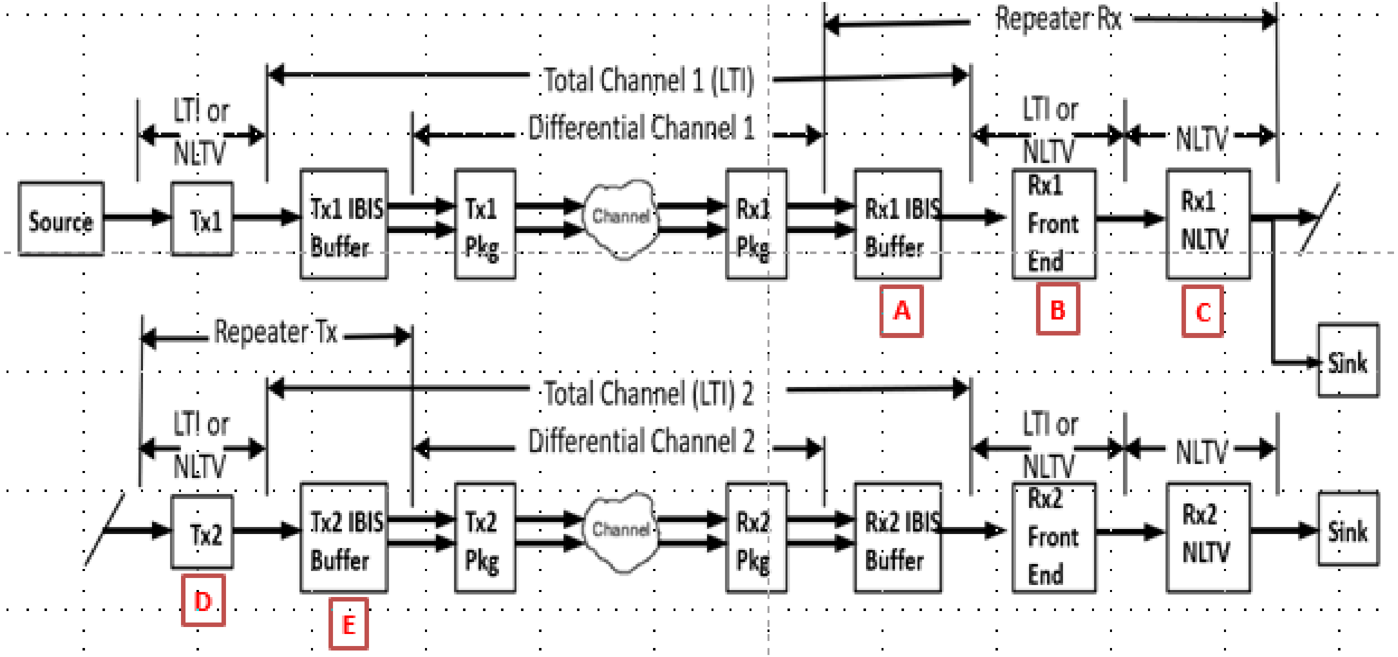
Automated E-O-E IBIS-AMI Model Generation

- **Using the modeling data**
- **Generating the IBIS-AMI model**

- **To do this, a Channel Simulator was used with models that readily accept characterization data from circuit simulations or hardware measurements.**

Automated E-O-E IBIS-AMI Model Generation

- **The EOE SerDes system was setup up using a series of blocks**



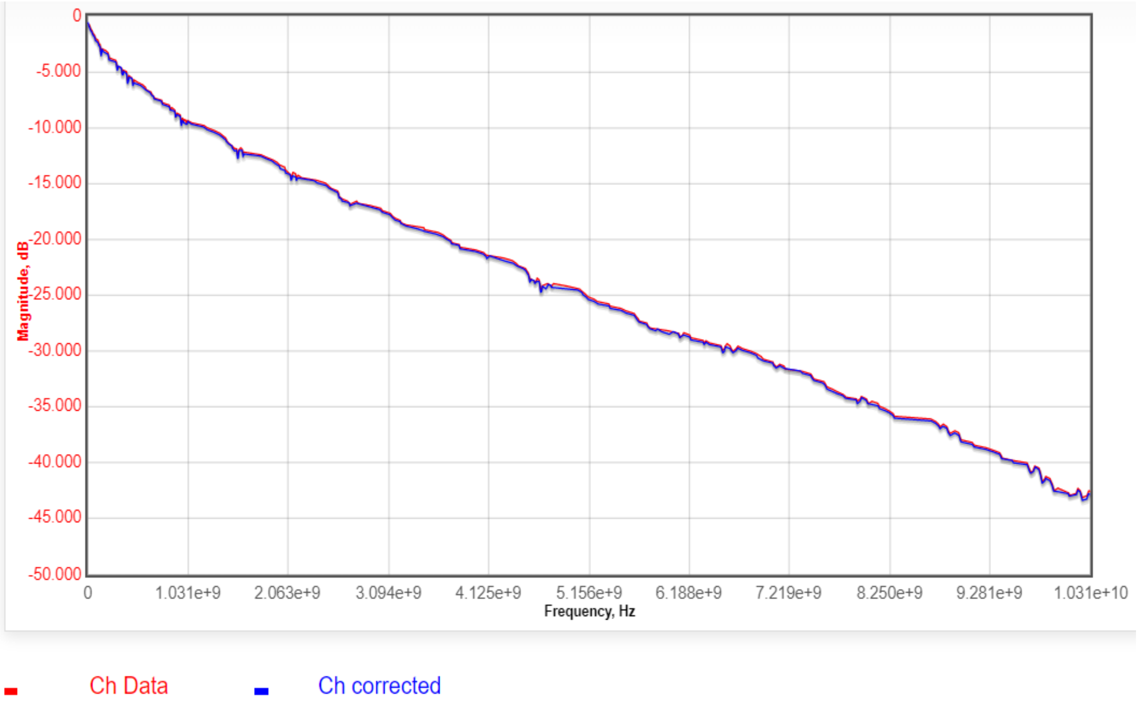
Automated E-O-E IBIS-AMI Model Generation

- All data needs to be combined into one IBIS-AMI model
- Data files are included for these sections
    - A: Rx Input IBIS buffer: S-parameter data
    - B: Rx Input Equalizer: Waveform data
    - C: VCSEL and driver: Waveform data
    - D: TIA nonlinearity: Small signal and large signal data
    - E: Tx Output IBIS buffer: S-parameter data

Automated E-O-E IBIS-AMI Model Generation

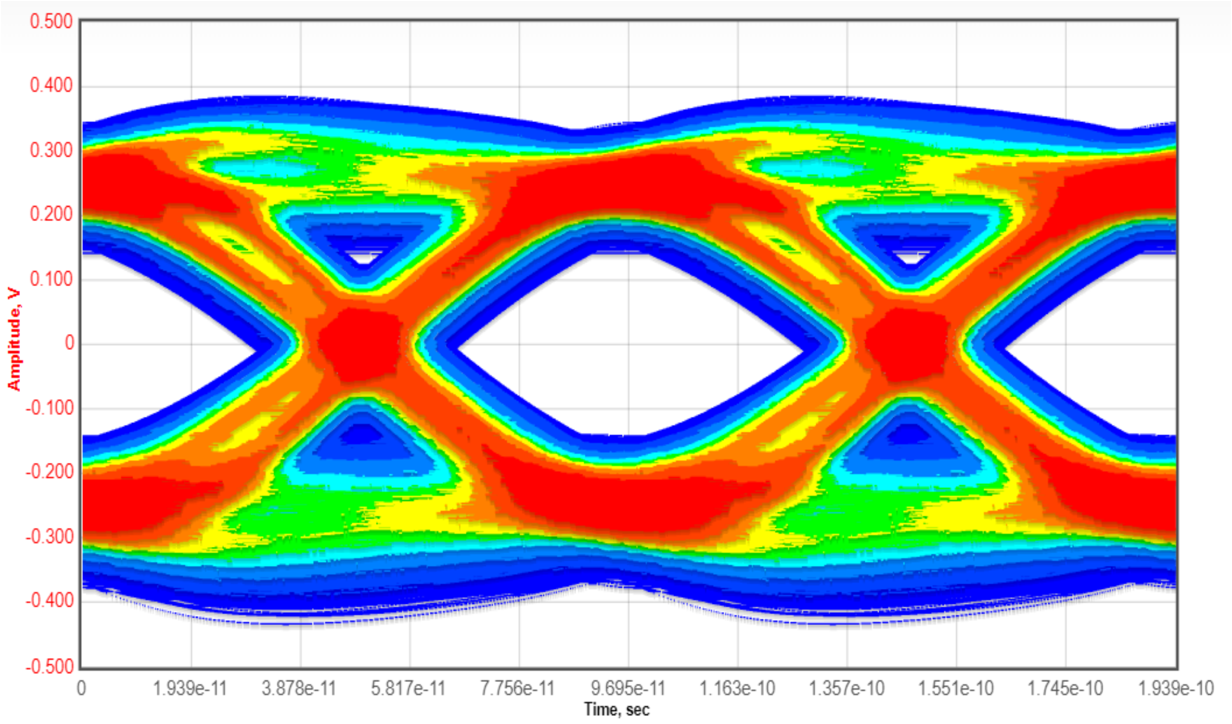
Total channel 1 response.

- **Red is the data s21dd response**
- **Blue is the impulse response in the frequency domain**

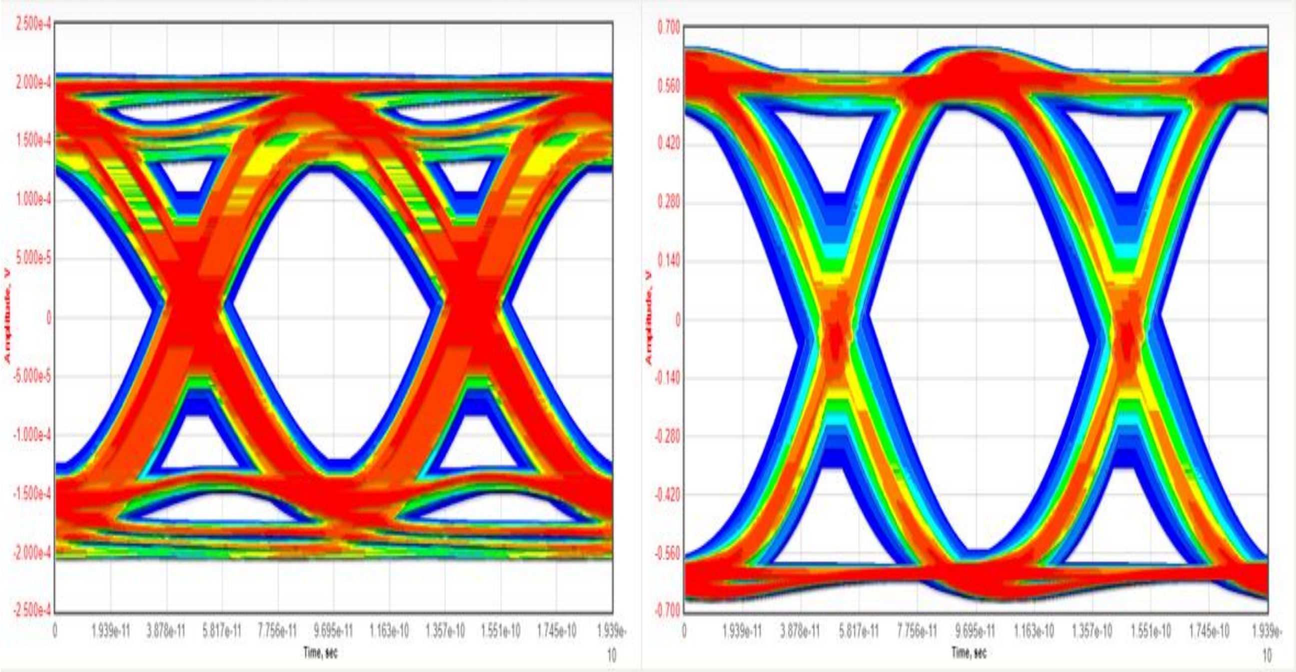


Automated E-O-E IBIS-AMI Model Generation

- **Eye density at the output of the Rx Equalizer**



Automated E-O-E IBIS-AMI Model Generation



- **Left: Eye density at VCSEL output**
  - **No VCSEL compensation**
- **Right: Eye density at TIA output**
  - **with VCSEL compensation**

Automated E-O-E IBIS-AMI Model Generation

- **Many simulations were run to verify proper EOE retimer model operation and performance**
  - **Waveforms**
  - **Eye density plots**
  - **Timing and amplitude BER waterfall plots with BER extrapolation**
  - **Other metrics**

Automated E-O-E IBIS-AMI Model Generation

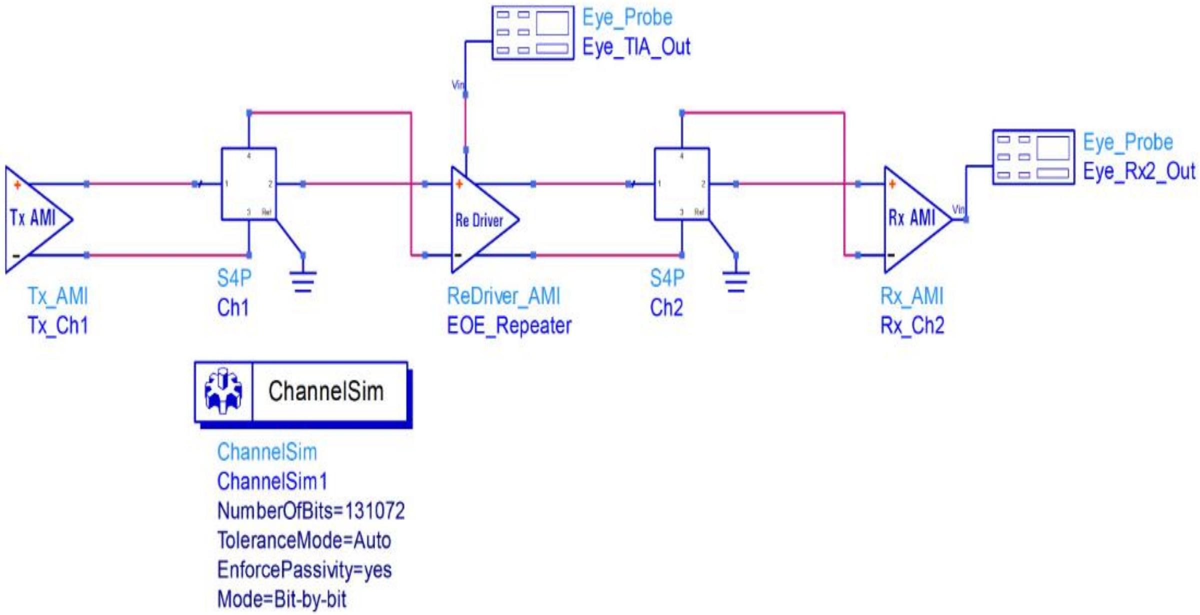
- Generate IBIS-AMI model after satisfied with simulation results.
- To do this, one enables the Channel Simulator analysis setup parameter GenerateModels and rerun a simulation.
- The IBIS-AMI model files are generated at the end of the simulation.
- The Windows/Linux build projects for the generated IBIS-AMI model can be provided with source code so that any part of the included data can be changed as needed to change the existing EOE IBIS-AMI model or create new EOE IBIS-AMI models

Testing the IBIS-AMI E-O-E Model

- The generated EOE IBIS-AMI model can be used in any Channel Simulator
- The model generated is named EOE_Repeater and is used two Channel Simulators:
  - 1) Channel Simulator A which contains the automated EOE IBIS-AMI modeling.
  - 2) Channel Simulator B which is another popular in the industry.
- When used in Channel Simulator A the results are the same as obtained during model development.

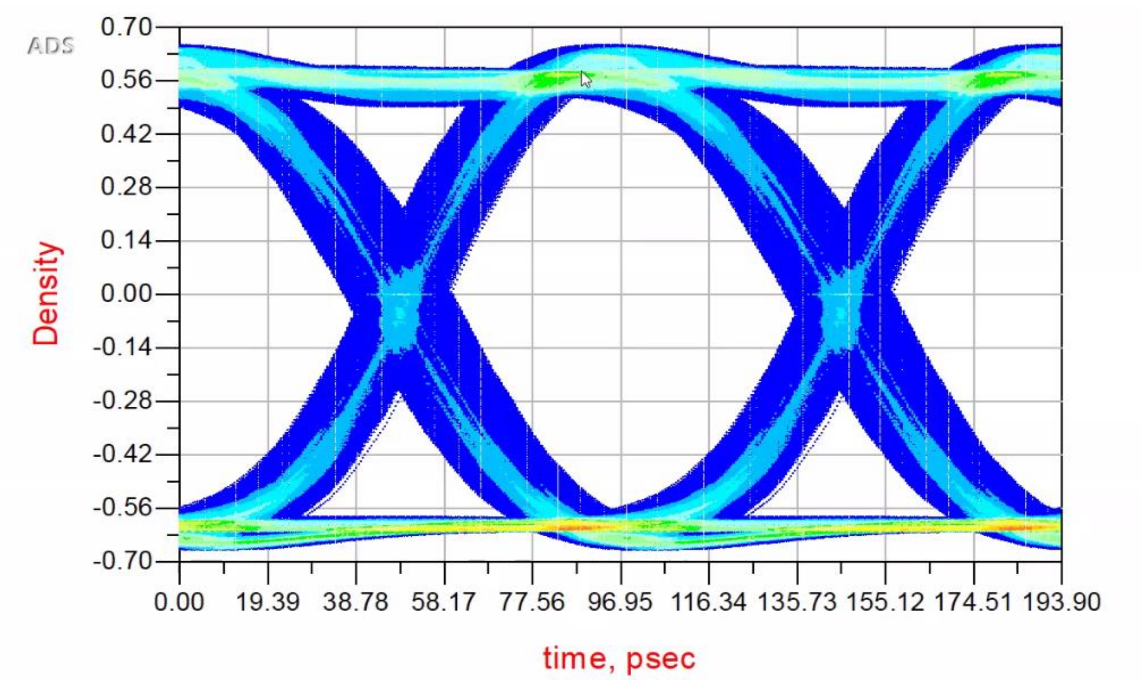
Testing the IBIS-AMI E-O-E Model

- **Channel Simulator B**
- **SerDes system EOE Repeater schematic**



Testing the IBIS-AMI E-O-E Model

- **Channel Simulator B**
- **Eye is essential the same as from Channel Simulator A with different eye coloring**



Engineering Trade-offs

- **Models using measured data inherently have high accuracy**
  - **Improve with better and more detailed measurements**
- **Optical fiber and optical detector used simplified parameterized algorithmic models**
  - **Improve with measured data**
- **Change architecture and add corner cases to better match EOE design**

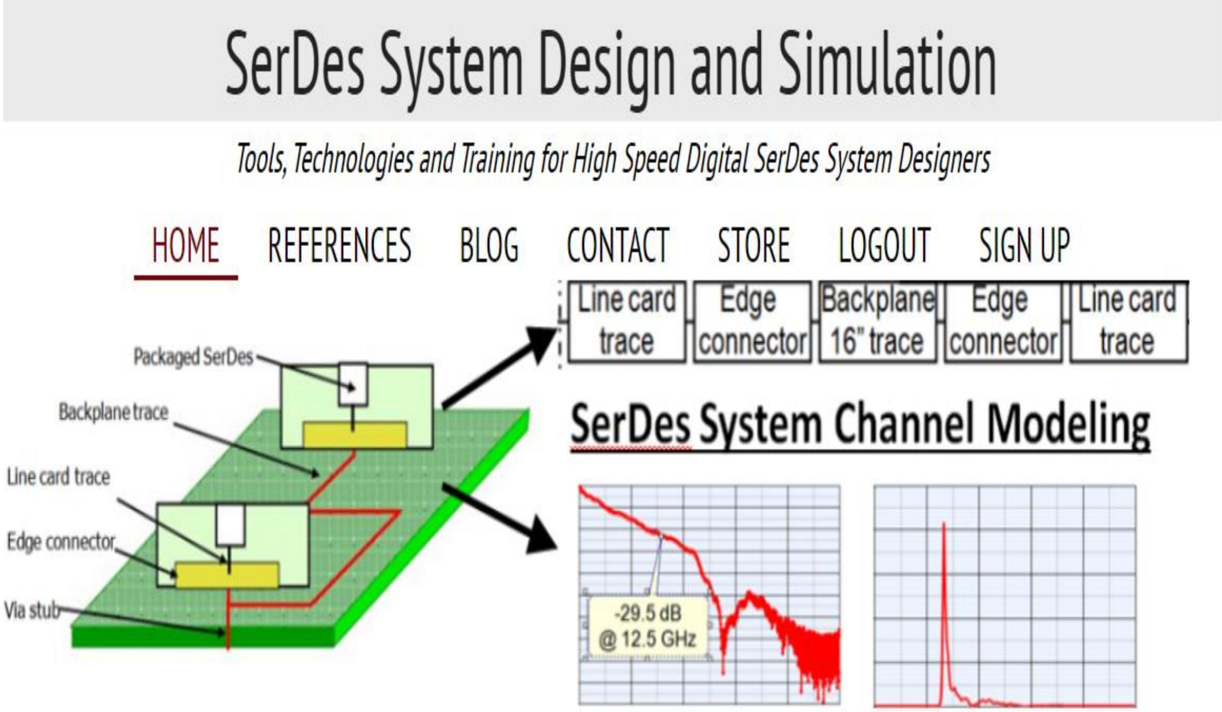
Conclusions

- A proposal for automating the generation of IBIS-AMI models for Electrical-Optical-Electrical repeaters was presented
- Modules in the EOE repeater can be modeled as “black boxes” with measurements in the time or frequency domain
  - This includes the VCSEL module
- The EOE developer can rely on an automated EOE IBIS-AMI model generation flow

MORE INFORMATION

SerDes Design.Com

- https://serdesdesign.com
- JohnB@serdesdesign.com



Thank you!

QUESTIONS?