Modeling Photonic Integrated Circuits in Synopsys Photonic IC Platform: OptoCompiler

Custom Design and Electronic-Photonic Cosimulation

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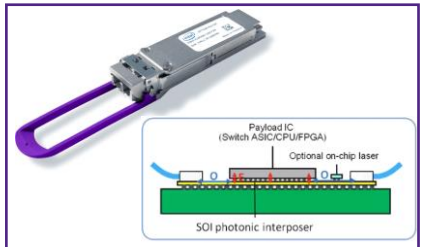
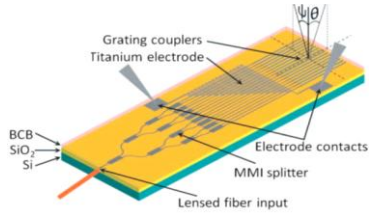
Outline

- Photonic Toolset and Photonic IC Design Platform
- Custom Photonic Design
- E/O Co-design
- Summary

Photonic Toolset and Photonic IC Design Platform

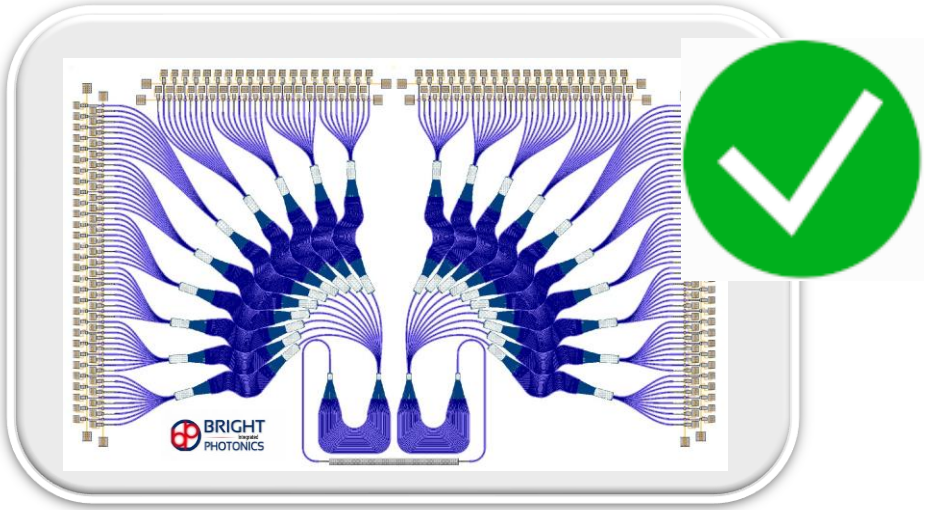
Photonics and PIC Technologies Emerging in many Areas

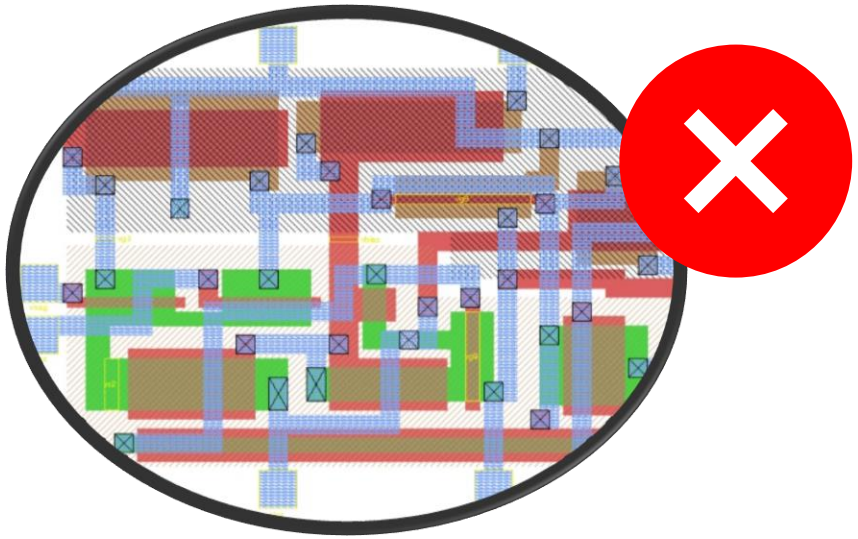
Technology	Market Segment	Hyperscale networks for Cloud	Cellular networks for 5G/IoT	Computing	Military / Aerospace	Automotive	Consumer	Energy
 Pluggable and co-packaged optics	Optical data communication	●	●	◐	●	◐	◐	
 VCSELs, fiber sensors, LiDAR	Sensing				●	◐	●	◐
 Wearables, Lab on a Chip	Bio-photonics						●	

● current ◐ prospective

Key Challenges In Photonic IC Design & Manufacture

For the Tool	For the Designer	For the Foundry
• Photonics has “RF-like” behavior • Needs curves, not corners • Uses waveguides, not wires • Unique physics and signal attributes	• Historically the “domain of experts” • Electrical models and simulators are inadequate for photonic devices • Manual layout • Fragmented flows → Low Productivity → Human Error	• Photonics process and PDKs are immature • Curvy data impacts layout, OPC and mask-prep → Low Performance and Yield

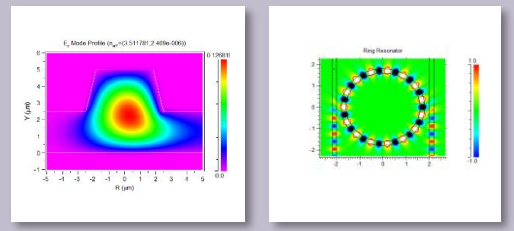




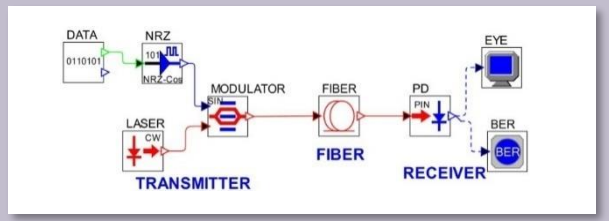
Synopsys Photonic Design Automation Solutions

Increasing quality of results, reducing errors and improving efficiency of photonics design

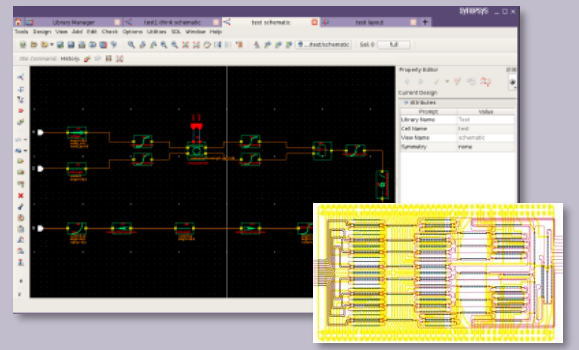
RSoft Photonic Device Tools



OptSim



PIC Solutions



Photonic Devices

Photonic Systems

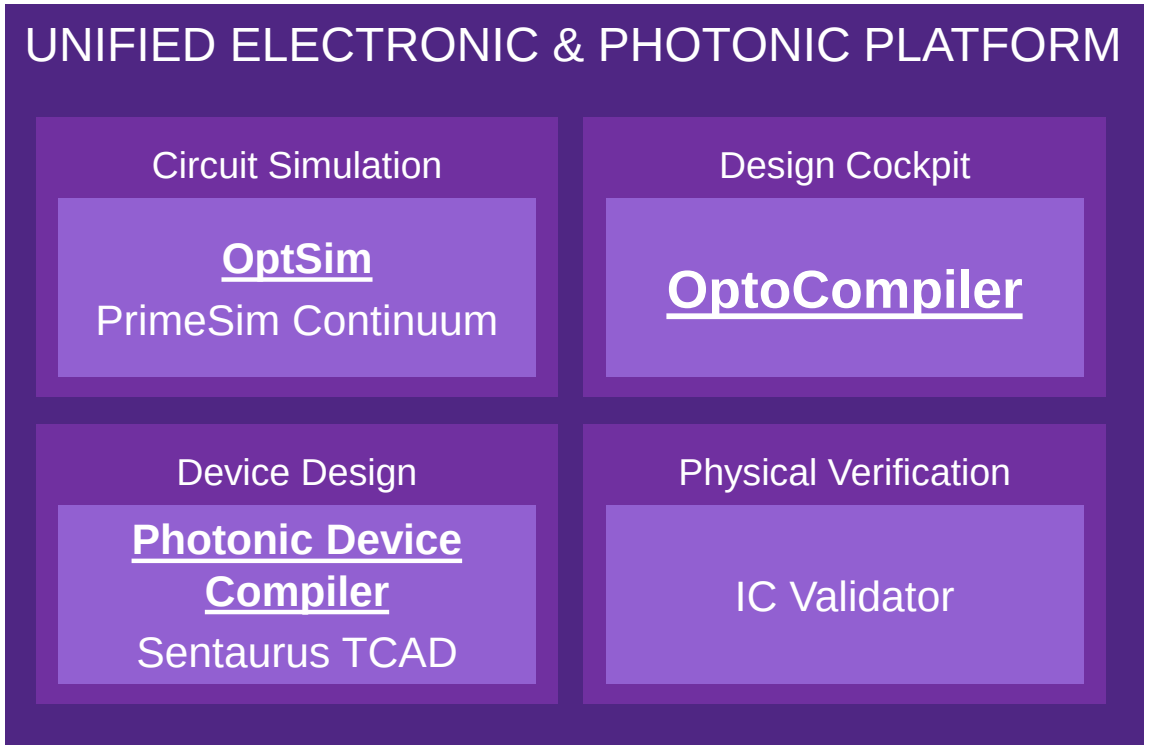
Photonic ICs

Synopsys provides Industries first Unified E/O co-design Solution

OptoCompiler – interactive design cockpit
- Complete custom/AMS capability
- Photonic-aware layout synthesis
- Exclusive Photonic Design Features
  - Seamless abutment
  - Photonic auto-align
  - Assisted Waveguide Routing
- Photonic DRC & LVS with **IC Validator**

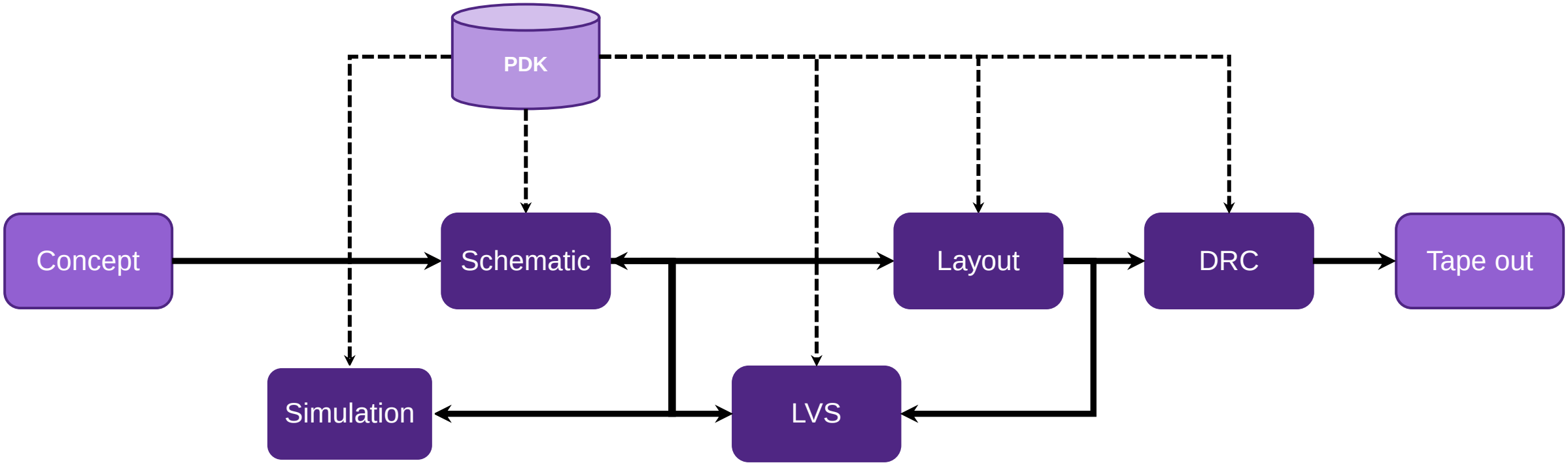
OptSim – photonic circuit & system simulation
- E/O co-simulation with **PrimeSim**

Photonic Device Compiler – device design
- E/O co-simulation with **Sentaurus TCAD**
- Automated photonic PDK and library development



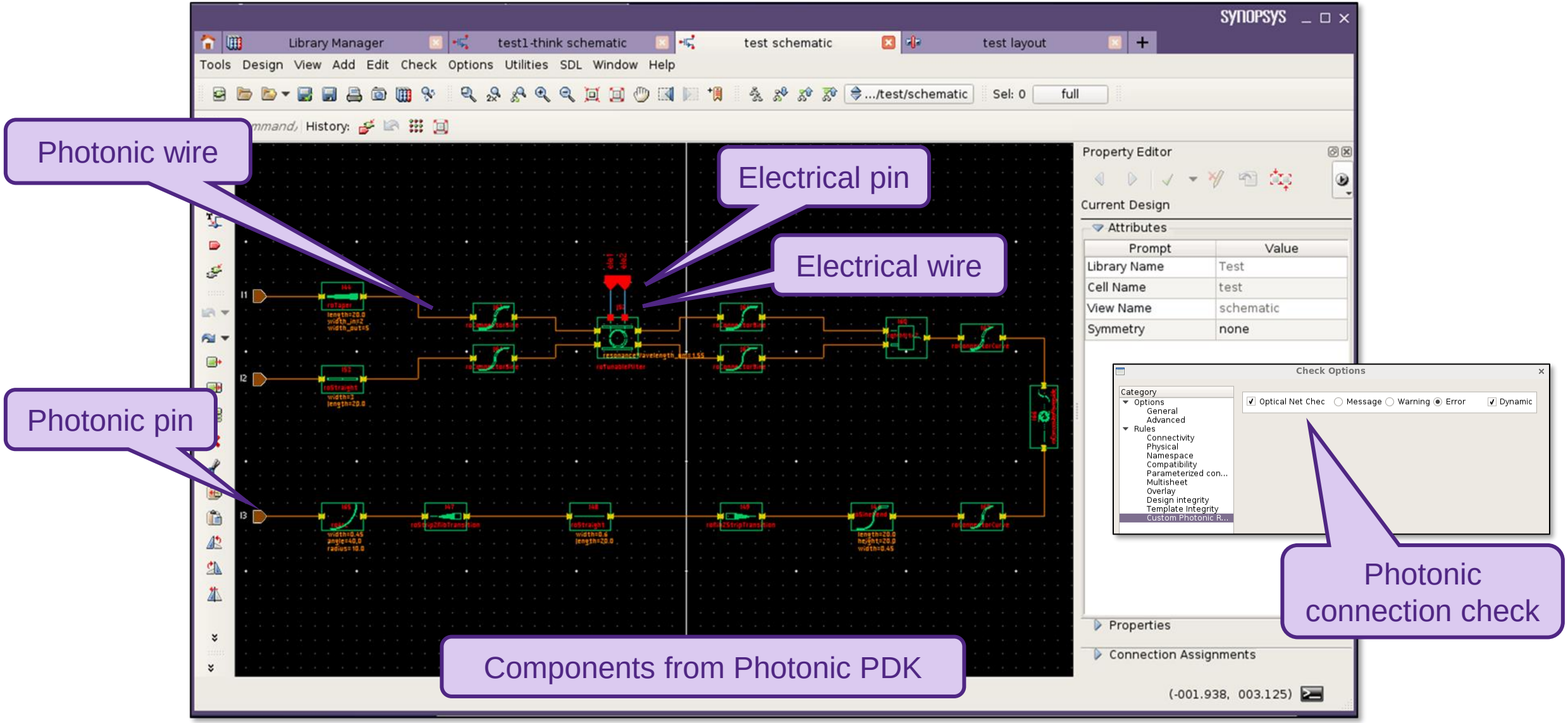
The industry's **only unified** electronic & photonic platform

OptoCompiler provides
PDK driven Schematic Driven Layout (SDL) Design Flow

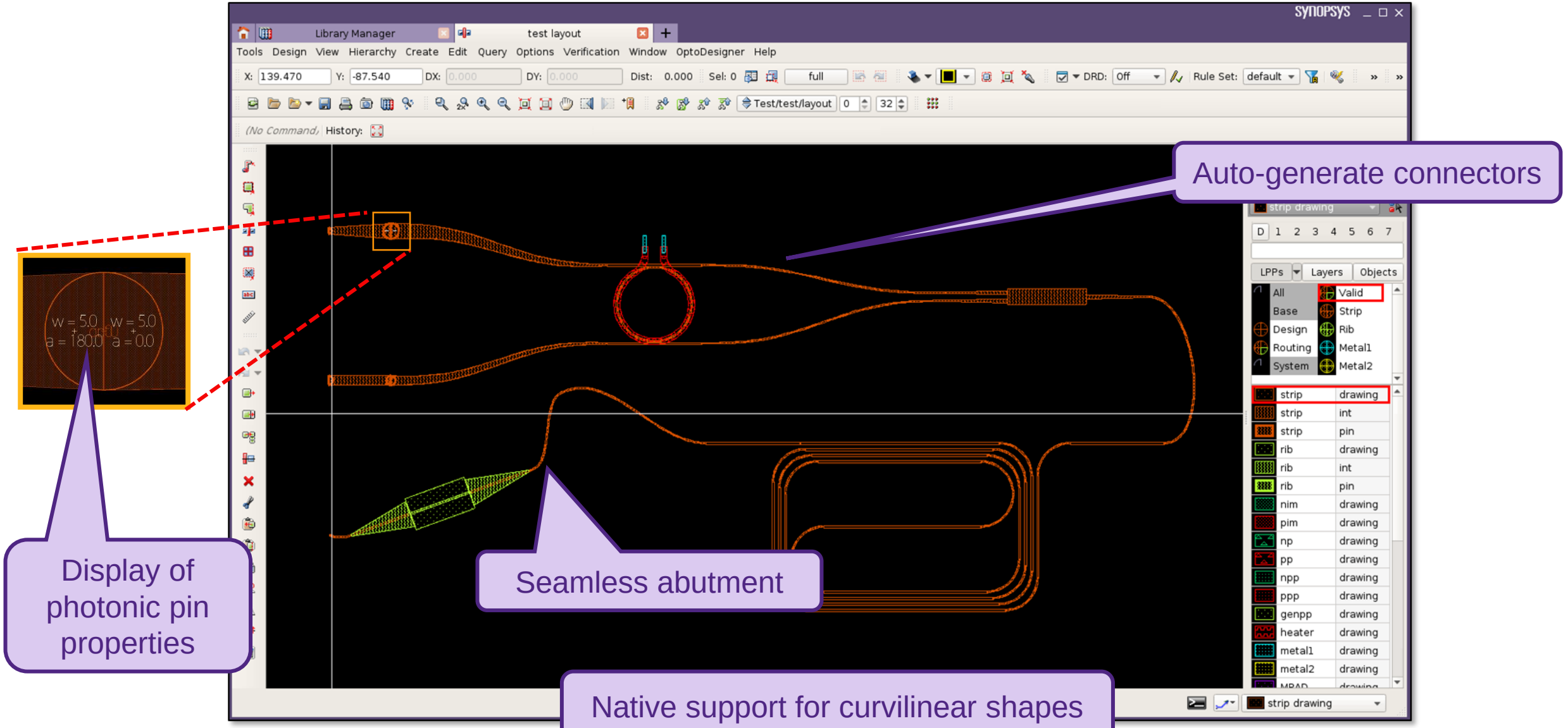


1. Schematic capture and simulation
2. Layout implementation
3. Back annotation and re-simulation
4. Design rule checking and layout versus schematic verification

OptoCompiler uses
modern and easy to use design environment, familiar for IC designers

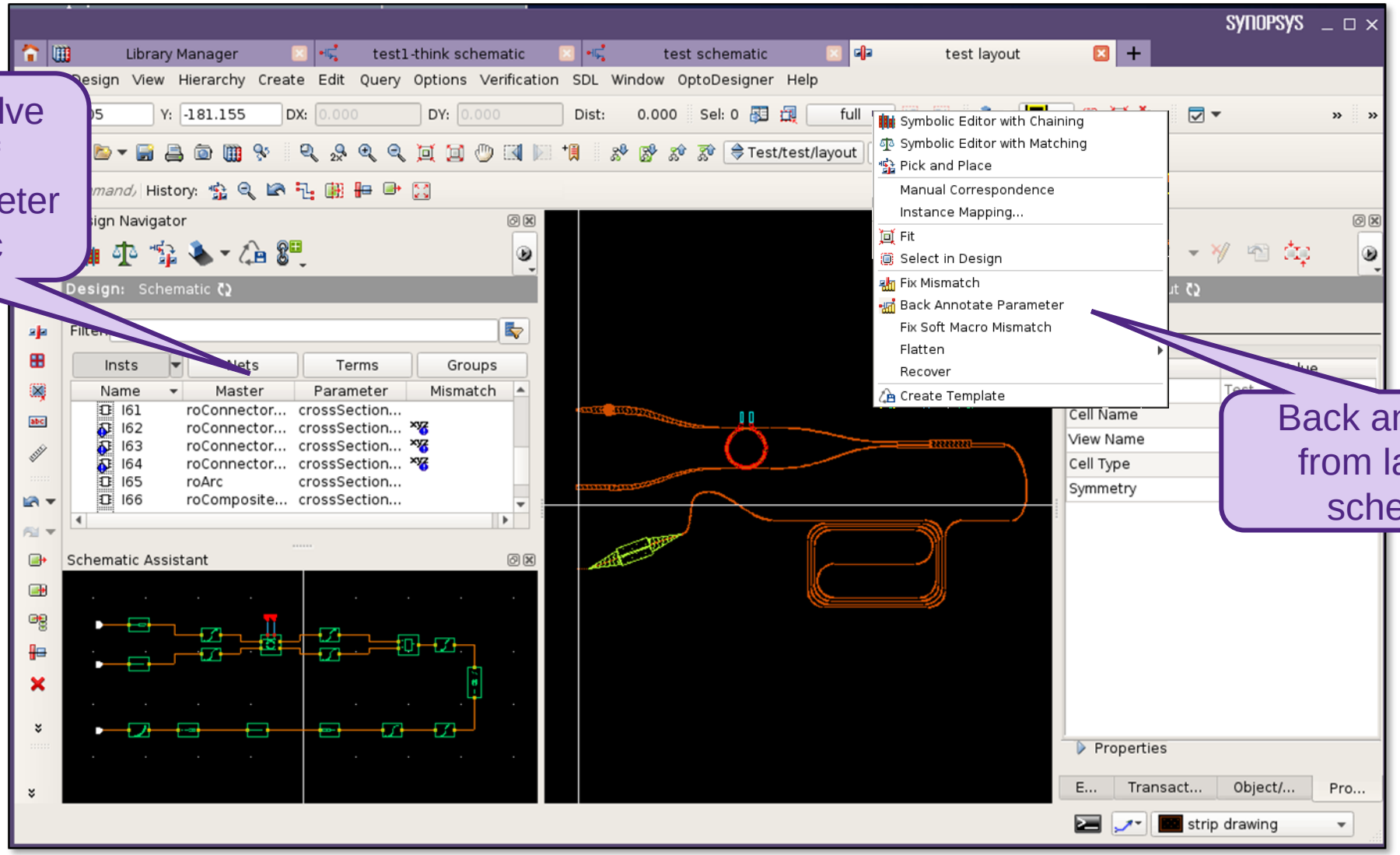


OptoCompiler provides interactive layout with productivity features for photonics



OptoCompiler provides back annotation to enable post layout verification

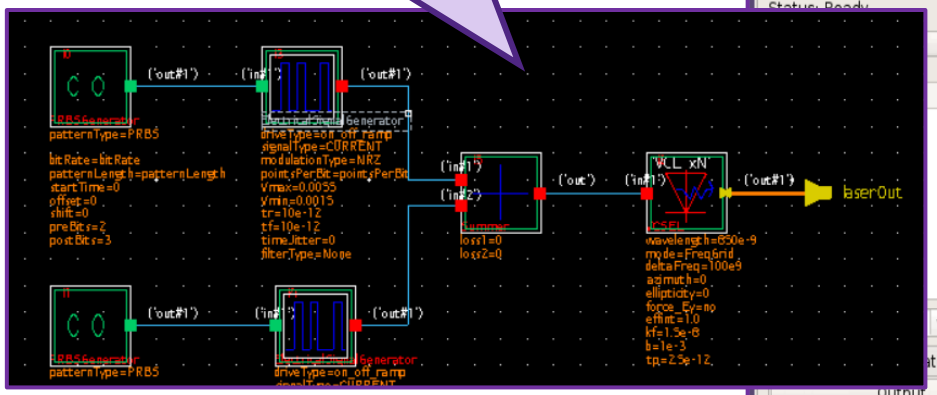
Identify and solve mismatch of photonic parameter in schematic



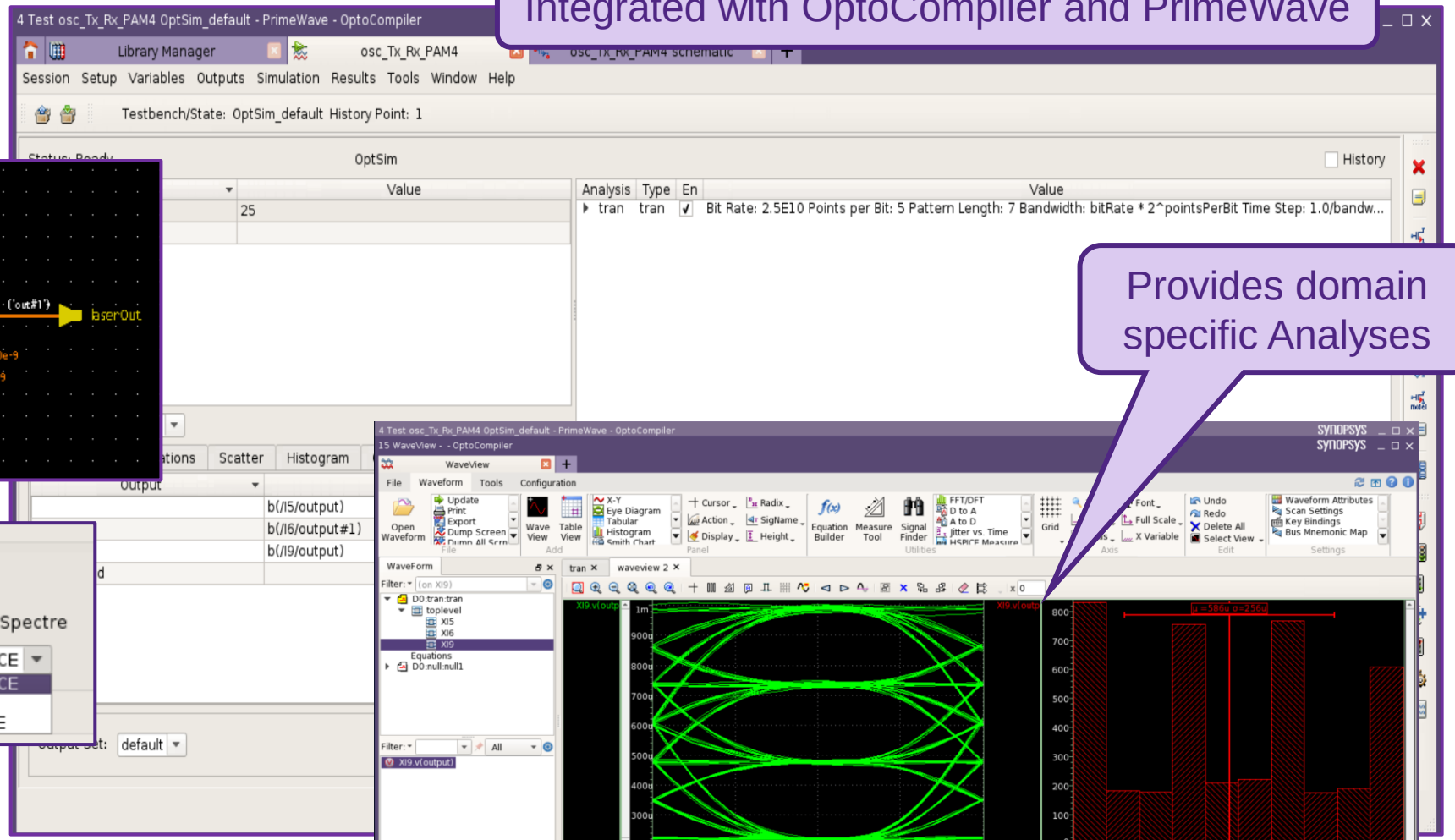
Back annotation from layout to schematic

OptSim enables seamless circuit and system simulation and analysis

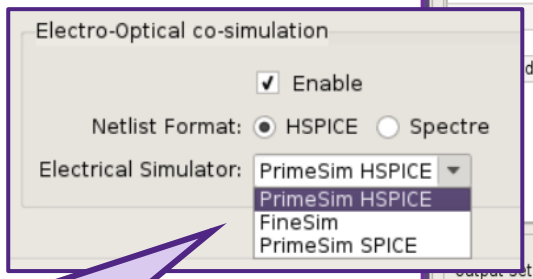
Supports Optical, Electrical and Logical Signals



Integrated with OptoCompiler and PrimeWave



Provides domain specific Analyses



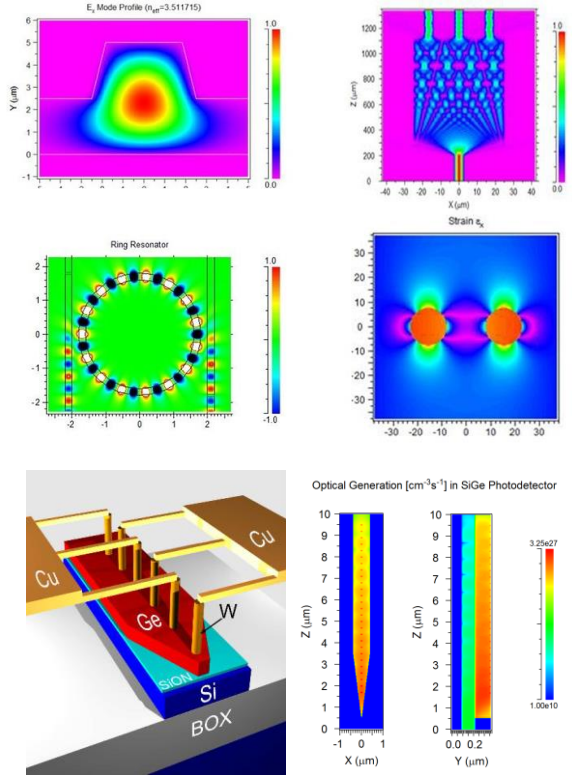
E/O co-simulation with domain specific engines

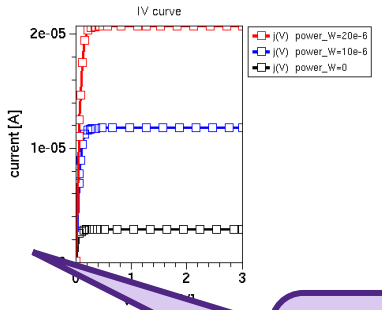
Custom Photonic Design

Photonic Device Compiler supports Photonic device design, PDK and custom library development

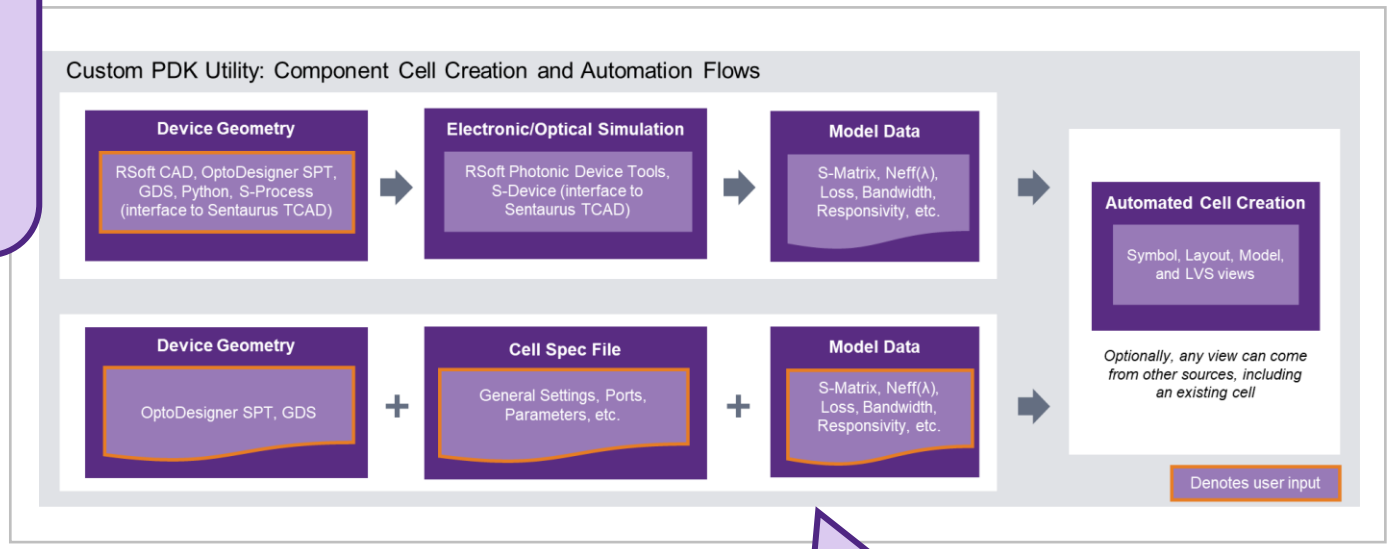
Design, simulate, and optimize passive and active photonic devices

Create Symbols, Layouts, Simulation Models and LVS information





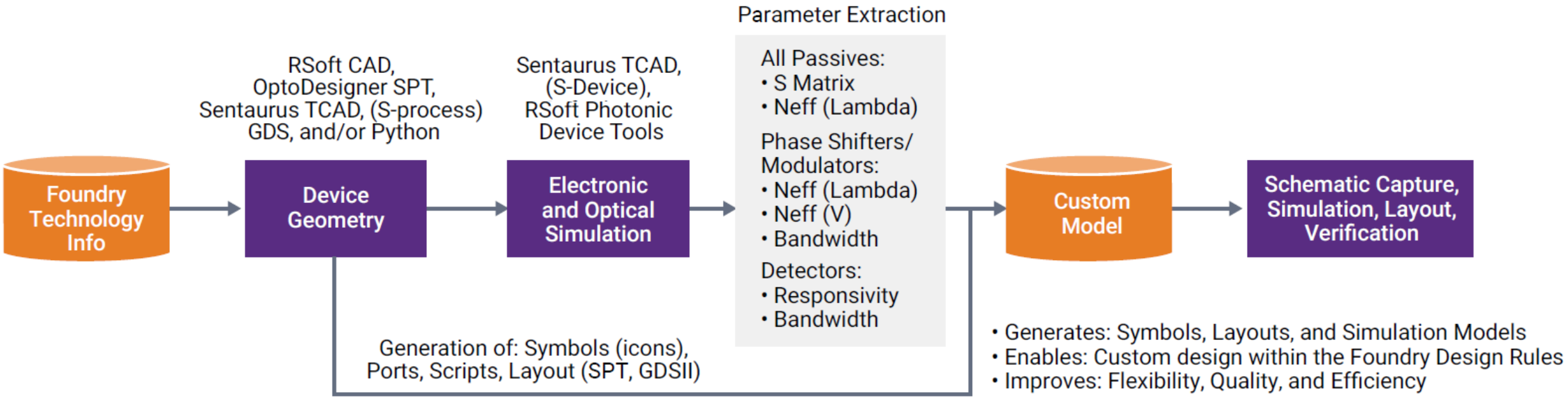
Industries largest set of tools and methods, including BPM, FDTD, RCWA



Automation for PDK and custom device creation

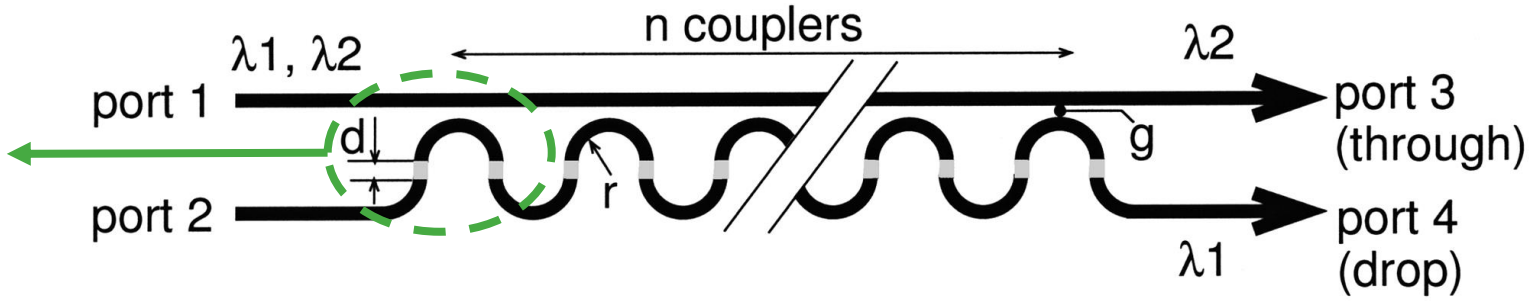
Interfaces with Sentaurus TCAD, CODE V and LightTools

Photonic Device Compiler supports
Photonic device design, PDK and custom library development



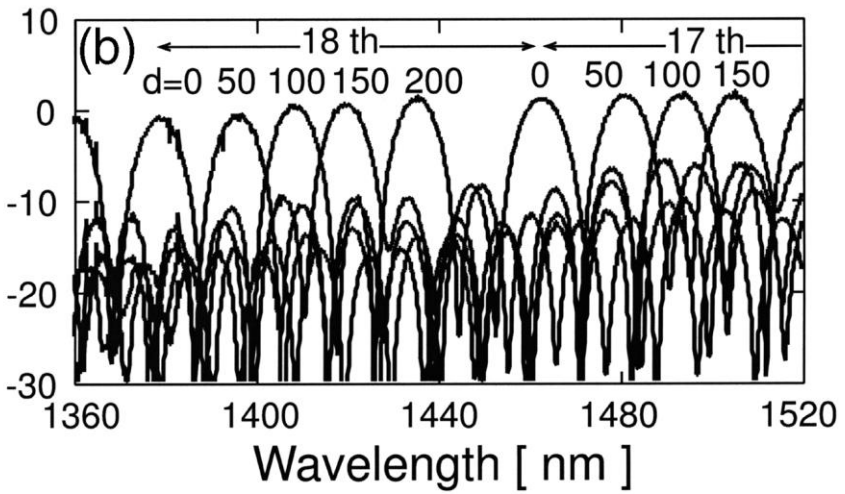
Example: Tunable Lattice Filters for Detector Array

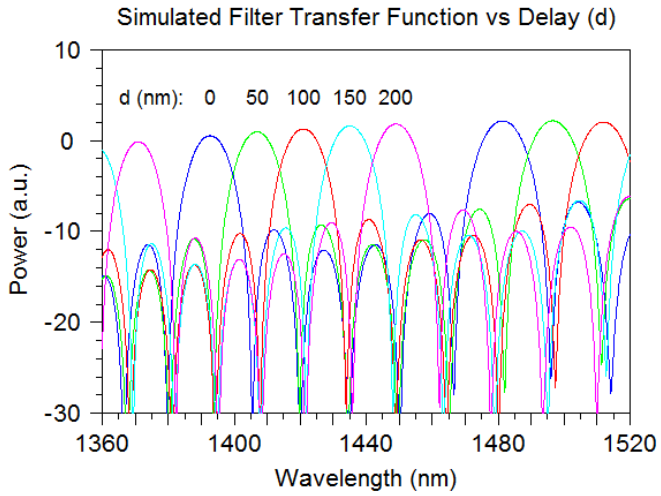
- Cascaded MZI coupler elements can be tuned to different wavelengths via adjustable delay length *d*



Koji Yamada, *at el, "Silicon-wire-based ultrasmall lattice filters with wide free spectra ranges," Optics Lett., vol. 28, No. 18, pp. 1663-1664, Sept. 2003.*

- Different cascade designs can be used as optical filters before detectors to create a multi-channel detector array



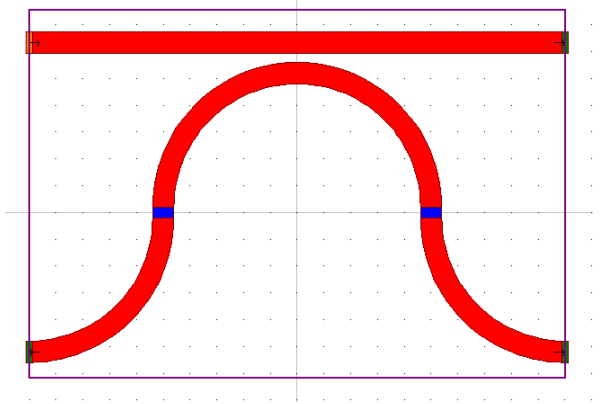


Example : Tunable Lattice Filters for Detector Array

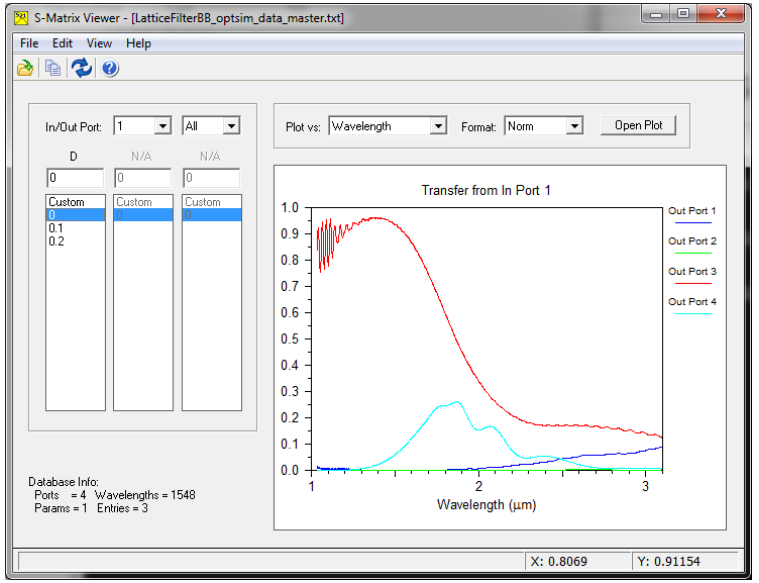
Device Overview

- The Building Block (BB) to construct the device is a single MZI coupler shown on the right.
- Synopsys Photonic Device Compiler used to generate transfer function for BB.
- Filter formed by cascading several coupler BBs
- 6-stage cascaded MZI couplers are used to balance ER and bandwidth requirements
- Resulting device:
  - Is tunable: Adjusting delay line length (d) changes dropped wavelength
  - Is small: A 2.5µm bend radius ⟶ overall length less than 100µm
  - Has a large free spectral range (FSR)

Component Model of Single Coupler (BB)



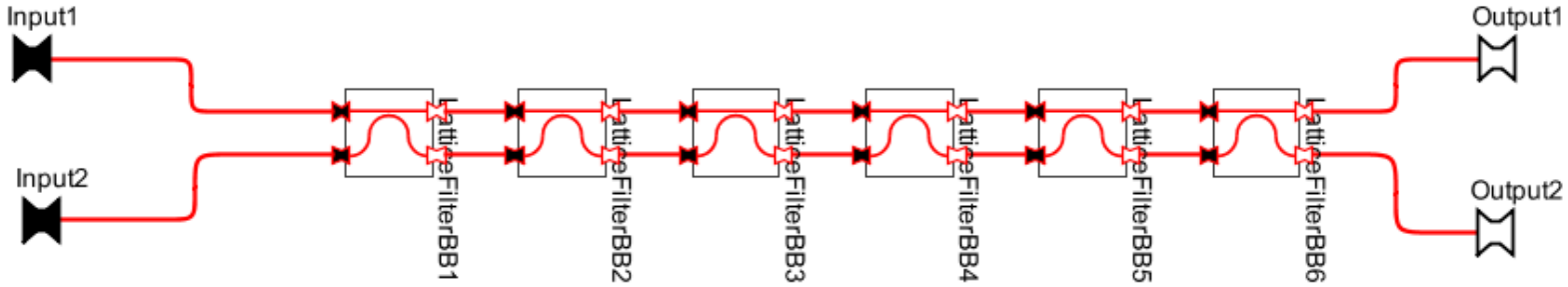
Generated S-Matrix for the BB



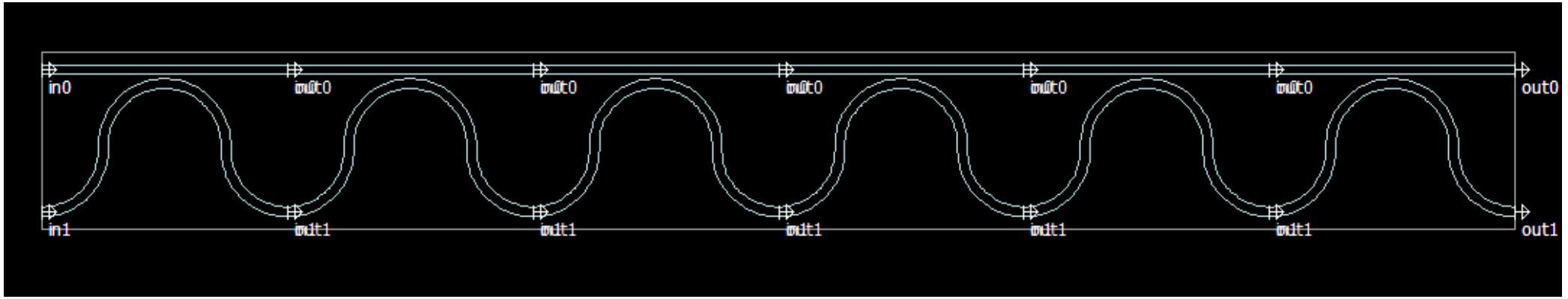
Example : Tunable Lattice Filters for Detector Array

Circuit Schematic and Layout: OptoCompiler

- Schematic



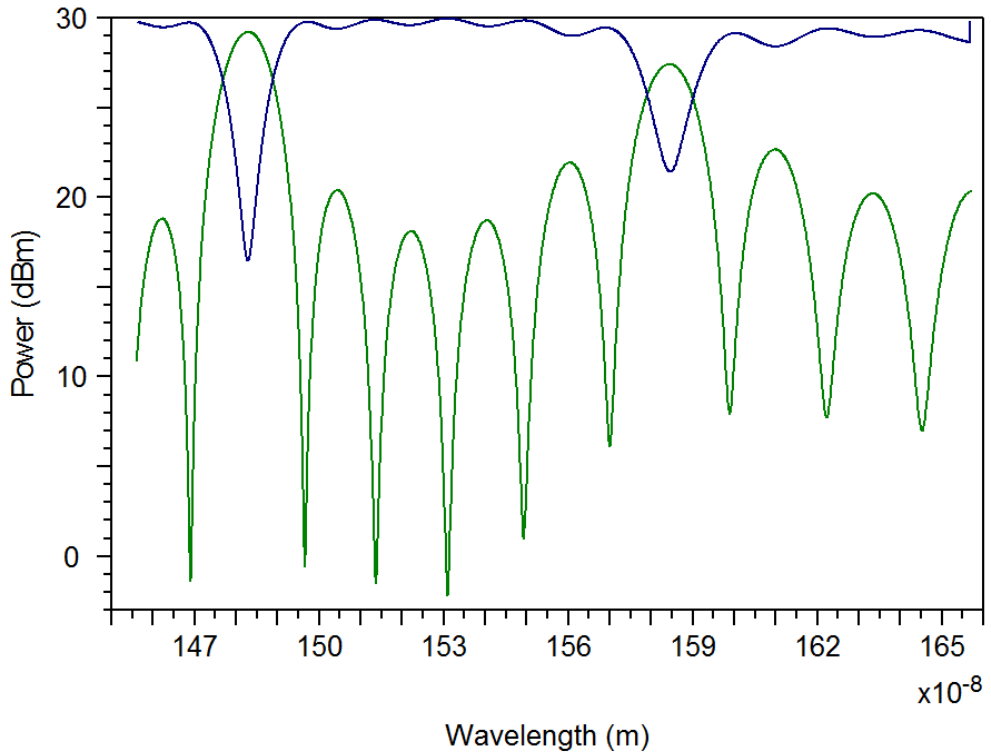
- Layout

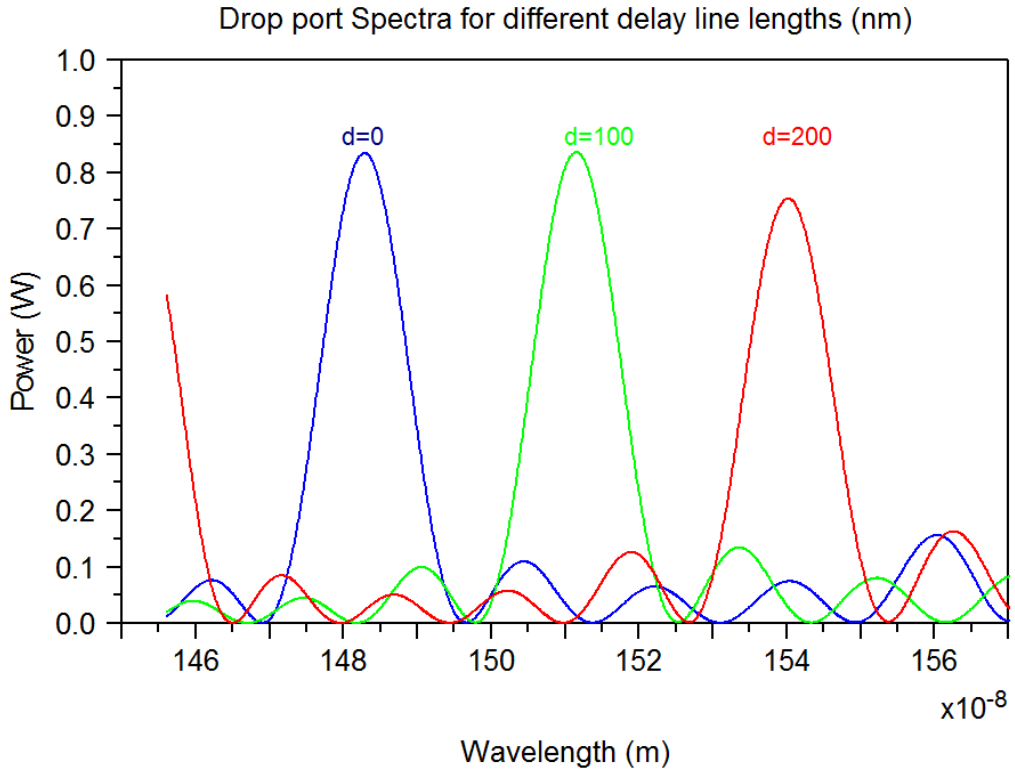


Example : Tunable Lattice Filters for Detector Array

OptSim Simulation Results (Using S-Matrix data from FullWAVE)

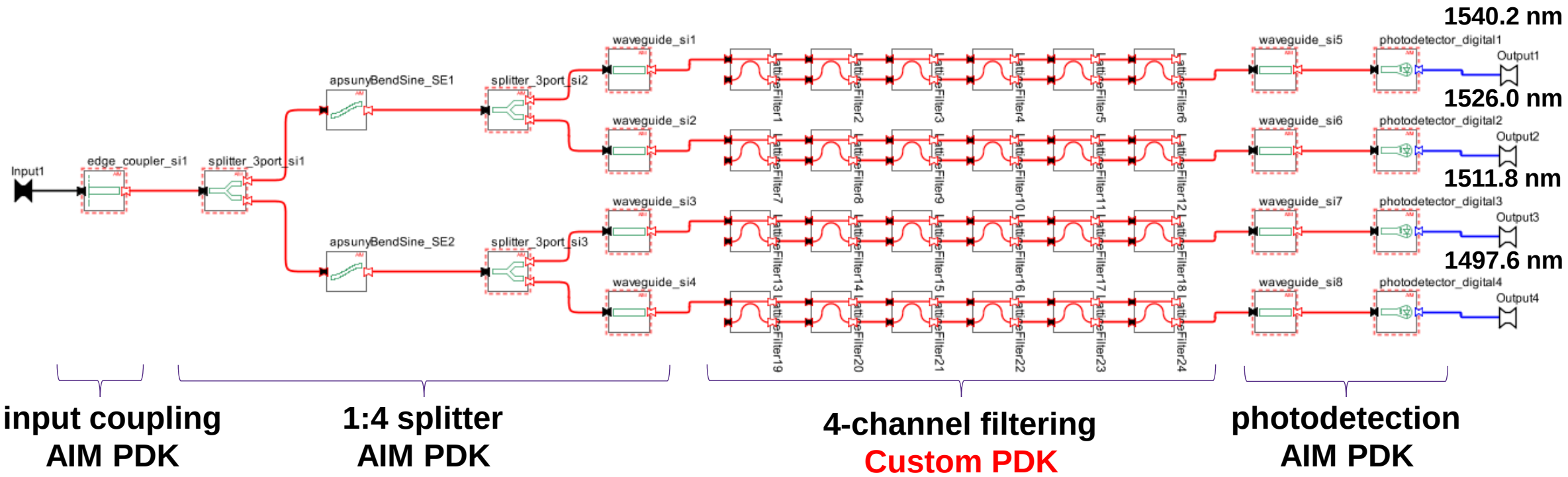
- Left: Through and Drop port Spectrum with FSR ~100nm+ (at delay length d=0)
- Right: Drop port Spectra for various delay line lengths





Example: Tunable Lattice Filters for Detector Array

4-channel Detector Array using both Foundry and Custom PDK Elements

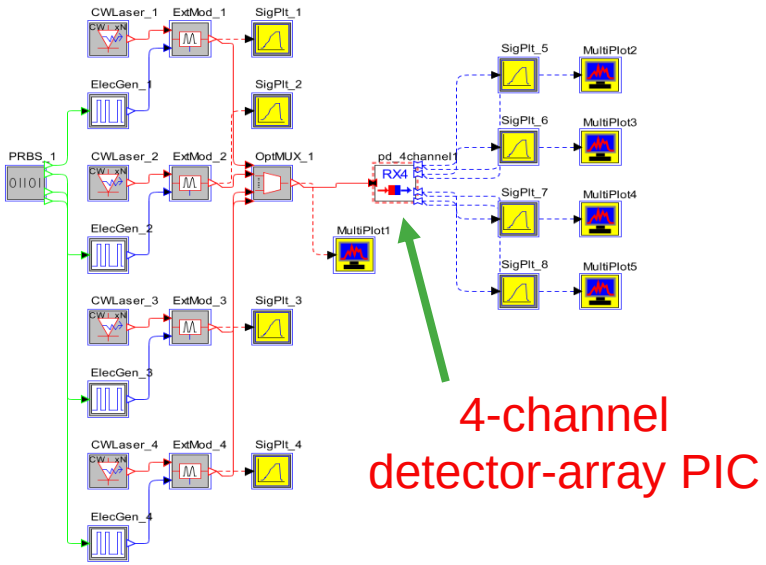


- 6-stage cascaded MZI couplers are used to balance ER and bandwidth requirements
- Adjustable delay lengths d = 50, 100, 150, and 200 nm accommodate center channels of 1497.6, 1511.8, 1526.0, and 1540.2 nm, respectively
- Standard AIM Photonics PDK elements provide input coupling, signal splitting, and photodetection

Example: Tunable Lattice Filters for Detector Array

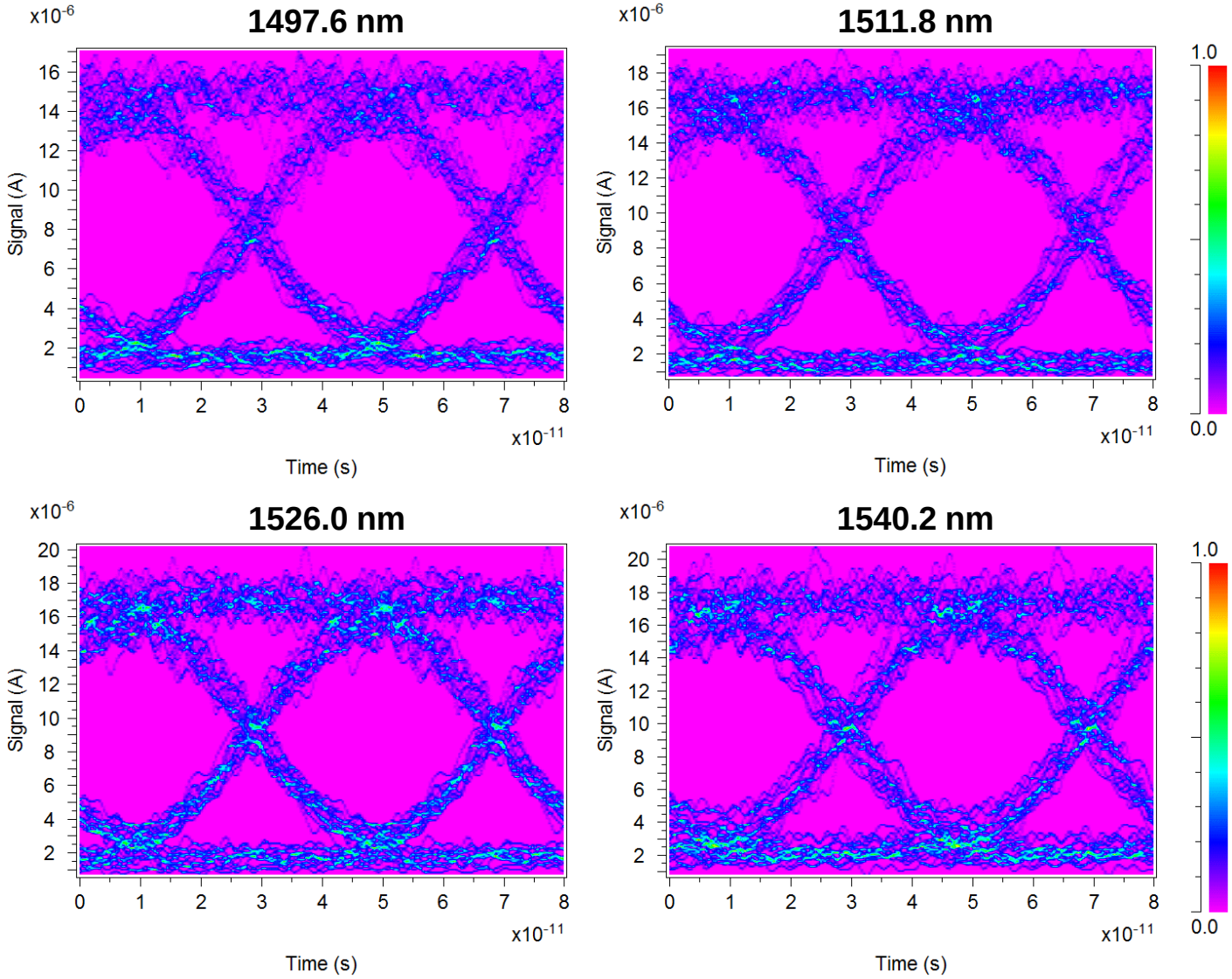
4-channel Detector Array Eye Diagrams

Test Circuit:



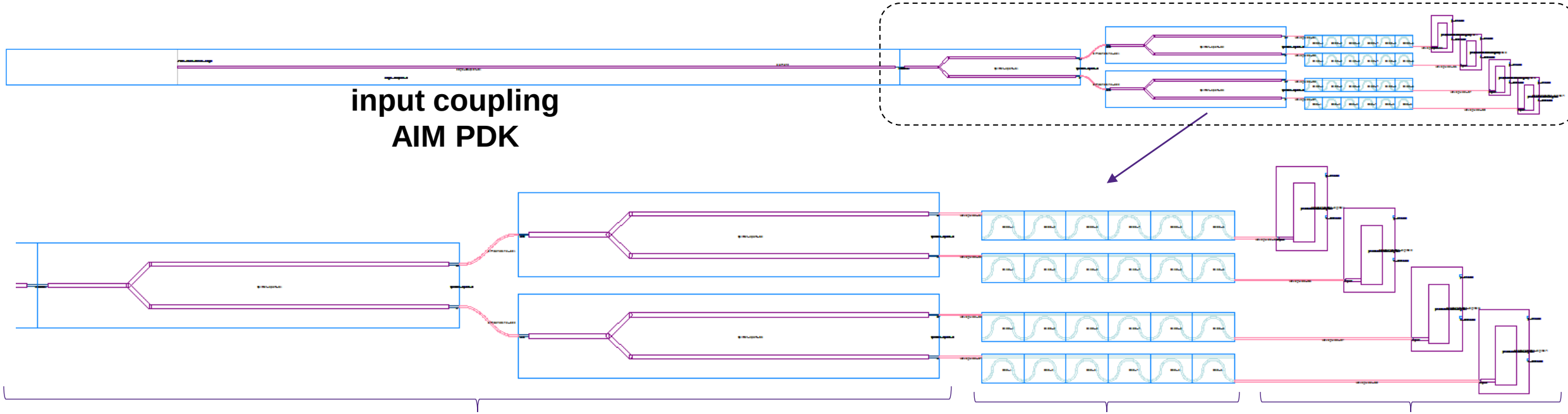
4-channel detector-array PIC

- 25 Gbps NRZ operation
- Approximately -8 dBm launch power per channel
- Open eye at all four wavelengths



Example: Tunable Lattice Filters for Detector Array

4-channel Detector Array Layout

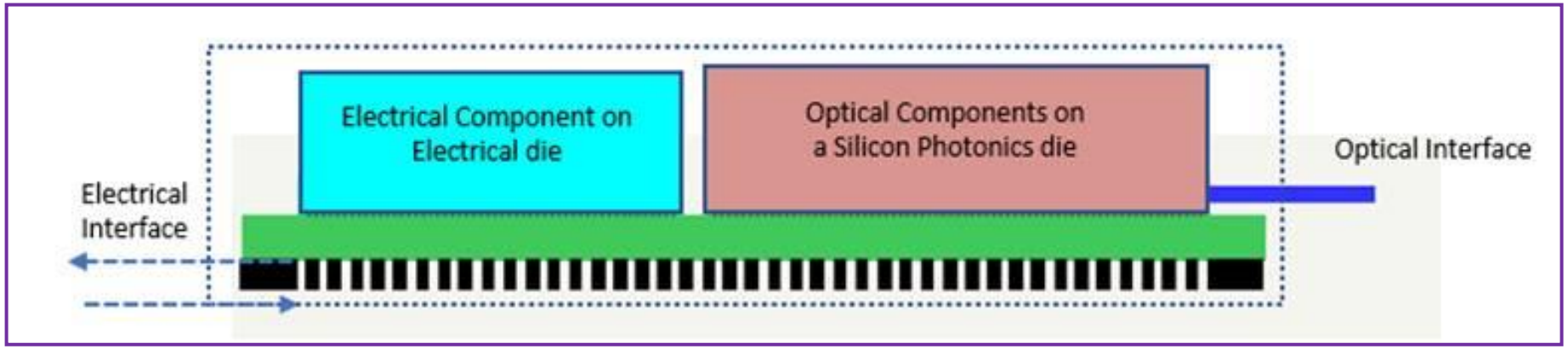


- Custom photonic components behave like foundry PDK components and follow the same schematic-driven layout (SDL) flow

E-O Co-Design

Electronics-Photonics Cosimulation

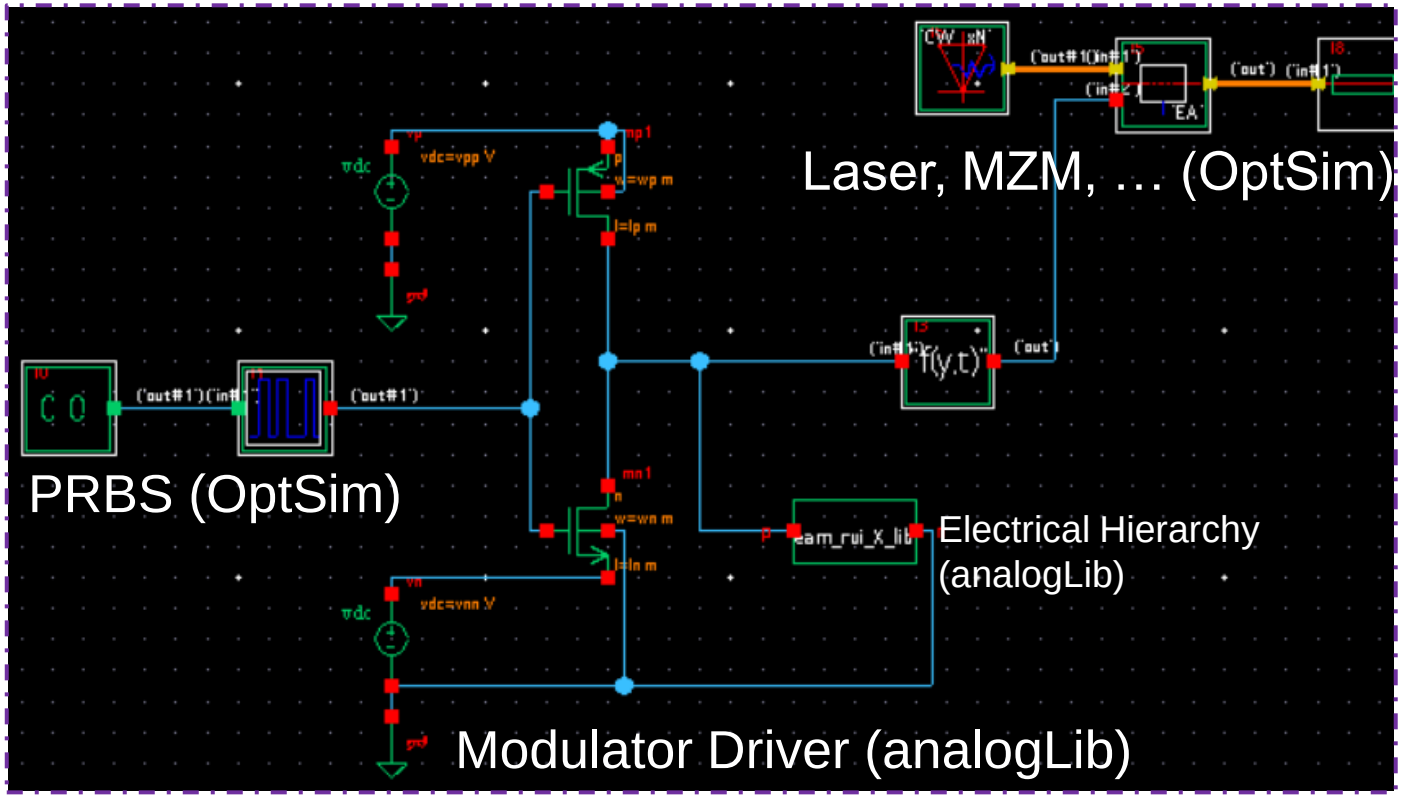
- Motivation:
  - Many applications require electronics to drive photonics (e.g., transceivers)
  - The transition from pluggables to co-packaged optics is inevitable



  - Modeling bidirectional photonic circuits as electronic circuits (Verilog-A,…) is too much pain with too little gain
  - Commercial electrical circuit simulators and photonic circuit simulators are mature today (i.e., no need to model photonics as electronics unlike in past)

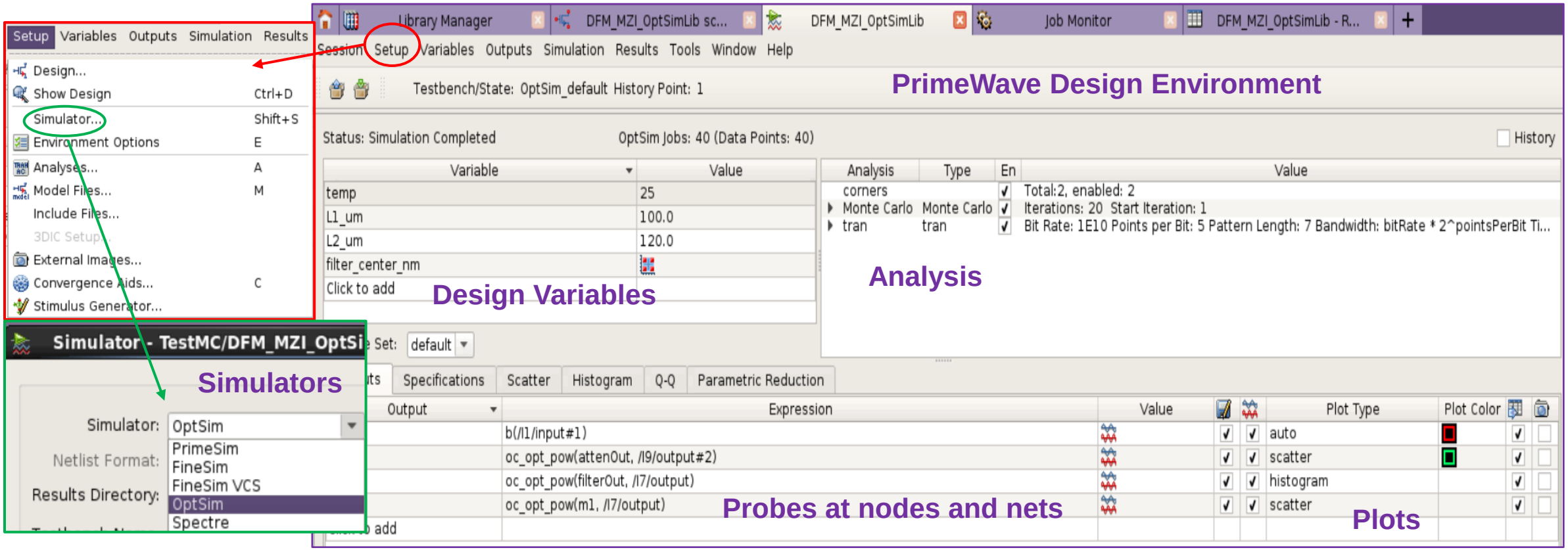
OptSim: Electronics-Photonics Cosimulation

- Philosophy:
  - Provide intuitive and seamless E-O schematic creation (Electrical + Photonic devices in the same Schematic)
  - Free designers from manual, error-prone cross-domain interventions

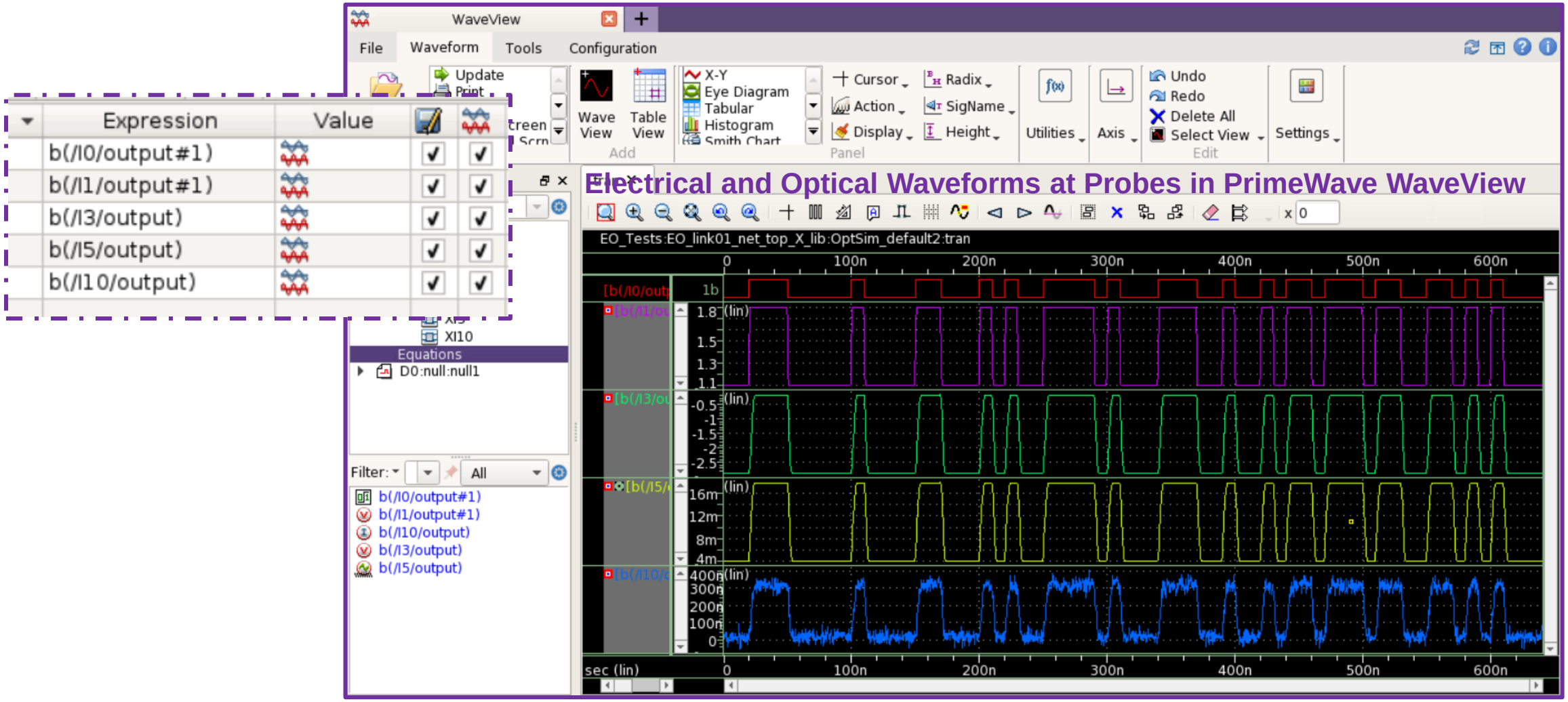


Testbench: Setting up E-O Co-Simulation

- A testbench is a simulation setup for the schematic under test
- PrimeWave Design Environment enables management of testbenches



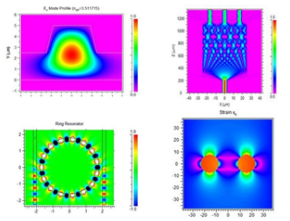
Results Analyzer and Waveform Viewer: E-O Waveforms



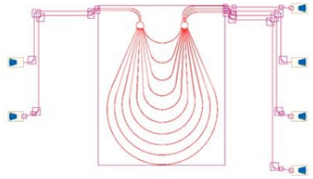
Summary

Synopsys' Differentiators Enable Fast & Accurate Results

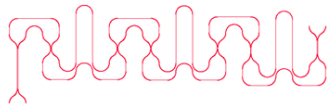
Photonic TCAD



Photonic Layout



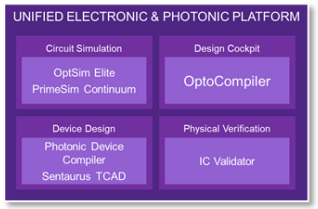
Photonic Synthesis



Photonic Expertise

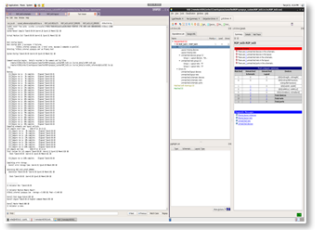
- Industry's largest photonics development and support team with 100s of person-years' experience
- **1500+** photonic tape-outs supported

10x Unified Workflow



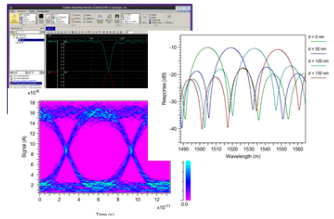
Up to 10 times faster from schematic to layout

20x Integrated DRC & LVS



Up to 20 times faster from layout to verified design

E/O Circuit Simulation



On target results for multi-wavelength and bidirectional signals

"With the Synopsys platform, we were able to reduce the time from schematic entry to final test chip layout by nearly 4X over legacy tools," said Dr. Radha Nagarajan, CTO and SVP, Platforms at Inphi Corporation. "Due to its productivity features and ease of use, we have successfully used OptoCompiler for tape-outs."

"Rockley's unique photonic chipset technology with silicon photonics at its core is driving the growth of integrated optical components in healthcare, machine vision and data communications," said Andrew Rickman, chief executive at Rockley. "The PDA platform Rockley has created by utilizing OptoCompiler allows our engineers to define, simulate, lay out and verify Photonic ICs quickly and efficiently to meet our quality and schedule goals. Synopsys' technical support has been instrumental in ensuring Rockley met its tape-out goals. We look forward to additional efficiency gains by expanding our use of Synopsys' Photonic Solutions tools."

SYNOPSYS®
Silicon to Software™

Thank You