Towards Accurate Yield Analysis for Real-life Photonic Integrated Circuits

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Ansys

Abstract

Photonic Integrated Circuits (PICs) are pervasive in modern technology and enable everything from 5G/6G communications to taking the next big step in quantum computing. For PICs to be successful, we need to equip the photonic circuit designer with the necessary tools to create robust and manufacturable designs for their circuits. Fabricated photonic circuits are always different from their nominal design due to variations in the foundry process as well as SOI chip variations. As a photonics designer, it is important to understand how these variations affect the expected output and hence the yield. Statistical simulations provide insight to these variations. These variations in fabricated photonic circuits are often spatially correlated and so the statistical simulation must be layout aware and account for the spatial correlation between the different circuit elements. However, manufacturing variability is just one of the many challenges faced by a photonic circuit designer. Thermal effects from the drivers in the electronic IC, distortions in the electrical driving signal due to loading effects, and RF losses from packaging can all affect the yield of a real-life PIC. To address these challenges, we need compact models that can capture these effects and solvers that can accurately predict yield with electro-optical co-simulation. This presentation will focus on the research and development at Ansys, which is pioneering PIC simulation and the PIC design ecosystem.

Outline

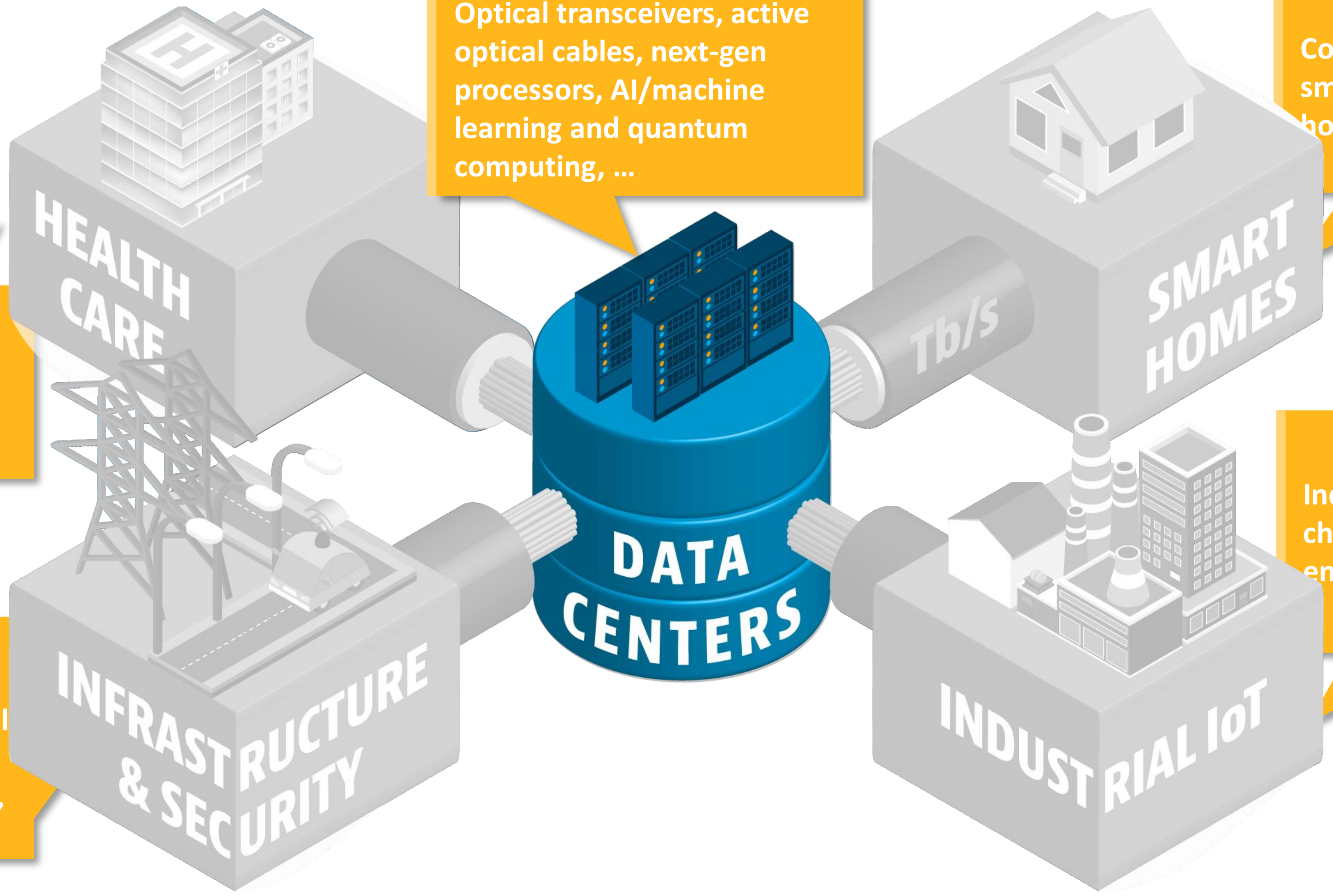
- Photonic integrated circuits (PICs) are pervasive in modern day technology
- Accurate yield analysis critical to the success of PIC designers
- Need to address an array of challenges:
    - Statistical variations + spatial correlation
    - Thermal effects on PIC
    - Electro-optical co-simulation – EPDA design flows
    - Source (laser) modeling for PIC simulations
    - Accurate compact model generation

Photonics is Everywhere, and Growing!

Optical transceivers, active optical cables, next-gen processors, AI/machine learning and quantum computing, …

Consumer electronics, smart phone sensors, IoT home sensors, displays, …

Medical imaging, sensing and diagnostics, lab on a chip, …

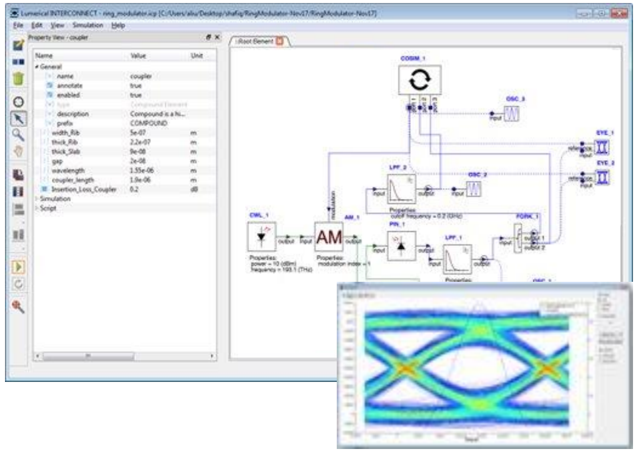


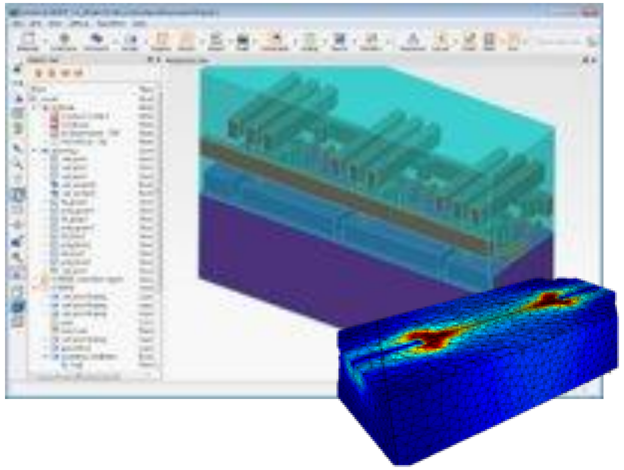
Industrial IoT, industrial chemical & environmental sensing, …

Optical communications, analog & RF systems, 5G, structural & environmental sensors, autonomous vehicle navigation (LIDAR), …

Ansys Lumerical Overview

A comprehensive set of tools and features for photonics

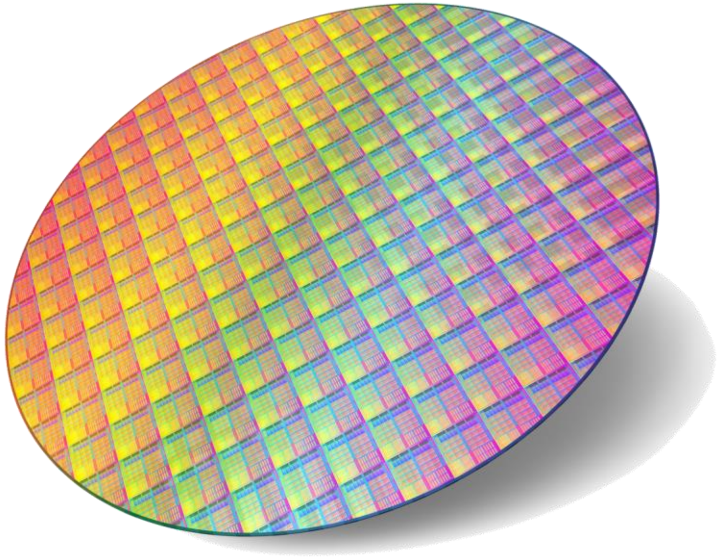


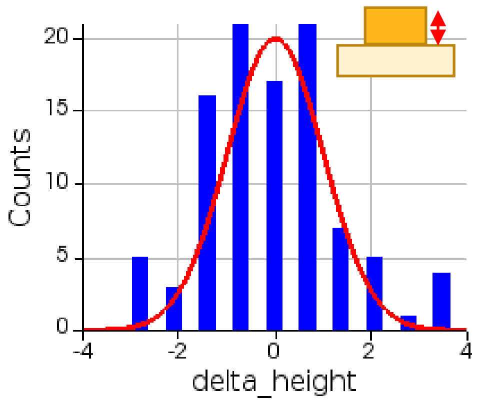


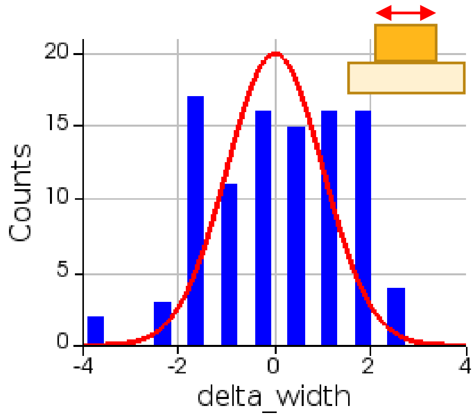
Photonic Integrated Circuit Simulation	Interoperability, HPC & Cloud features
INTERCONNECT Photonic Integrated Circuit Solver **Photonic Verilog-A Platform** **CML Compiler** Photonic Model Development	**HPC & Cloud** HPC clusters, AWS, Azure, schedulers, … **Automation APIs** Matlab, Python, Lumerical Script **Tool Integrations** IPKISS, Klayout, Matlab, Tanner, Virtuoso, ADE, Zemax **Foundry Support** AIM, AMF, CompoundTek, HHI, imec, SMART, TowerJazz
Photonic Multiphysics Simulation	
FDTD 3D Electromagnetic Solver **MODE** Waveguide Simulator **CHARGE** 3D Charge Transport Simulator **HEAT** 3D Heat Transport Solver **DGTD** 3D Electromagnetic Solver **FEEM** Waveguide Solver **MQW** Quantum Well Gain Solver **STACK** Optical Multilayer Solver	

Manufacturing Variability : Why Yield Analysis?

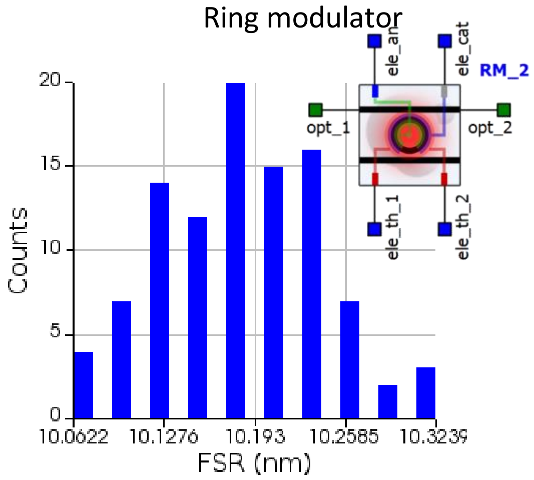
- Introduces project risk
- Process variability
  - Wafer height
  - Waveguide width
  - Side wall angle
  - Doping
  - Etc

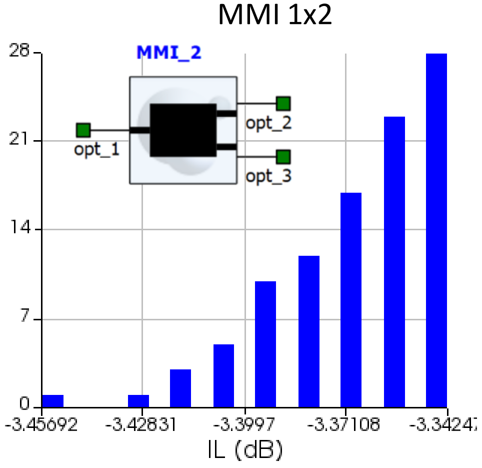




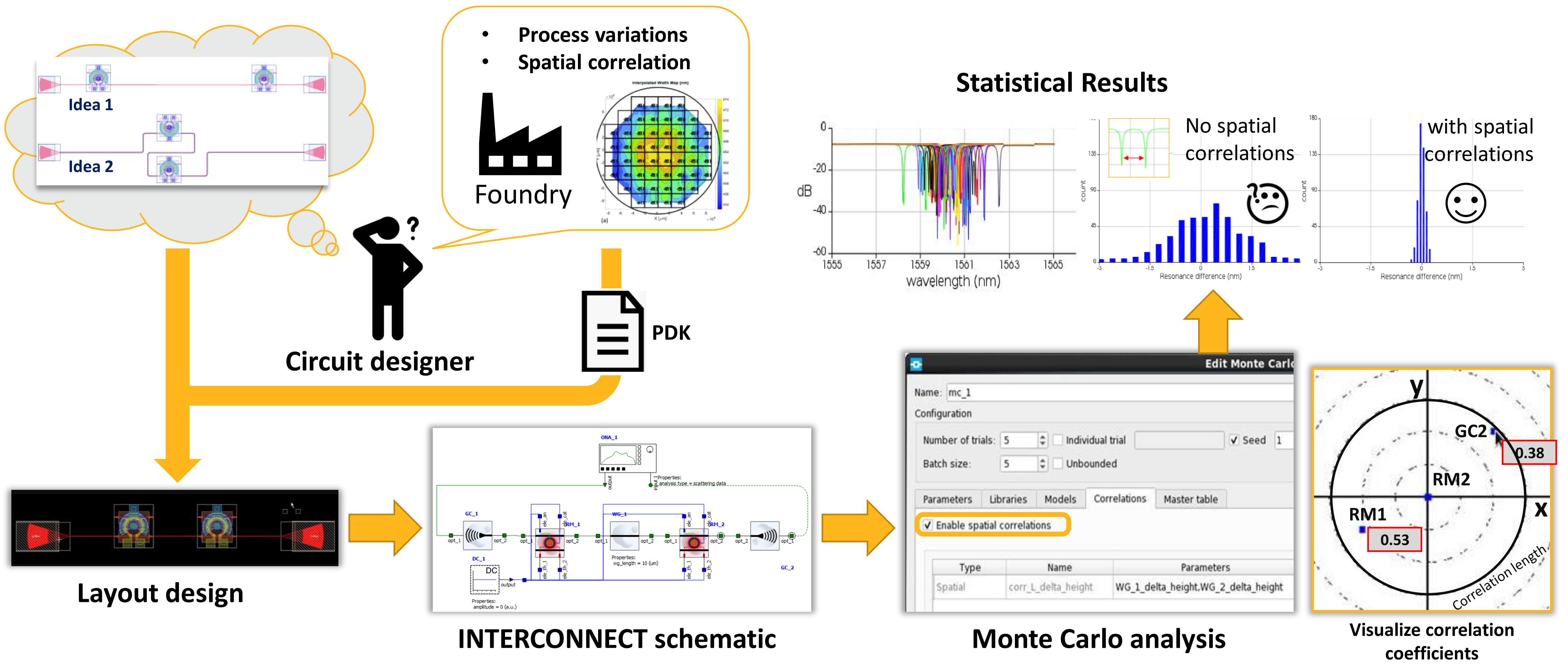


- Circuit designers want to know what to expect.
- Best/worst case scenarios (corner analysis)
- Yield (Monte Carlo analysis)



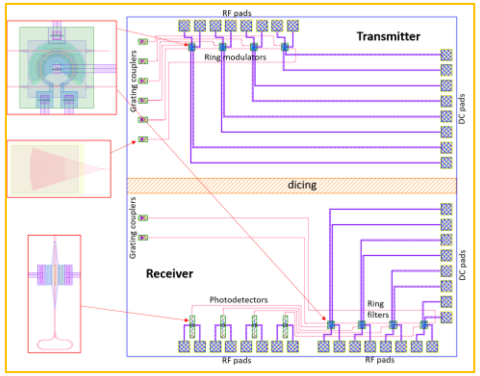


Modeling Spatial Correlation



Thermally Aware PIC Simulation

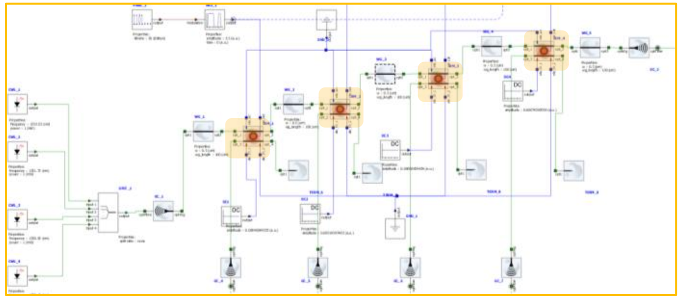
Layout



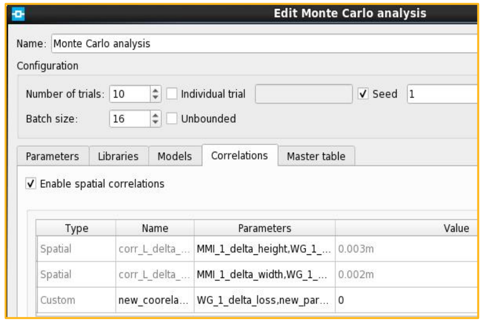
Netlist

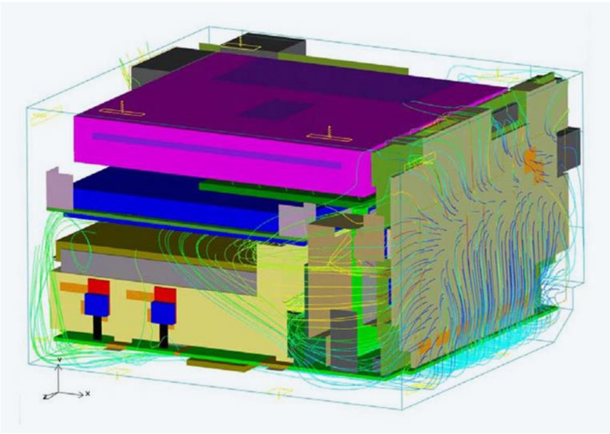
import

INTERCONNECT schematic

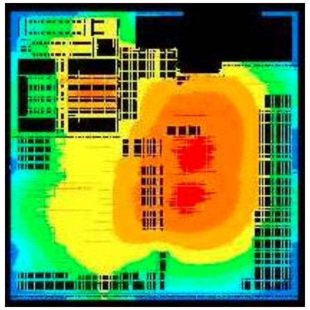


Monte Carlo analysis



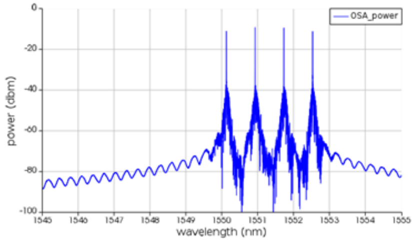


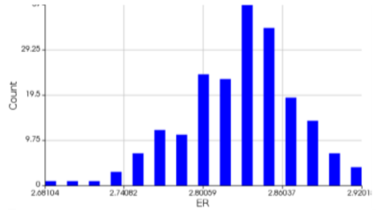
Thermal Simulation in ANSYS Icepak

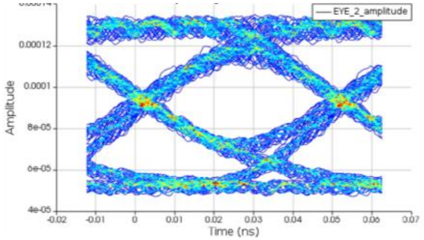


Temperature Map

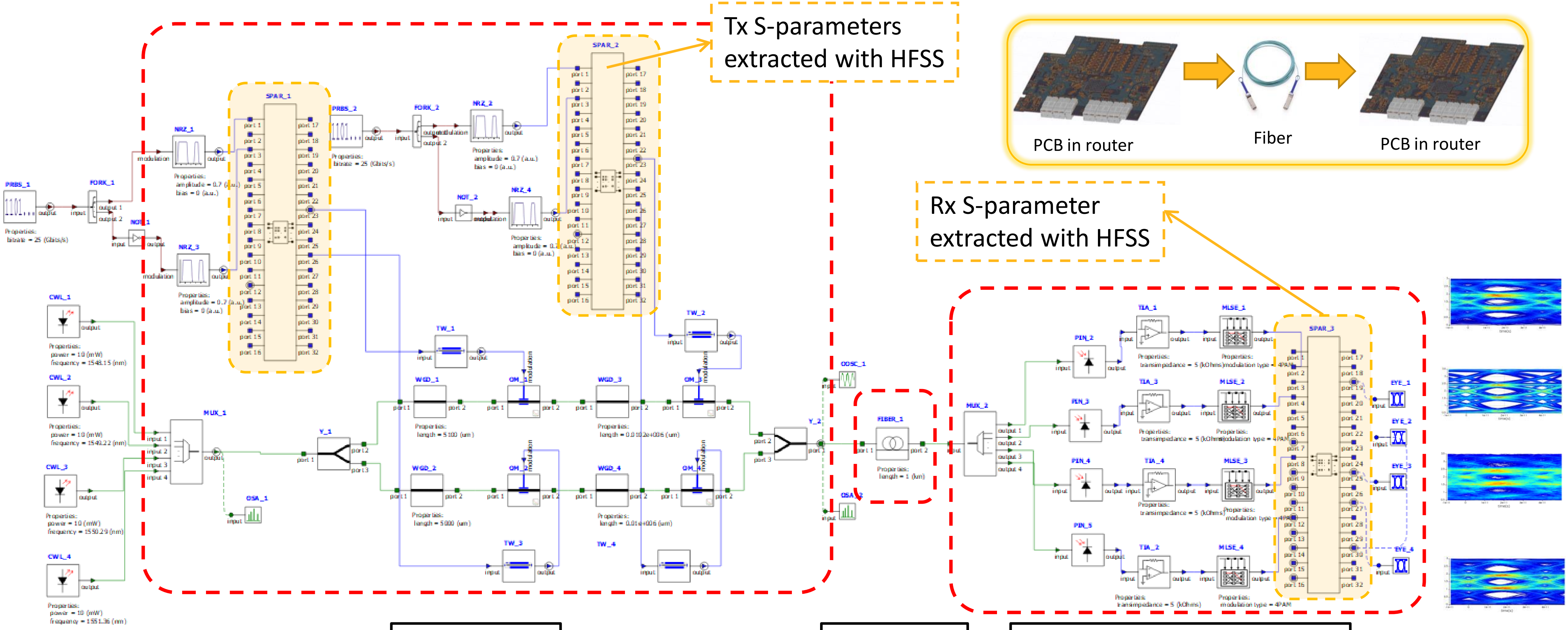
import







System Level Simulation with HFSS and INTERCONNECT



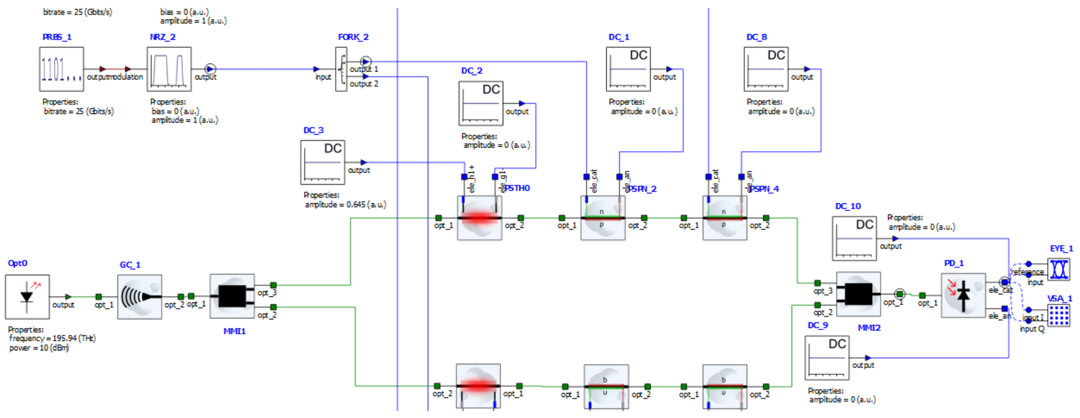
Tx:
MUX + MZM

1 km fiber
channel

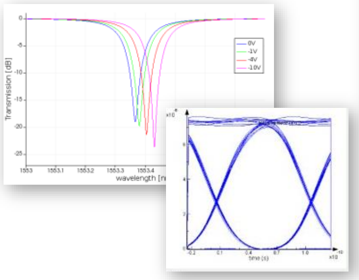
Rx:
DEMUX + PD + MLSE+ filters

EPDA Design Flows

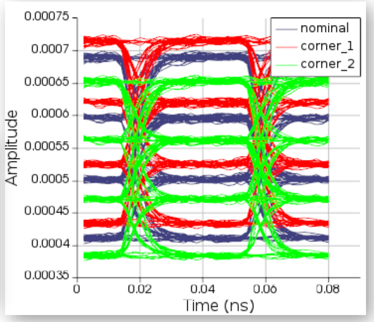
Ansys Lumerical INTERCONNECT platform



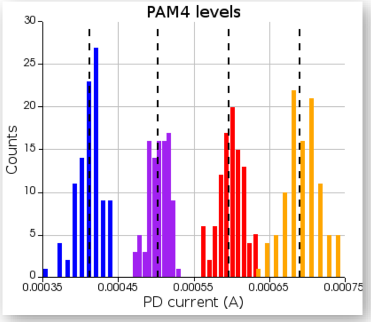
Frequency and time domain simulation



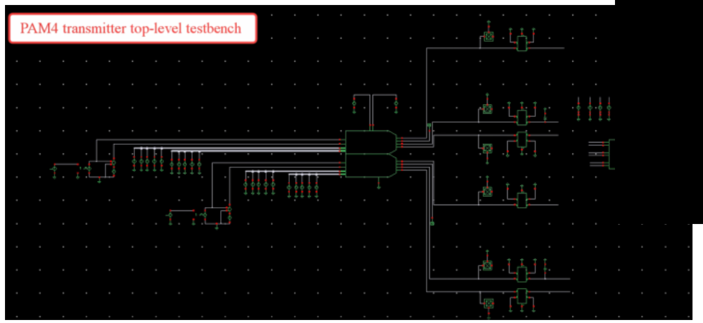
Corner analysis

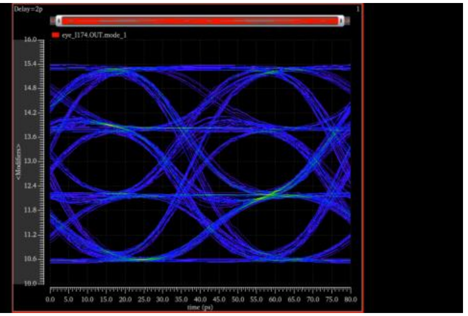


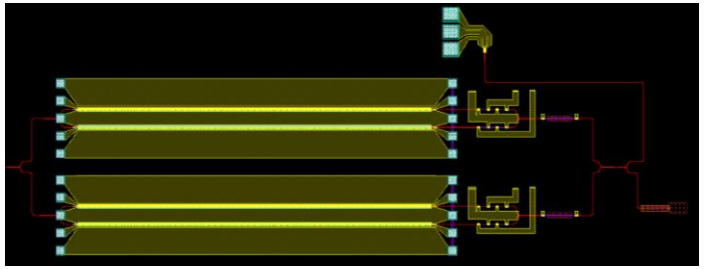
Monte Carlo analysis

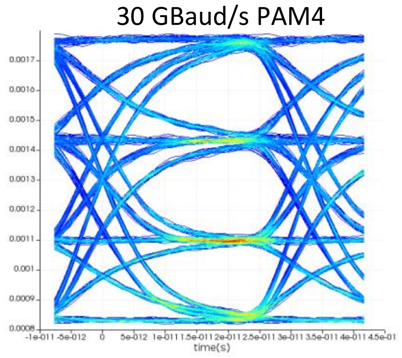


EPDA Design Flows

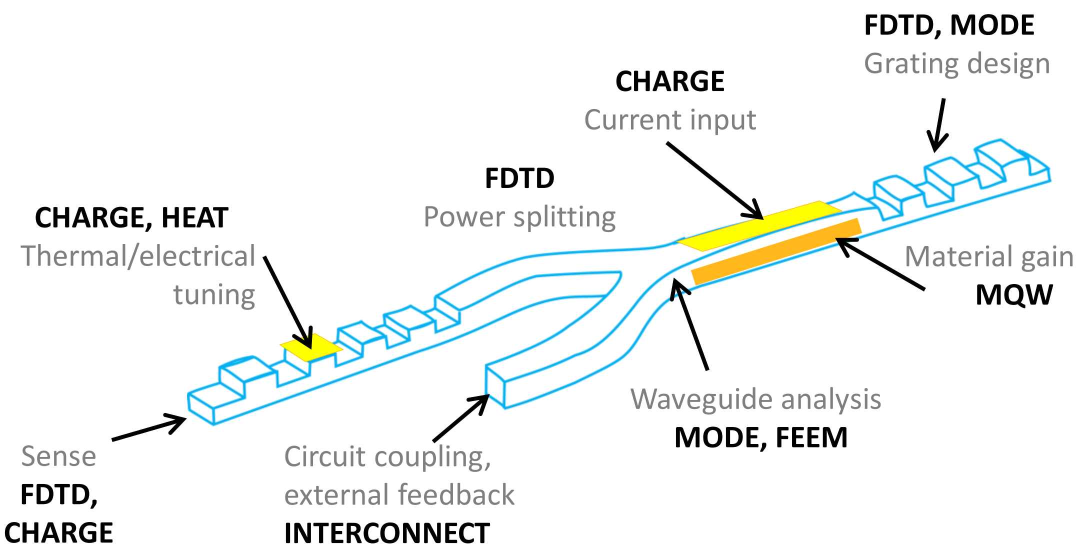


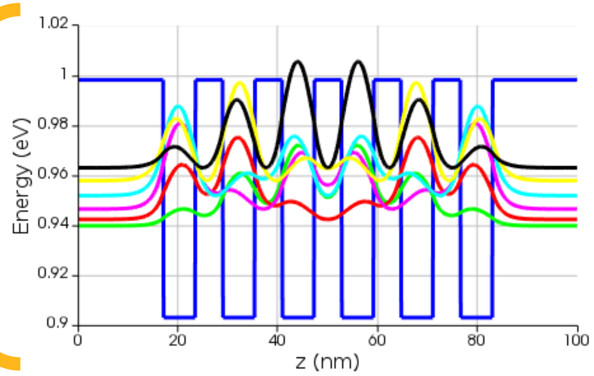


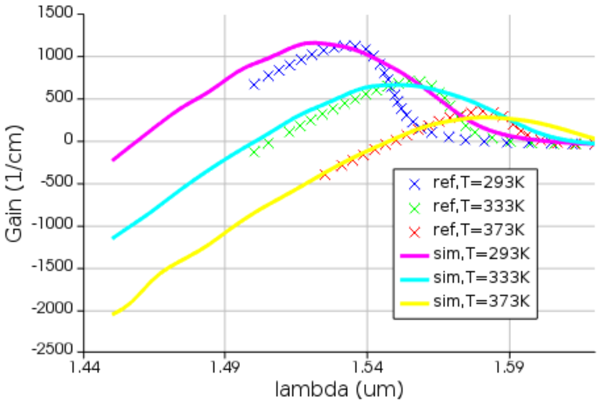


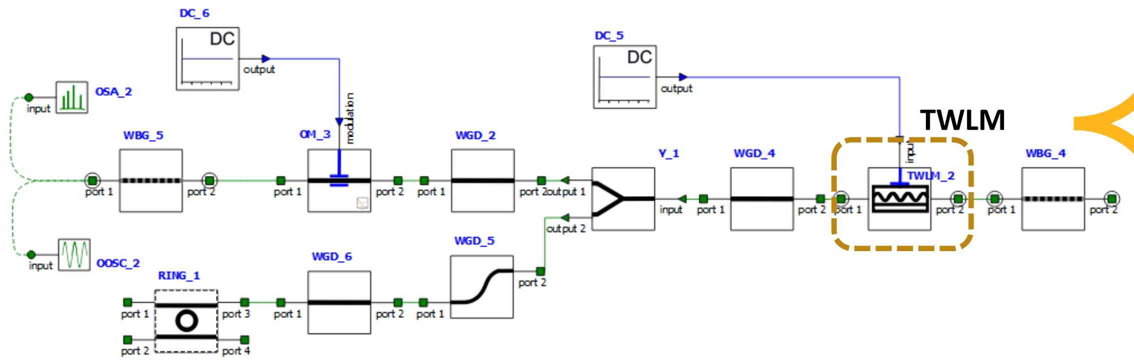


Ansys Lumerical Simulation Tools for Lasers and Gain

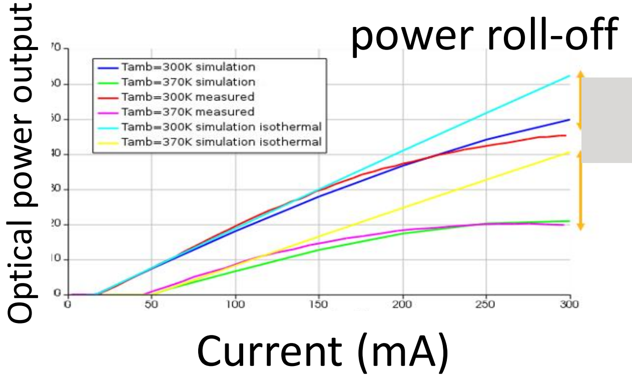




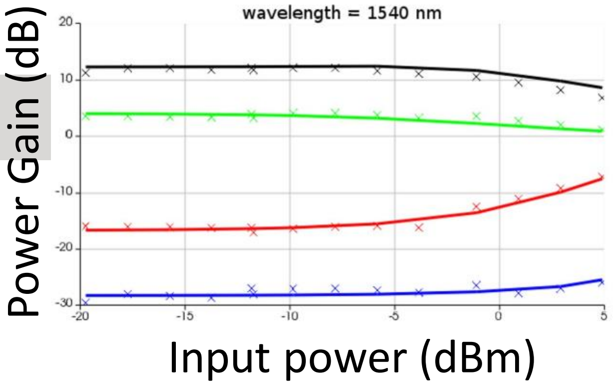




Laser self heating

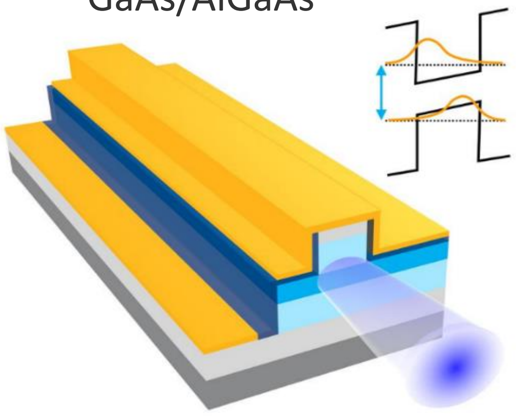


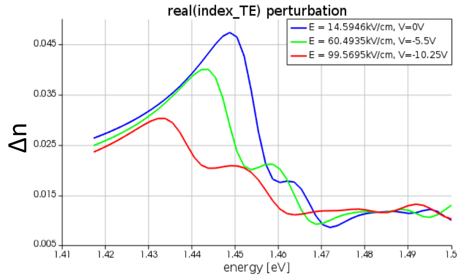
Fraunhofer HHI
Calibrated SOA Compact Model

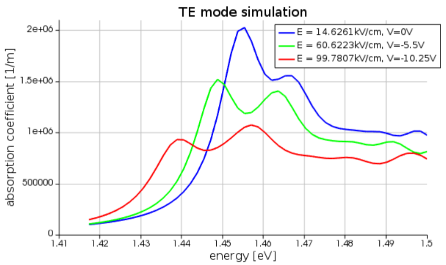


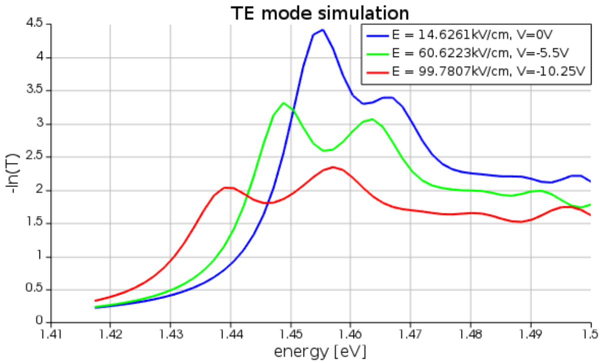
QCSE-based Electro-Absorption Modulator (EAM) Simulation

GaAs/AlGaAs



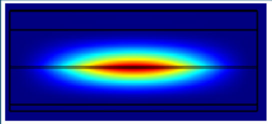






Step 1

MODE

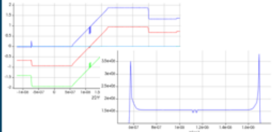


Calculate mode effective index and overlap with the gain region

Mode properties

Step 2

CHARGE

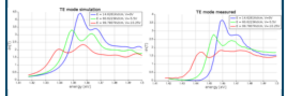


Calculate the electric field as a function of applied bias voltage

Electric field vs applied voltage

Step 3

MQW

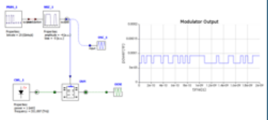


Calculate absorption coefficients and transmission

Absorption coefficients and transmission

Step 4

INTERCONNECT



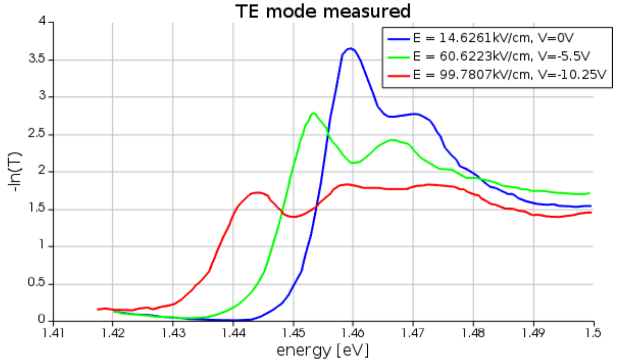
Calculate time-domain modulation response

Modulation response

ΔE(V)

T(λ,V)

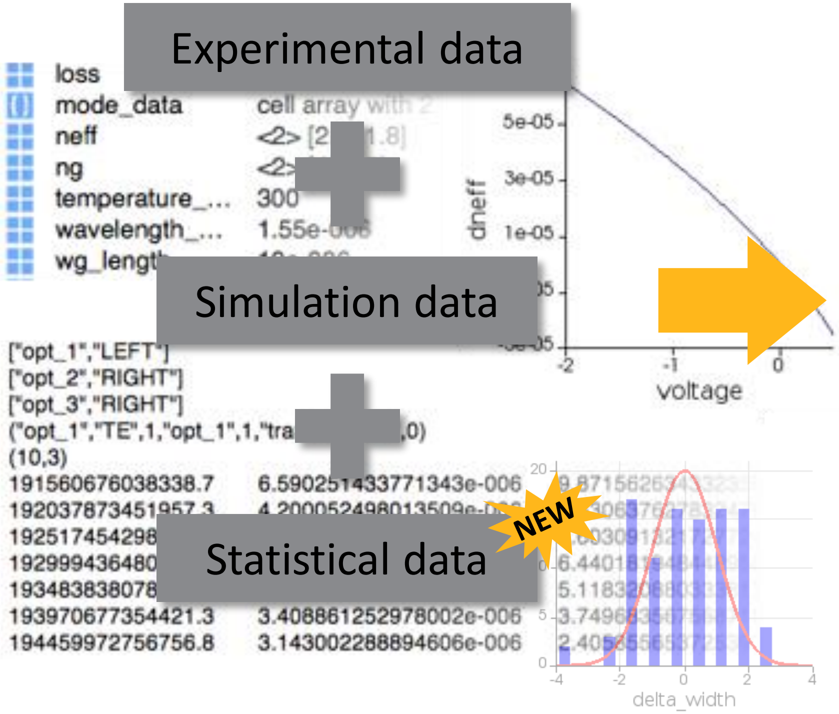
n_{eff} (λ), Mode Confinement



Reference: C Y.-P. Chao and S. L. Chuang, Phys. Rev. B, 48, p. 8210, 1993.

CML Compiler : Enabling Accurate Photonic Compact Models

- Automates generation of photonic compact model libraries



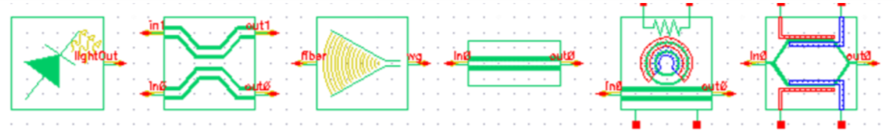
CML Compiler

Photonic Models

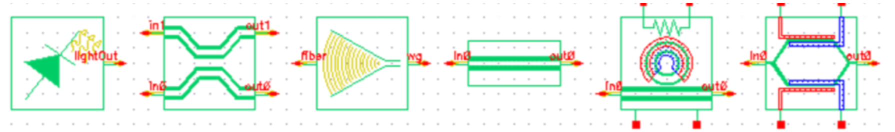
Waveguides
Couplers
Photodetector
Modulators
etc.

INTERCONNECT compact models (statistical)

Virtuoso symbols



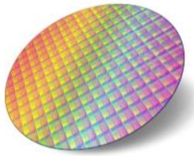
Photonic Verilog-A models (Virtuoso)



Compact Model Generation with CML Compiler

Statistical parameters

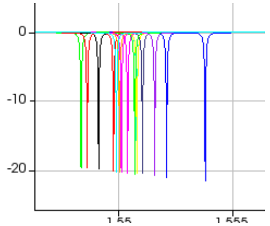
Physical



Width variability

Height variability

Performance

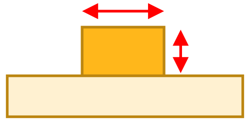


FSR variability

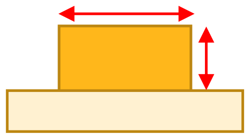
Peak λ variability

CML Compiler input data

Corners



Narrow

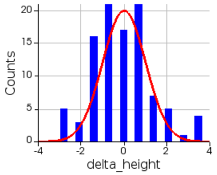


Wide

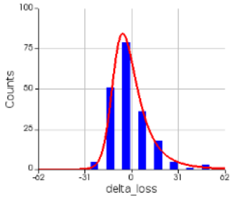
Other!

Distribution data

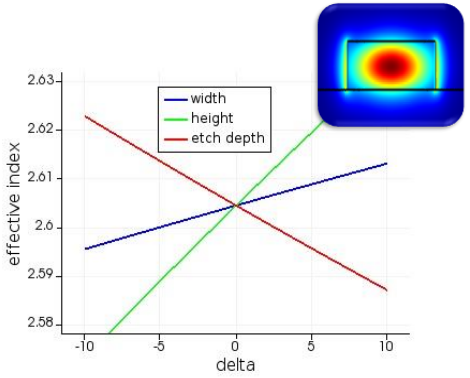
Gaussian



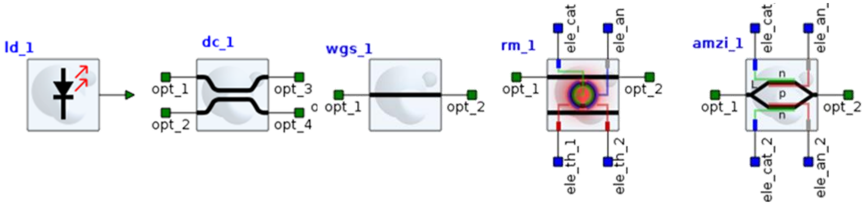
Pearson IV



Model sensitivity data



CML Compiler outputs



- ✓ Compact models with statistical parameters
- ✓ Supports spatial correlation and thermally sensitive
- ✓ Enabled for statistical simulation (INTERCONNECT and Virtuoso)

Ansys