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JP2-4

Electro-Optic Co-Simulation in High-Speed Silicon Photonics Transceiver Design Using Standard Electronic Circuit Simulator

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Yokohama National University (Now with Institute of Science Tokyo)

IEEE RWW 2026

Jan. 20, 2026, Los Angeles / Hollywood, CA, USA

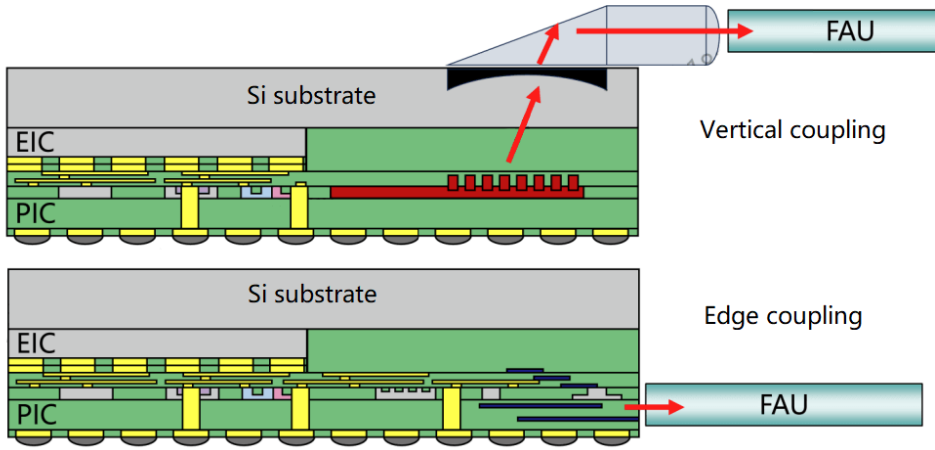
This work was supported by JSPS KAKENHI Grant Number JP23KJ0988.
This work was supported through the activities of VDEC, The University of Tokyo, in collaboration with Cadence Design Systems, Inc. and Keysight Technologies, Inc.

AI Data Center Demands Si Photonics

Date Center

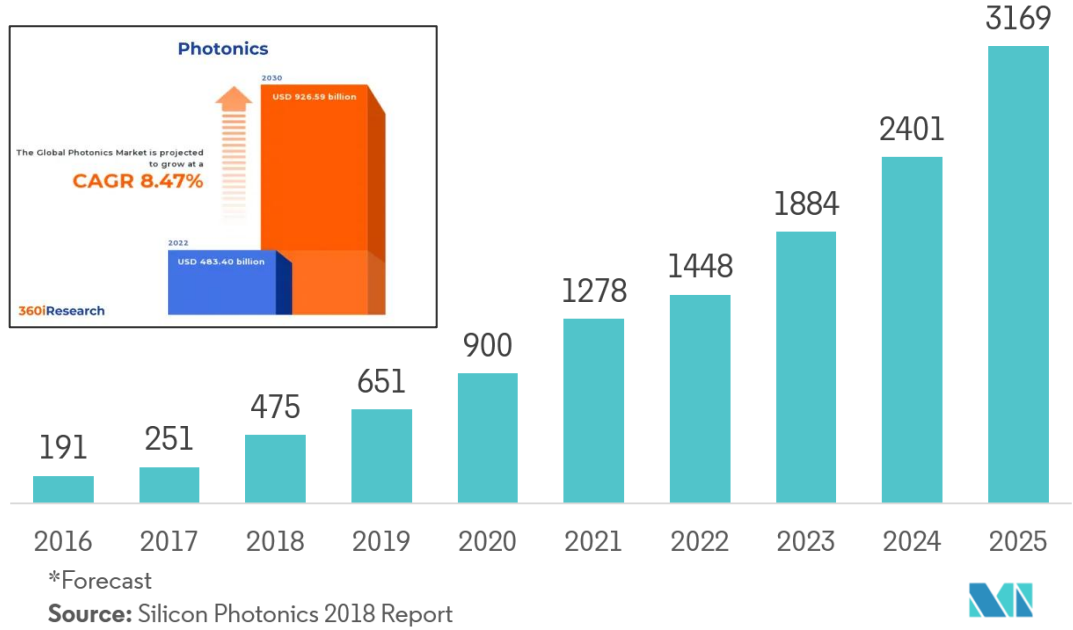


Co-Packaged Optics using Si Photonics



TSMC COUPE（Apr. 2024）

Revenue of 100G Silicon Photonics Transceiver, in USD million, Global, 2016-2025*



*Forecast

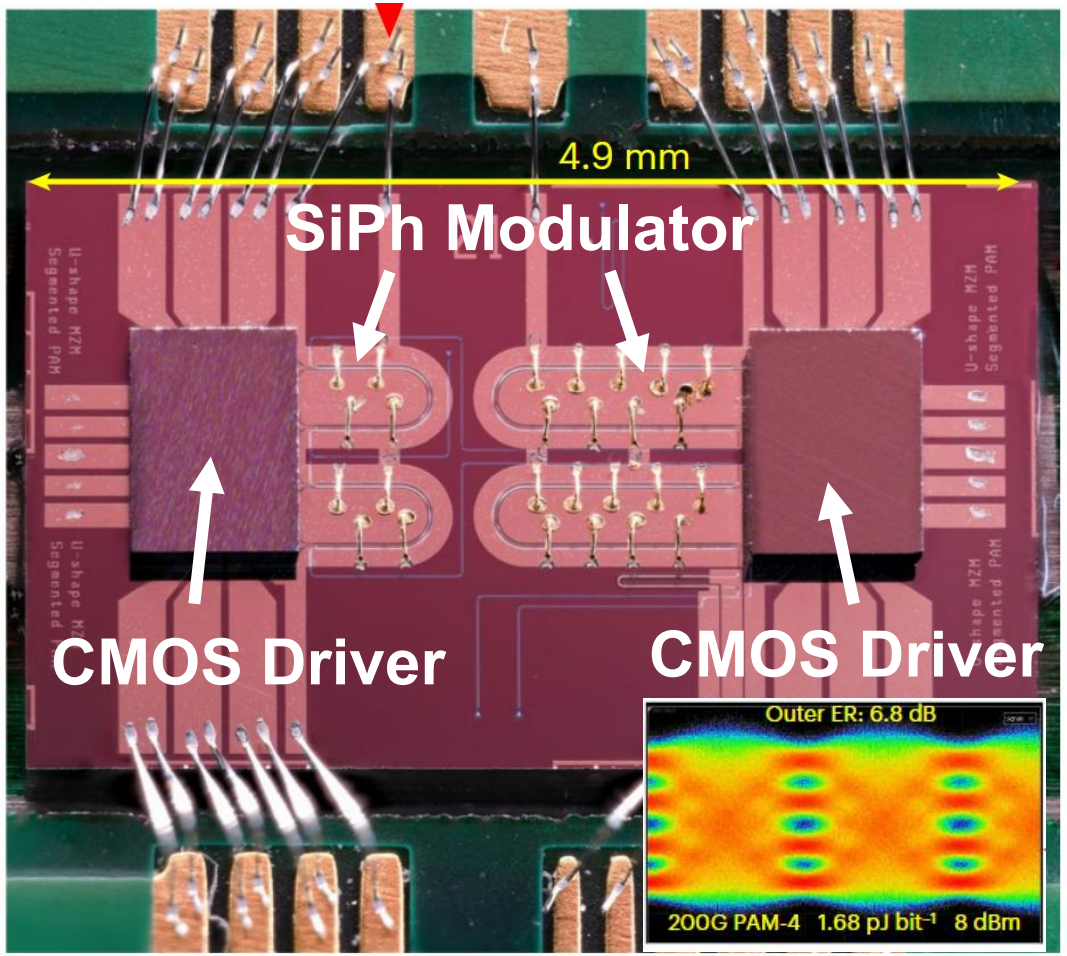
Source: Silicon Photonics 2018 Report

Rapid growth of the Photonics Market

Electro-Optic (EO) Integrated Transceivers

200 Gbps PAM4

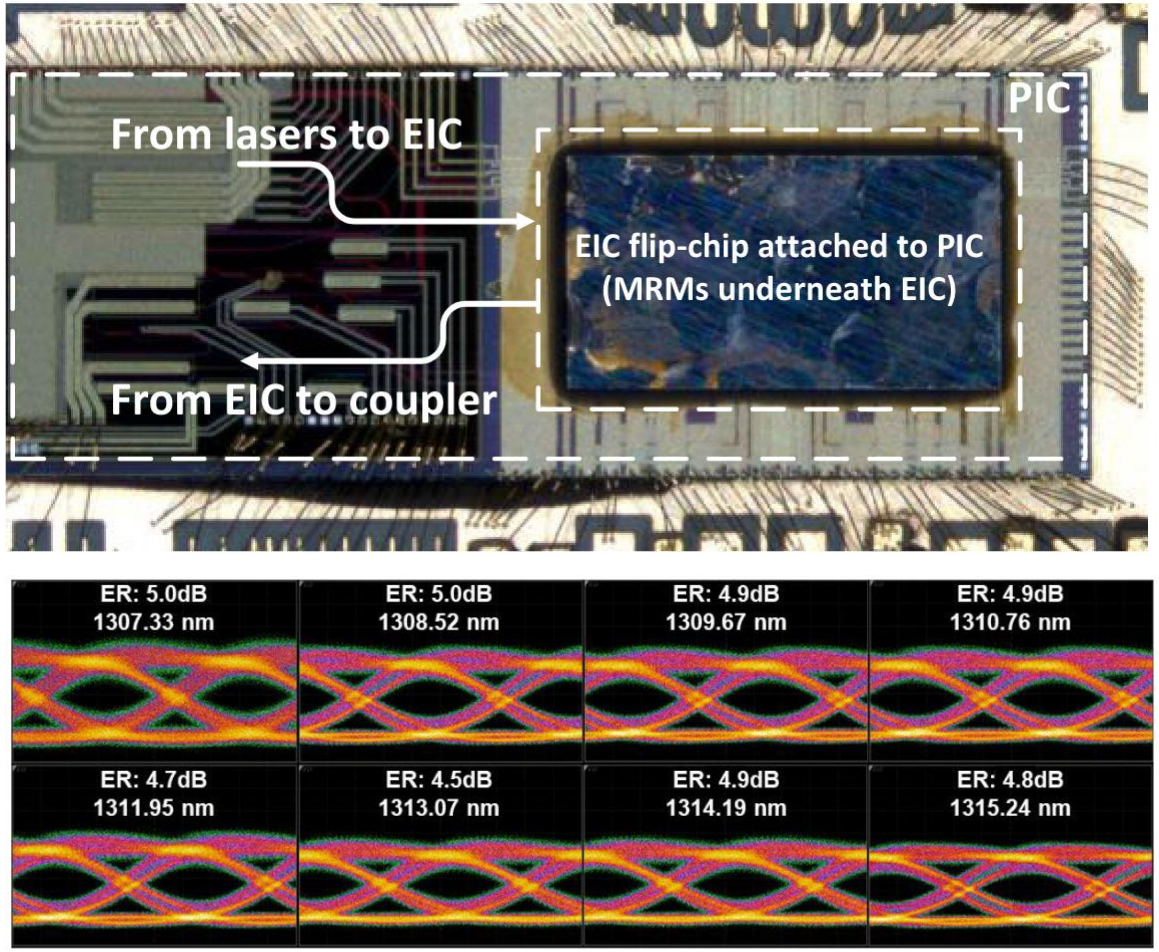
(Soton University)



K. Li *et al.*, *Nat Electron*, vol. 6, no. 11, pp. 910–921, Oct. 2023.

400 Gbps (50G OOK 8λ)

(Intel)

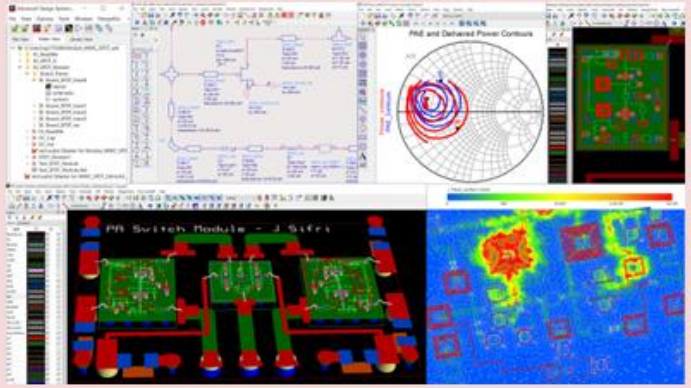


C. S. Levy *et al.*, *IEEE J.SSC*, vol. 59, no. 3, pp. 690–701, Mar. 2024.

Design Challenge

Electronics and Photonics use totally different design environment (software)
→ Low design efficiency and simulation accuracy

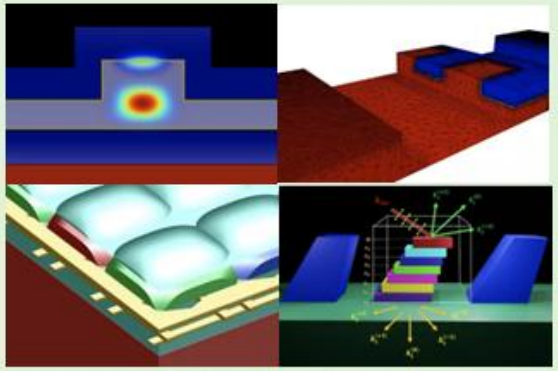
Electronics



© Keysight Technologies, Inc.

- HSPICE
- Spectre
- ADS
- etc…

Photonics



© Ansys, Inc.

- Lumerical
- Rsoft
- OptDesigner
- etc…

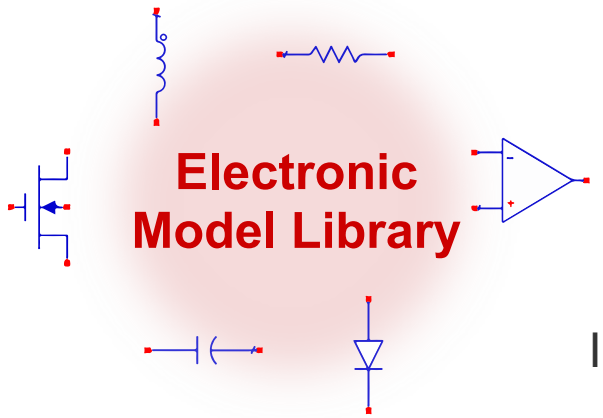
Semiconductor prototype requires long TAT and expensive cost
→ Performance prediction is important

Electro-Optic (EO) Co-Simulation

EO co-design has been tried using electronic circuit simulators

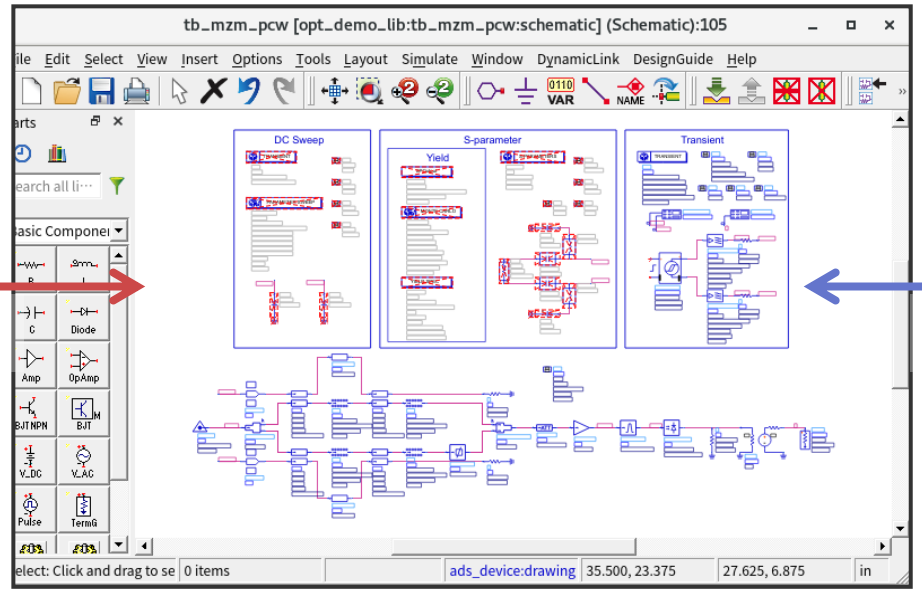
(Synopsys, Cadence, Keysight etc...)

Electronic Circuit Simulators

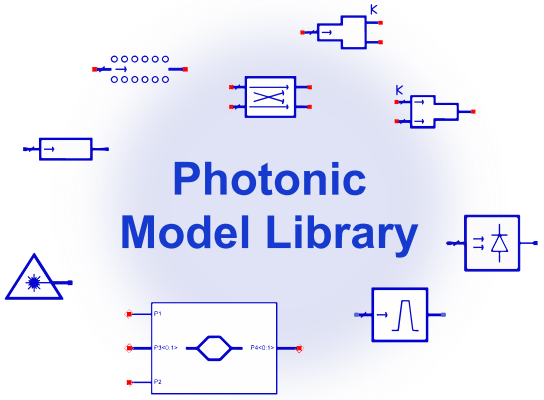


Netlist, SPICE Model
(e.g. BSIM)

Import



Import



Hardware Language
(e.g. Verilog-A)

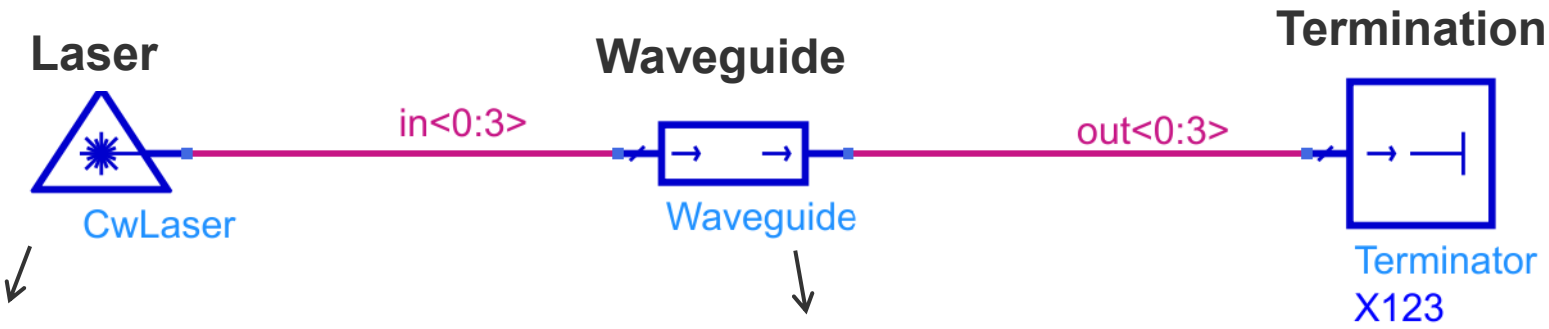
😊 Total characteristics can be analyzed

😊 No data transfer

😊 Interoperable in various environments using Verilog-A

Example: Optical Propagation

C. Sorace-Agaskar *et al.*, *Optics Express*, vol. 23, no. 21, pp. 27180–27203, Oct. 2015.

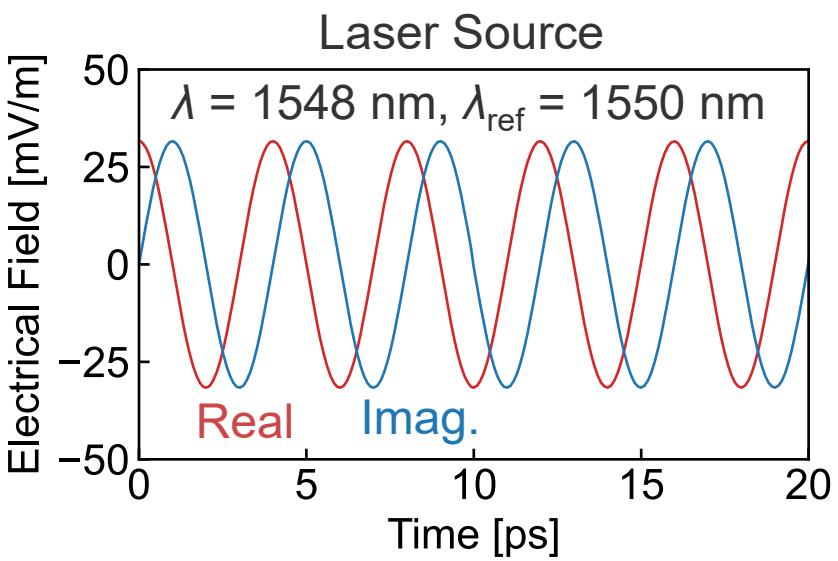


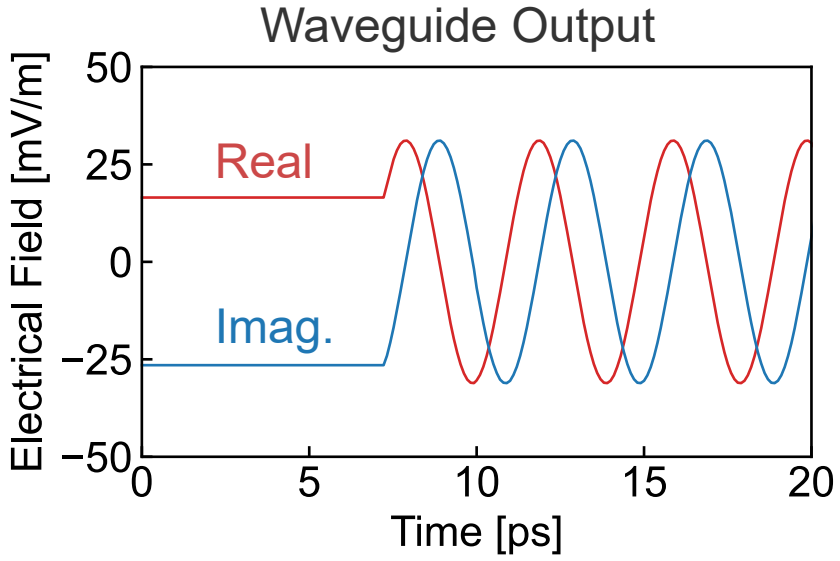
$$E_{LD}(t) = A_{LD}\exp[j(\omega_O - \omega_{ref})]$$

Frequency-Shifted Complex Sin Wave

$$E_{out}(t) = \exp(\alpha_0/2 - j\varphi)\, E_{in}(t - t_d)$$

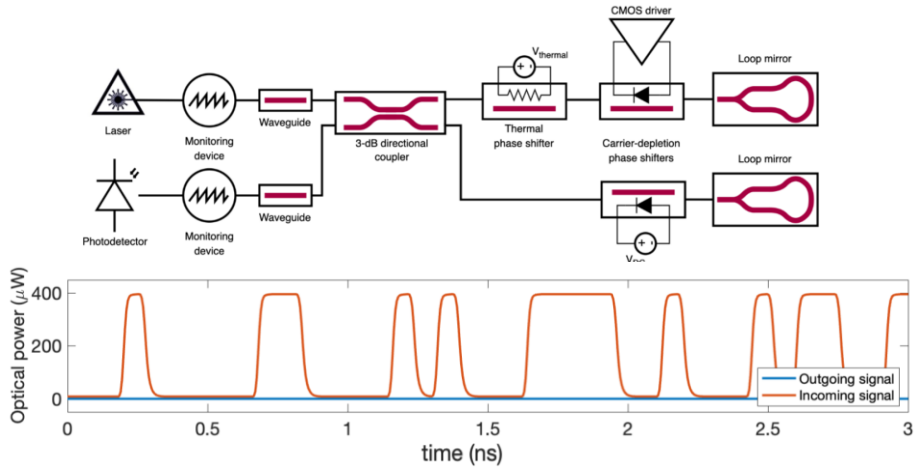
Loss · Phase Rotation · Group Delay





Recent Model Libraries & Challenges

UBC & Ansys Lumerical (Opt. Express 2024)

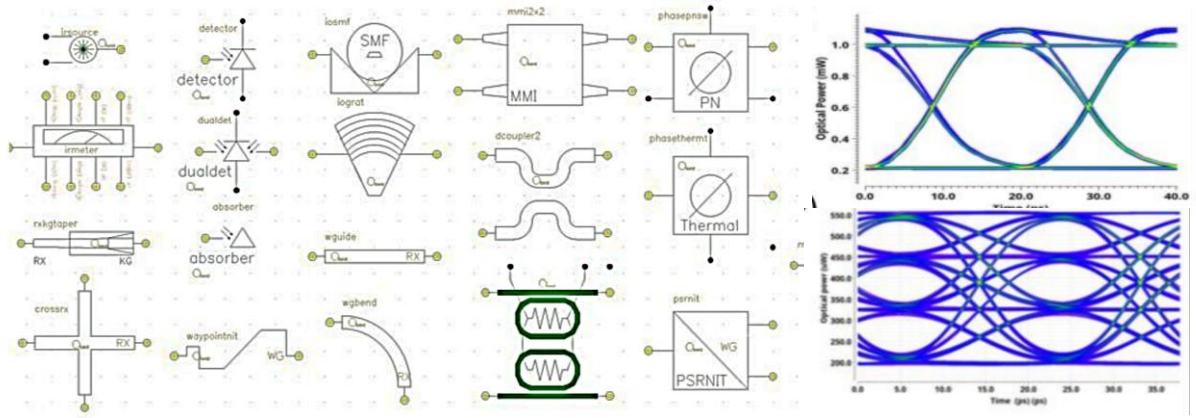


Not Supported

Not Supported

Insufficient (Only Optical Transmission)

Global Foundries (OFC 2024)



Insufficient (26.5 GBd for MZM)

Not Supported

Insufficient (Only S_{11}, Thermal Transience)

RF Model

Noise Model

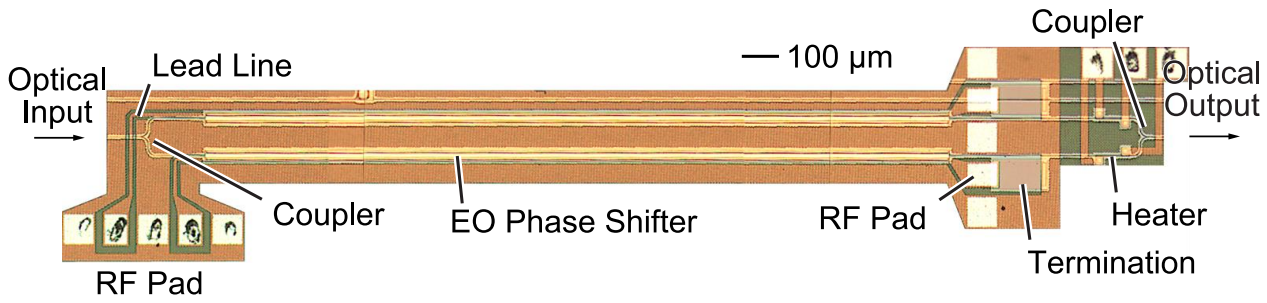
Experimental Verification

😢 **Lack of Accuracy for 800G Requirement (>50 GBd / Lane)**

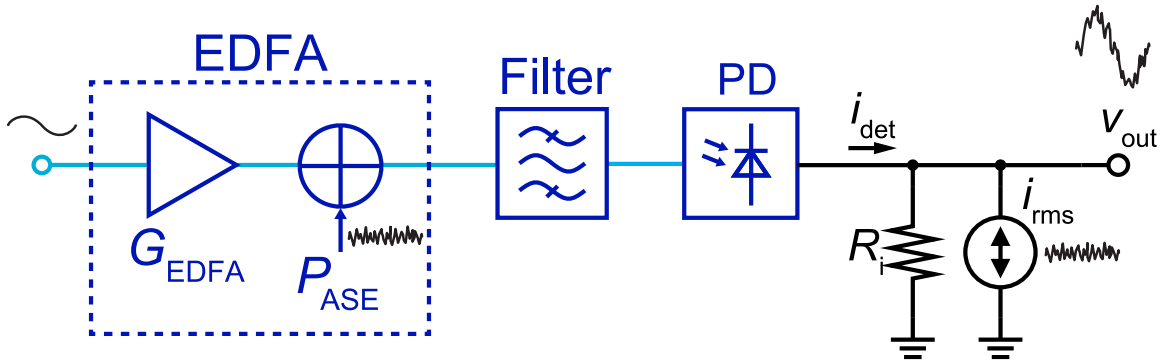
This Work: Accurate Co-Simulation Models for Electronic Circuit Simulators

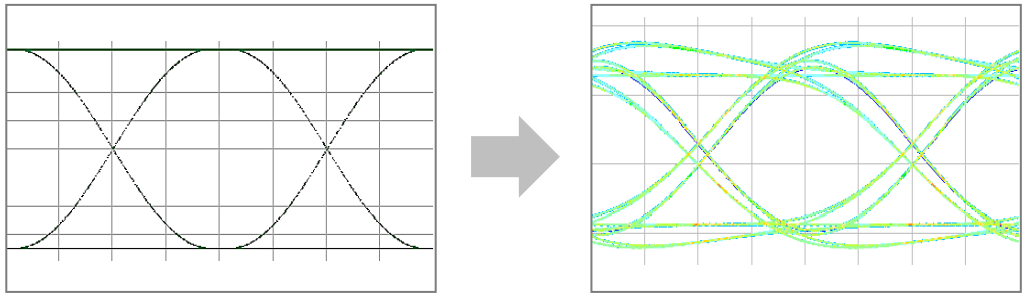
Two Stages to Improve Accuracy

1. **RF Modeling** of Mach-Zehnder Modulators



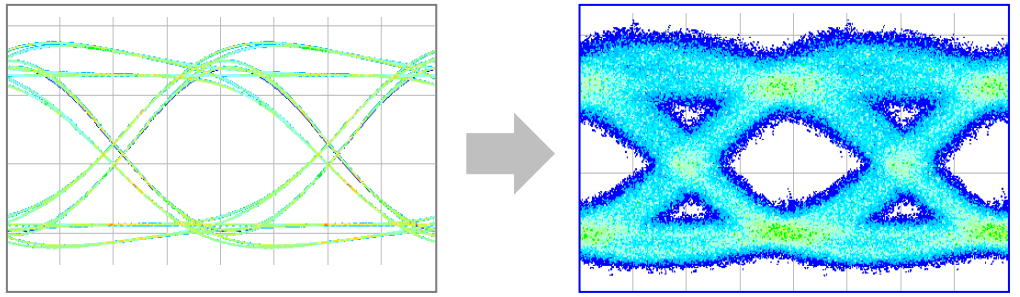
2. **Noise Modeling** of Optical Receivers





Ideal Model

RF Model

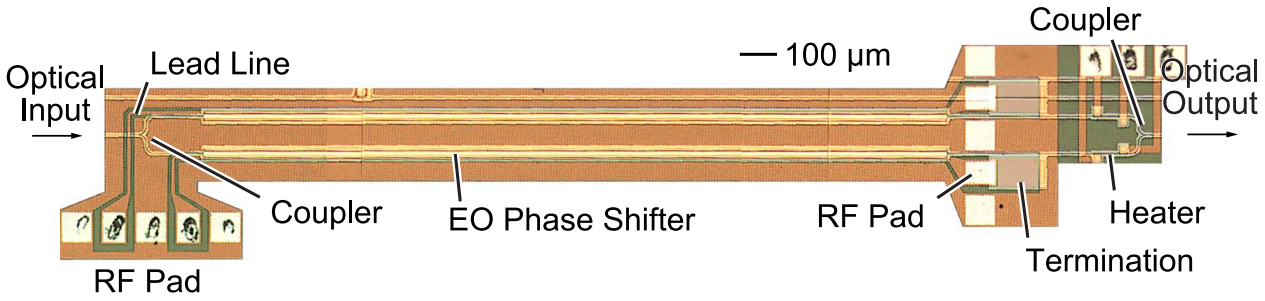


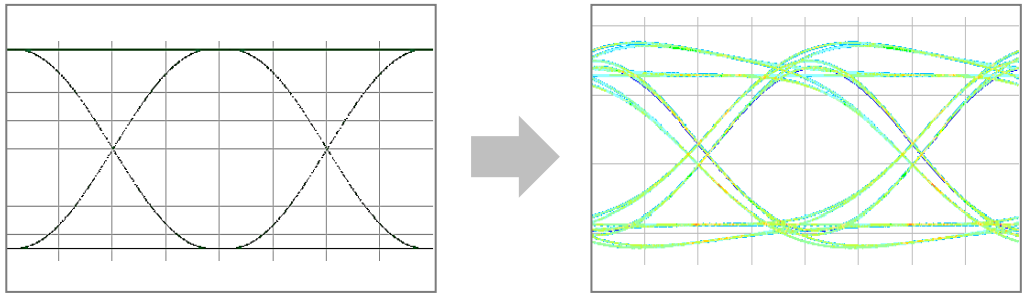
w/o Noise

w/ Noise

Two Stages to Improve Accuracy

1. **RF Modeling** of Mach-Zehnder Modulators

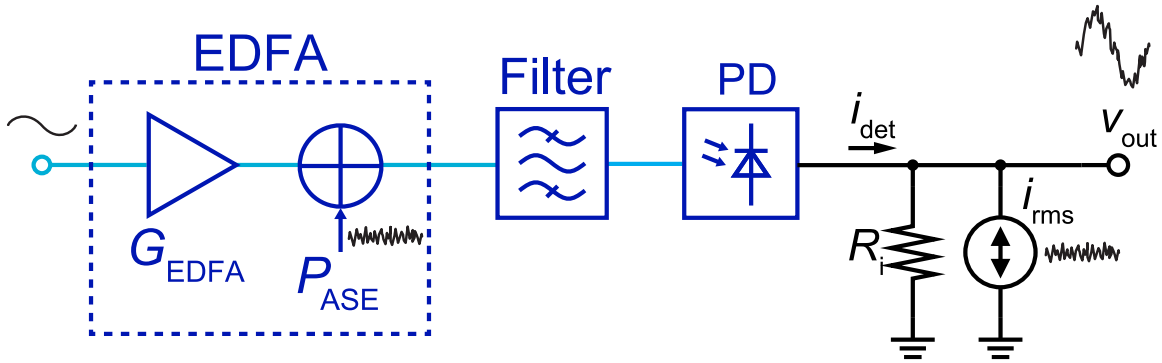


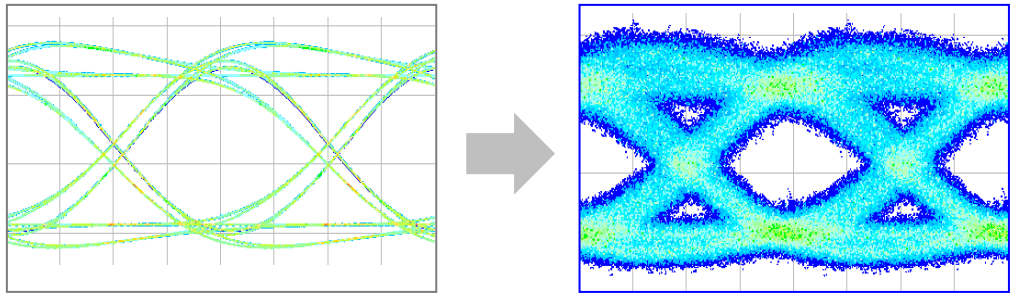


Ideal Model

RF Model

2. **Noise Modeling** of Optical Receivers



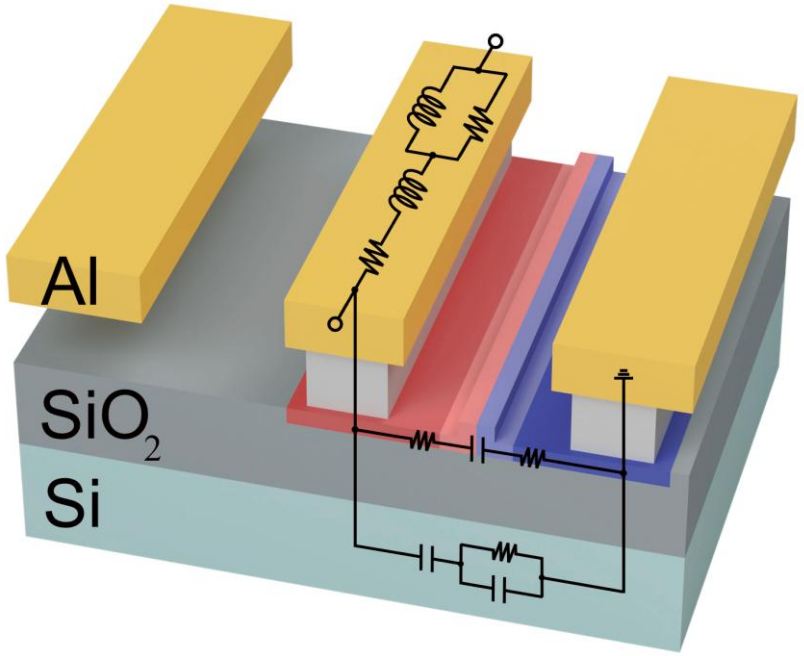


w/o Noise

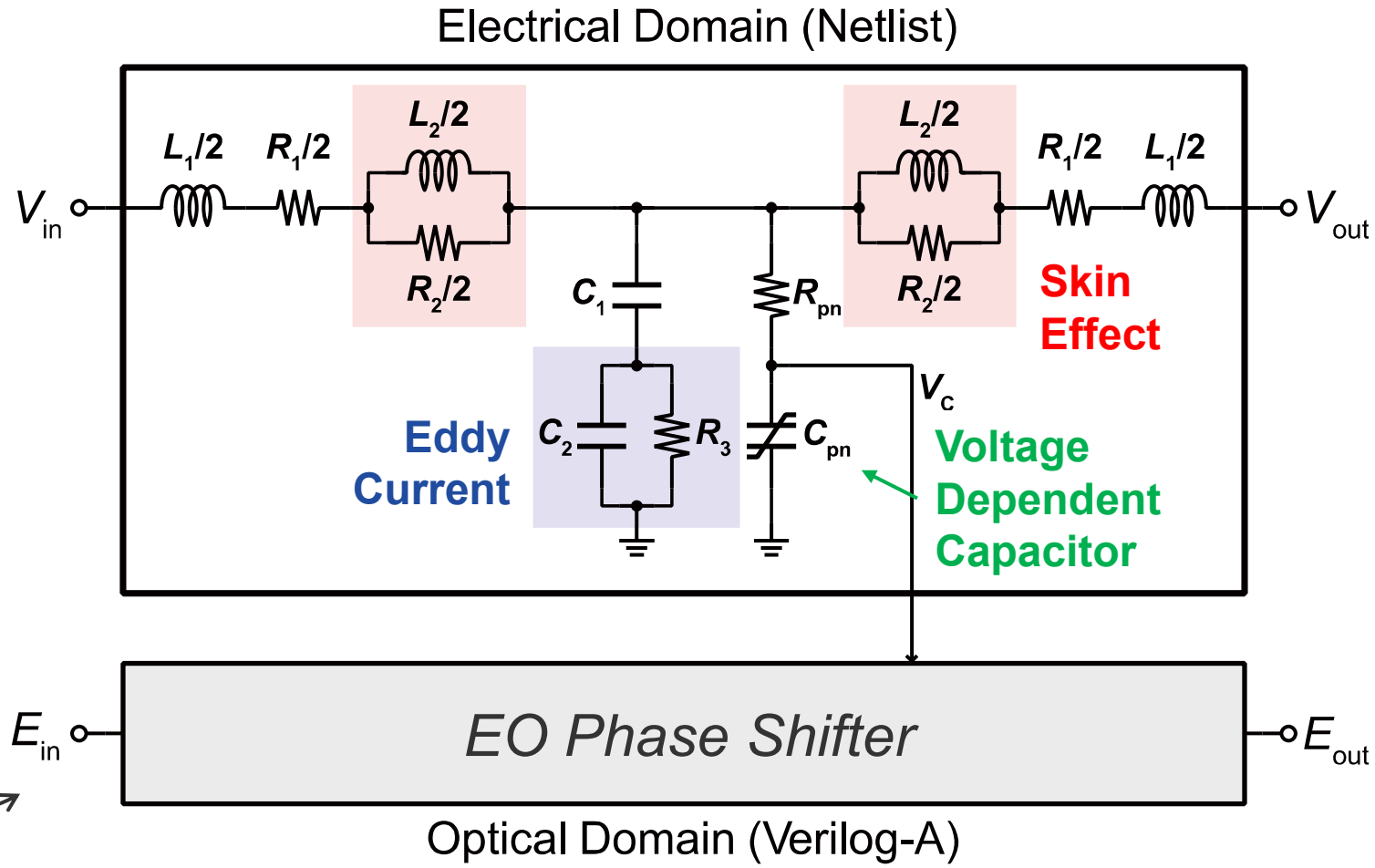
w/ Noise

Segmented Model for Travelling-Wave Electrode

Travelling-Wave Electrode



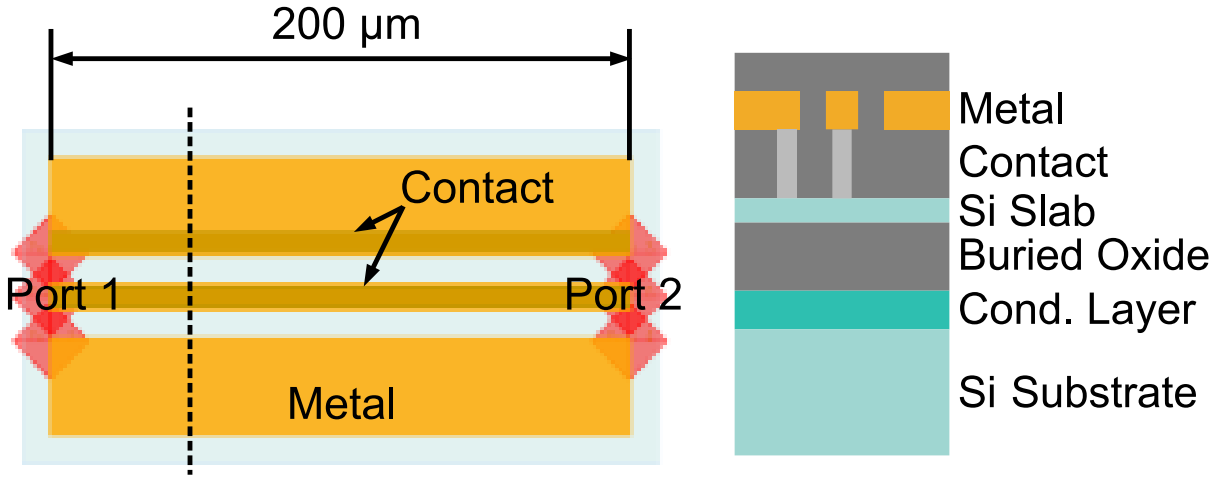
Segmented Model



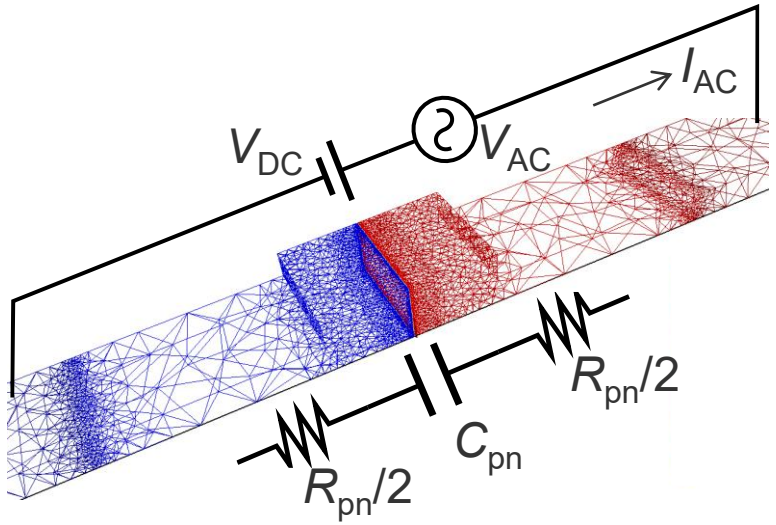
→ Accurate simulation of RF losses, impedance mismatch, and phase mismatch

Electrical Parameters Extraction

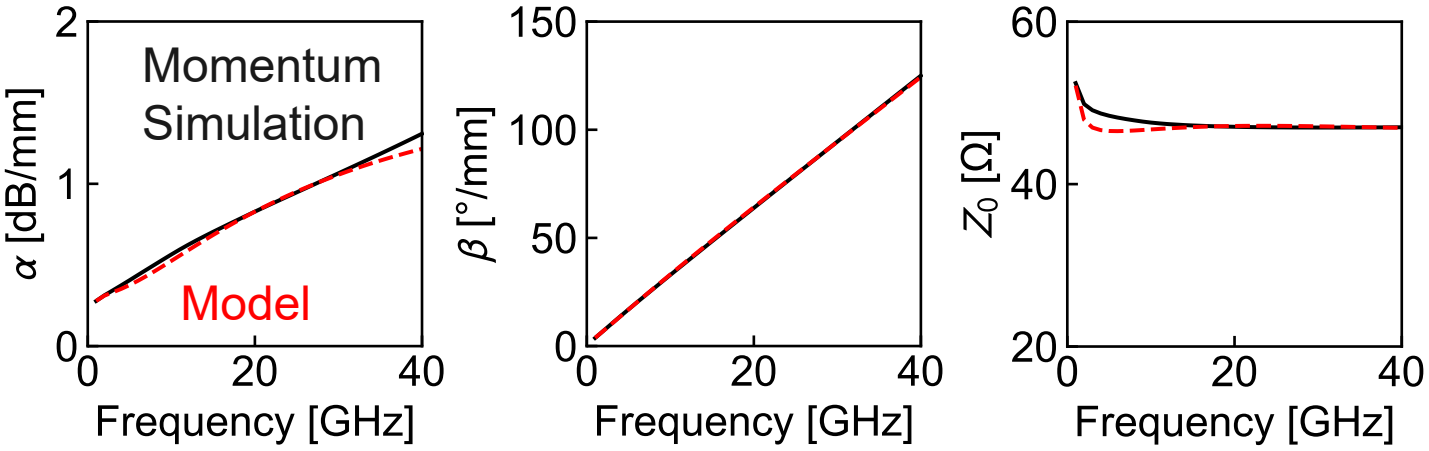
Coplanar Electrode



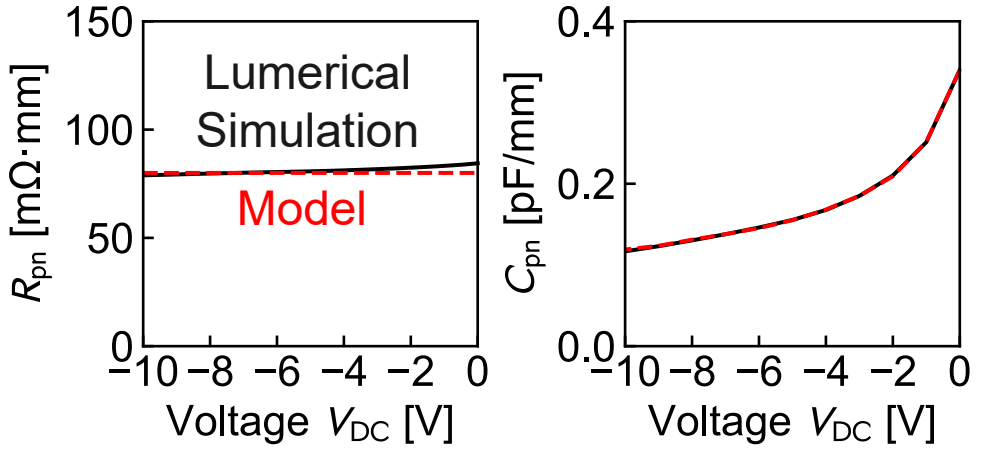
p-n Junction



Electro-Magnetic Simulation (Keysight Momentum)



Charge Transport Solver (Ansys Lumerical)

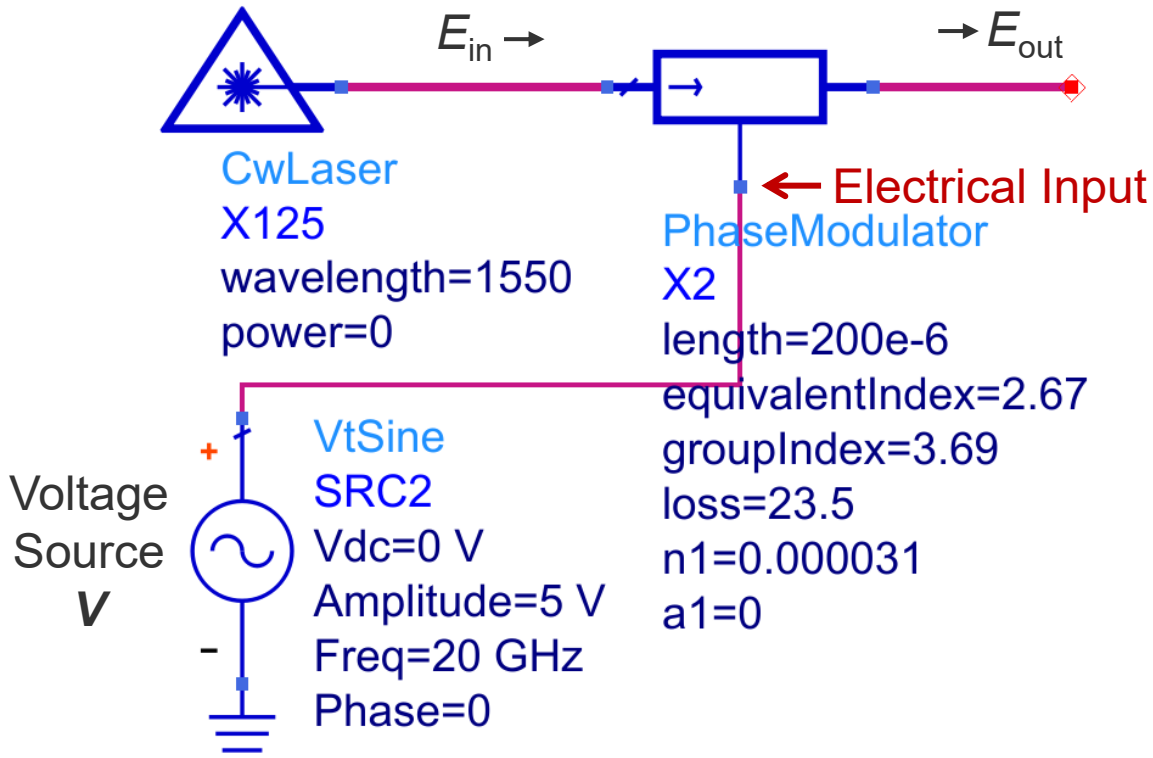


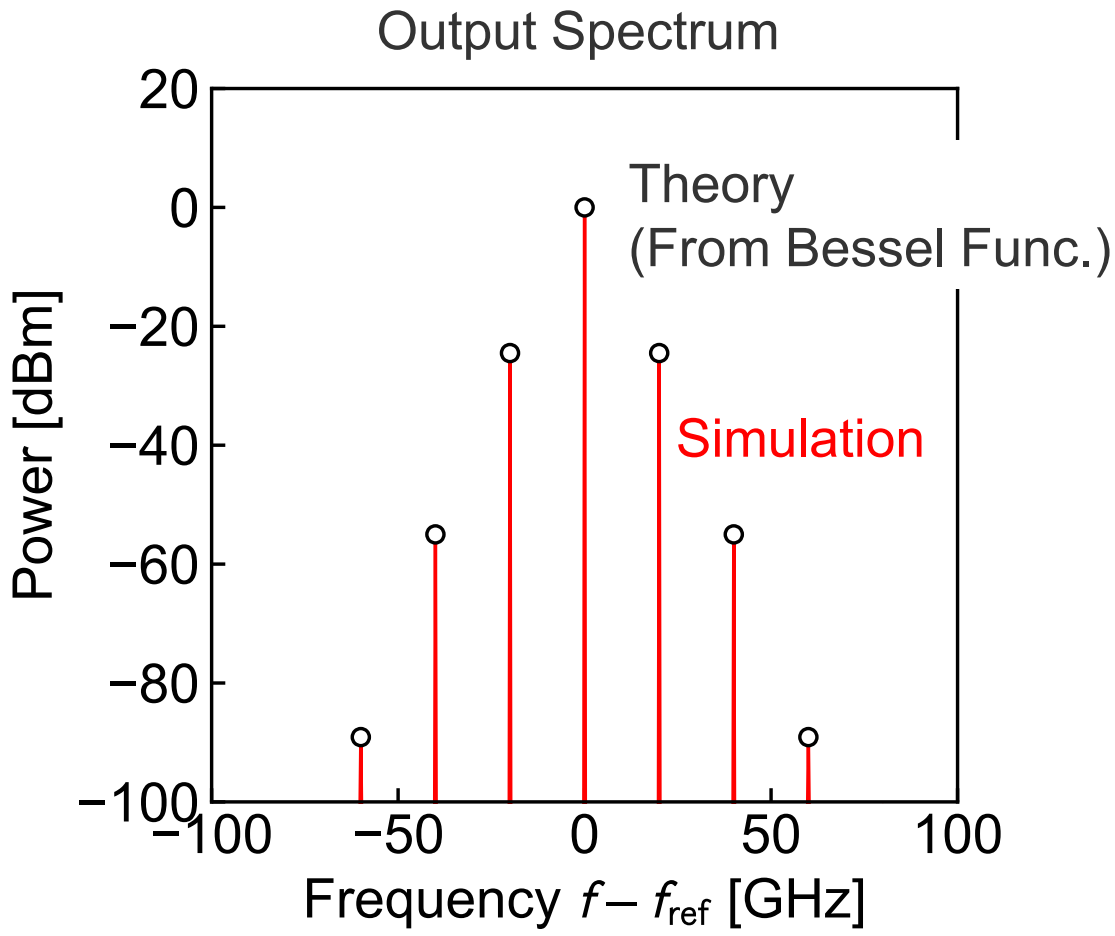
Modeling of EO Phase Shifter

Phase shifter was modeled using polynomials $n_{eq}(V) = n_0 + n_1 V + n_2 V^2$

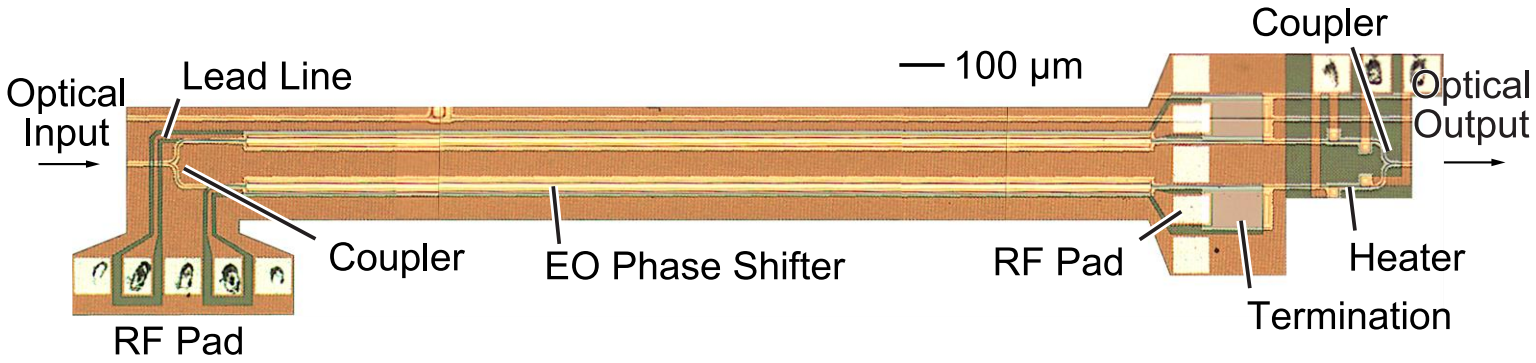
$$E_{out}(t) = \exp[\alpha_0/2 - j\varphi(V)]\, E_{in}(t - t_d)$$

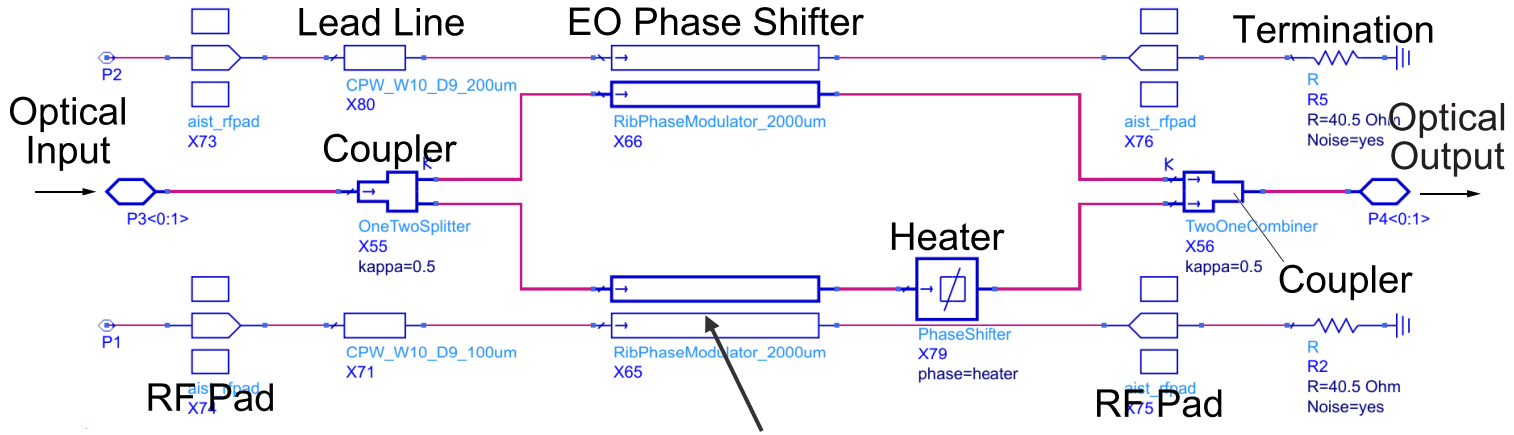
Phase Modulation





Mach-Zehnder Modulators

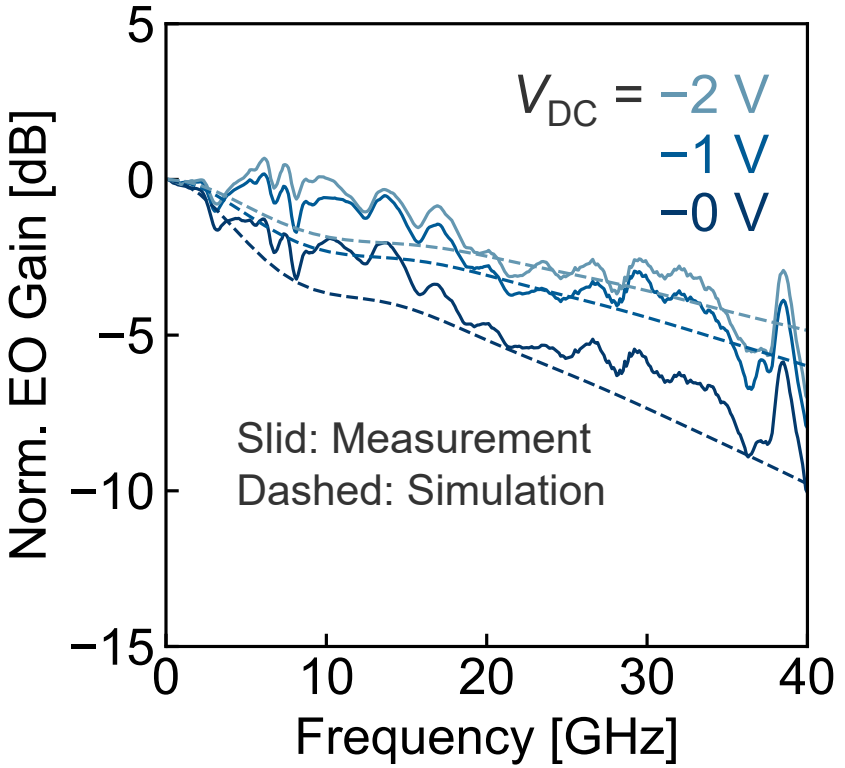




Including 40 Segments

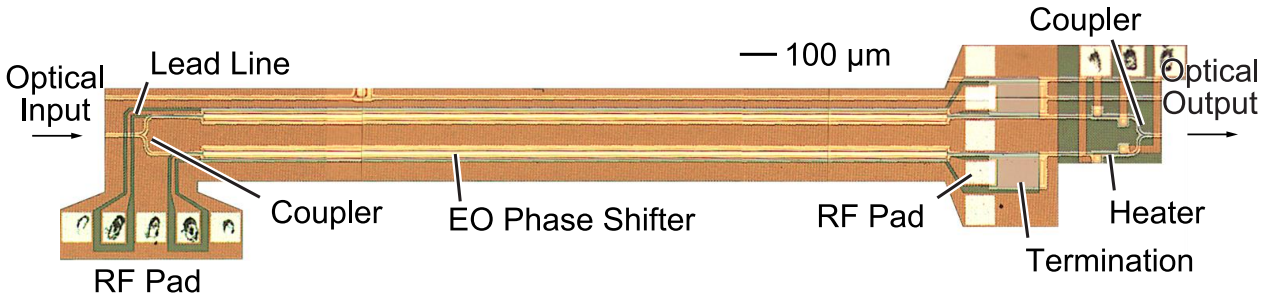
✓ Frequency Dependency

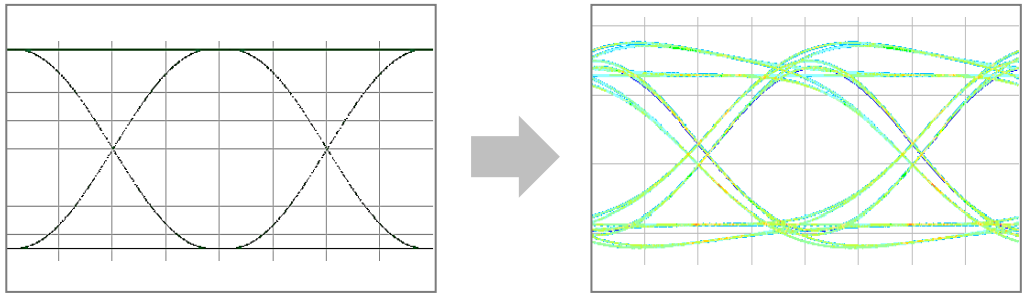
✓ Voltage Dependency



Two Stages to Improve Accuracy

1. **RF Modeling** of Mach-Zehnder Modulators

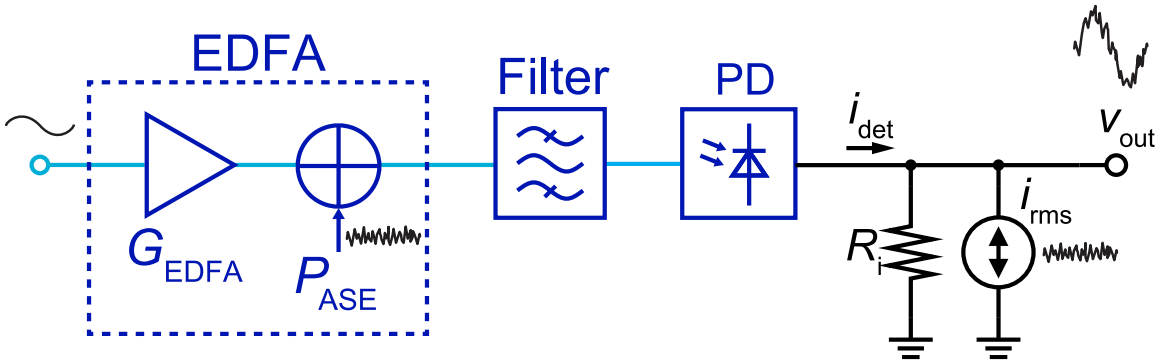


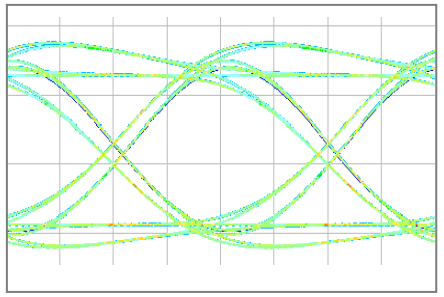


Ideal Model

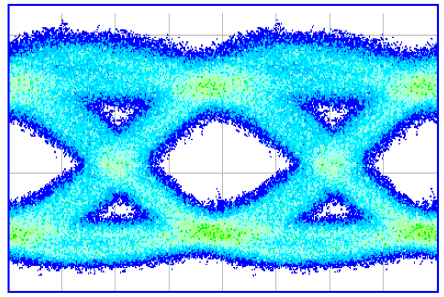
RF Model

2. **Noise Modeling** of Optical Receivers



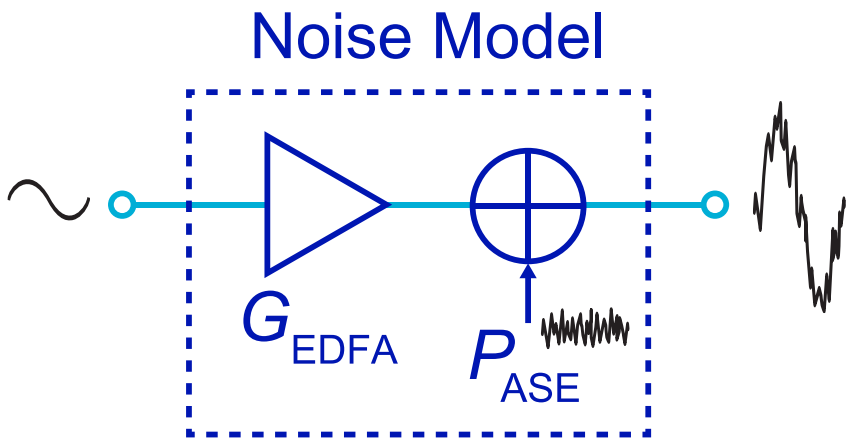


w/o Noise



w/ Noise

Modeling of EDFA's ASE Noise



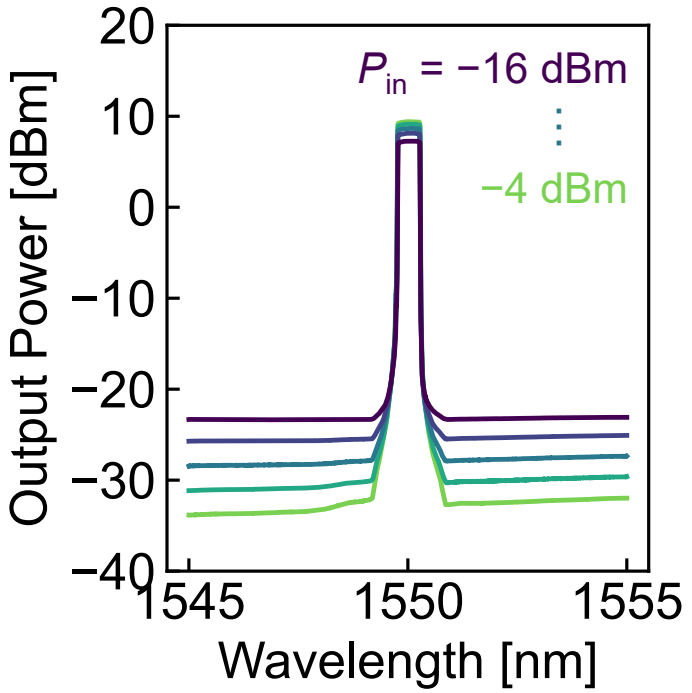
$$P_{ASE} = \mu h \nu \Delta \nu (G_{EDFA} - 1)$$

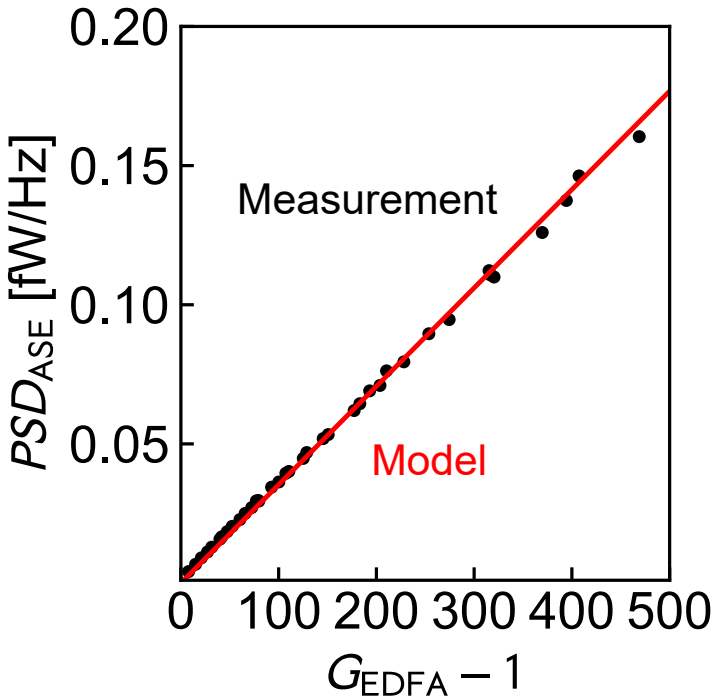
ASE power is proportional to gain

ASE level was measured by a spectrum analyzer

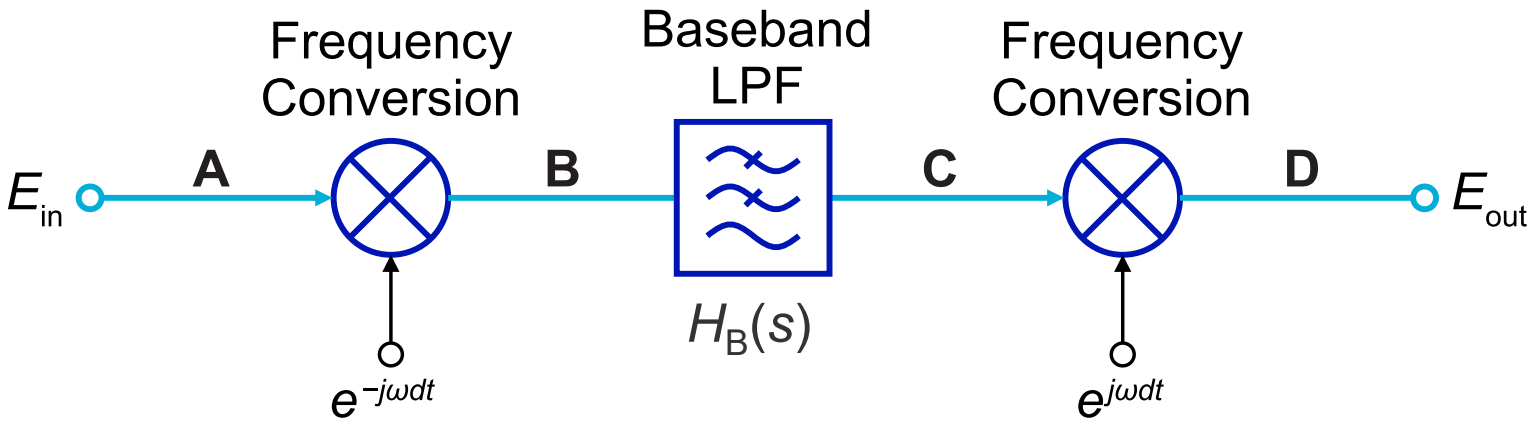
Test EDFA: Alnair CPA-100CL

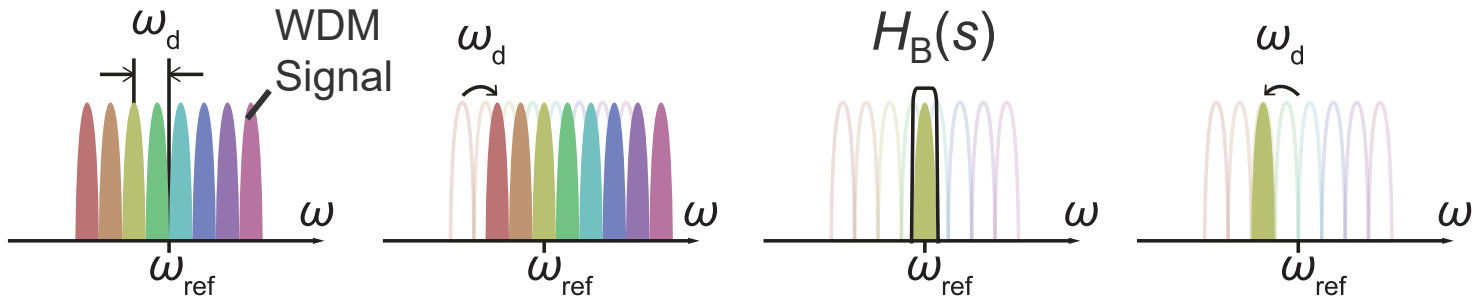






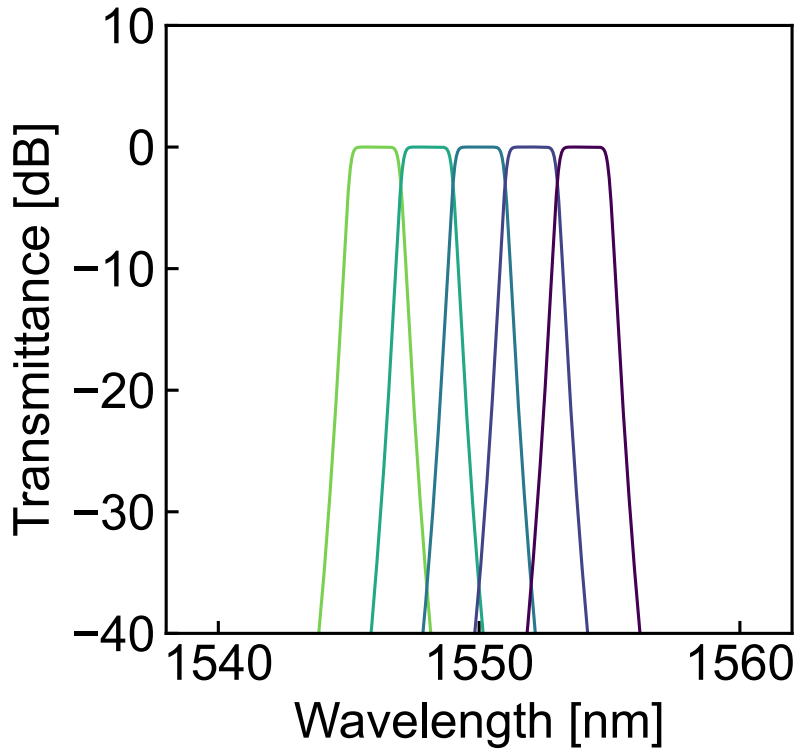
Wavelength Tunable Filter





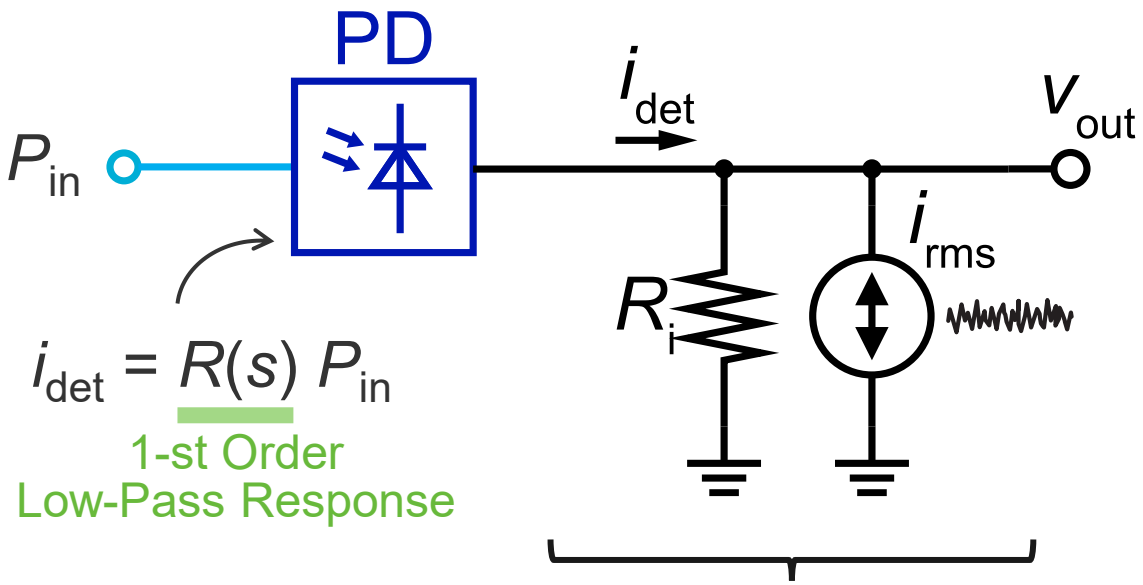
$$H_B(s) = \frac{n_0}{d_6 s^6 + d_5 s^5 + d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s^1 + d_0}$$

Available in a WDM System



Photodetector (PD)

PD causes roll-off and noise

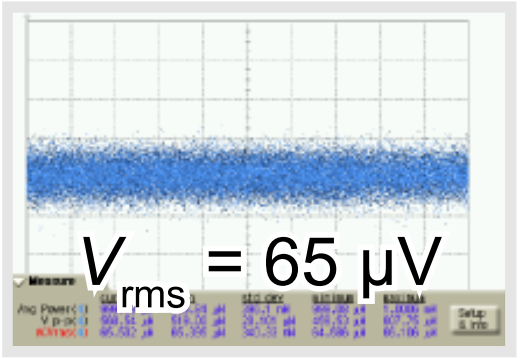




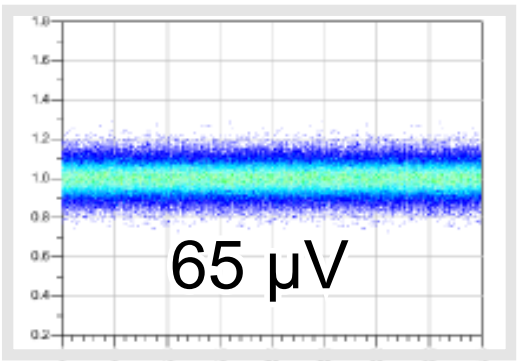
Test PD Module: Keysight 86116C

[Incl. Photodiode, TIA, and ADC
65-GHz Optical Bandwidth]

Measurement



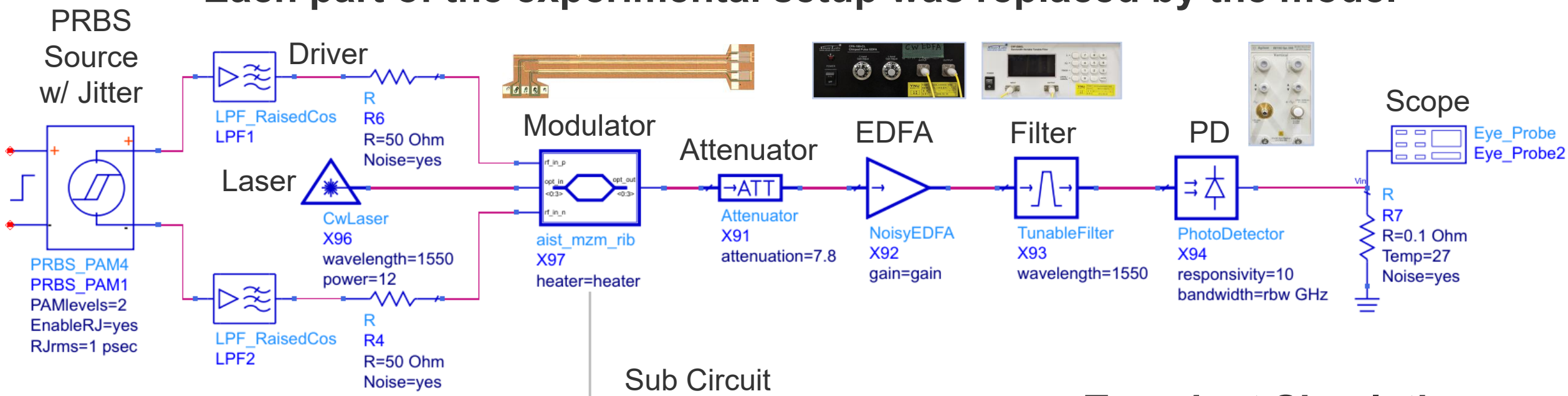
Model



P_{det} = 0 dBm

Test Bench for Communication Link

Each part of the experimental setup was replaced by the model



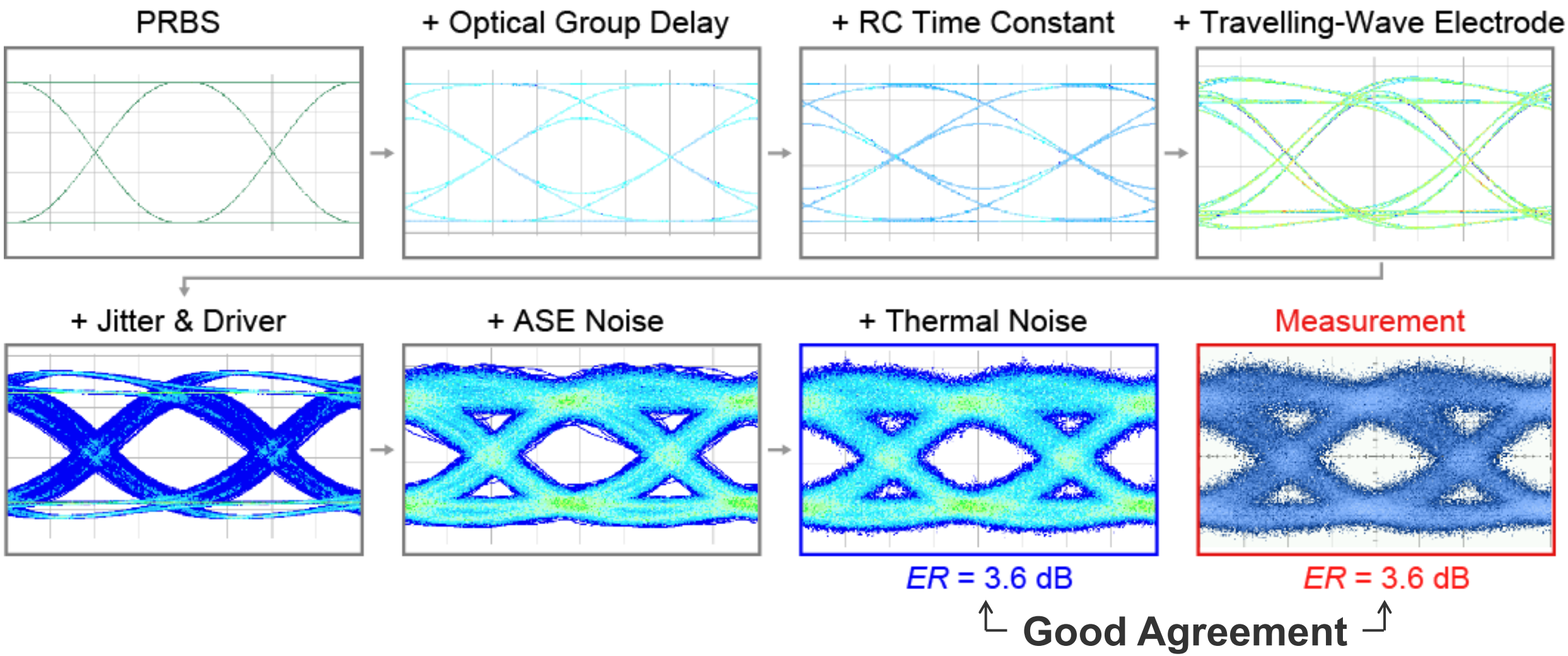
Transient Simulation

Time Step: 200 fs

The Number of Bits: 2048

Symbol Rate: 50 or 64 Gbaud

50-Gbaud Eye Diagrams (PCW-Type Modulator)

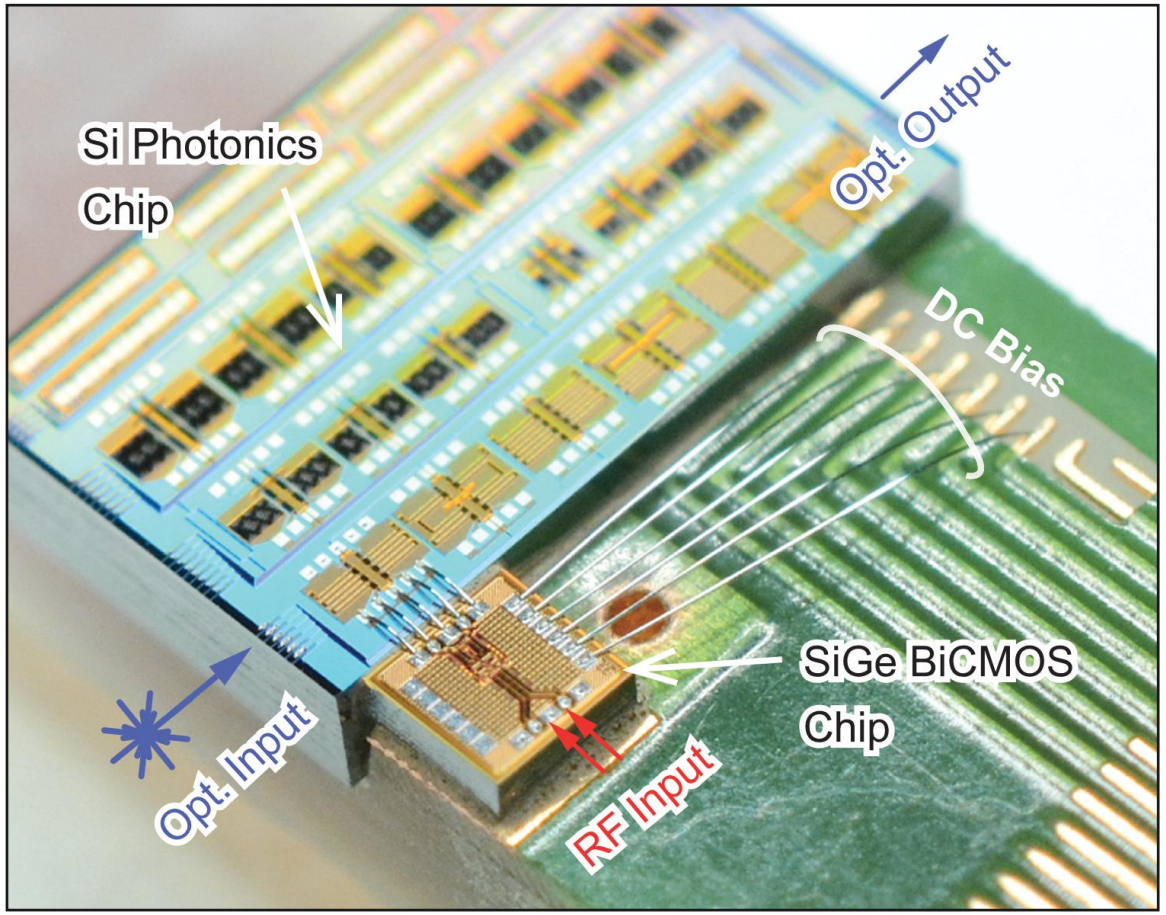


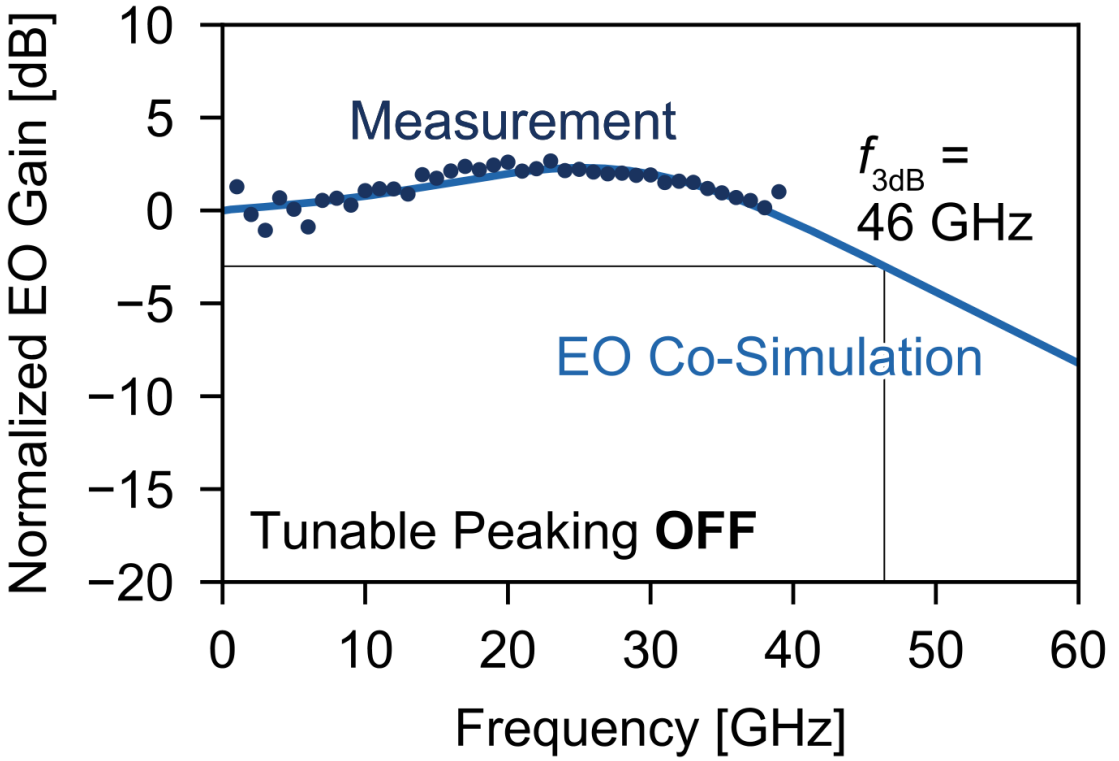
Simulation accurately reproduces experimental results

Frequency Response

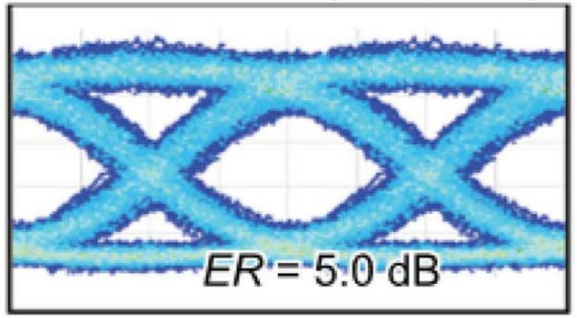
Co-Packaged Transmitter (MZM + Driver)

K. Kawahara *et al.*, *IEEE JSTQE*, vol. 32, no.2, Mar. 2026.

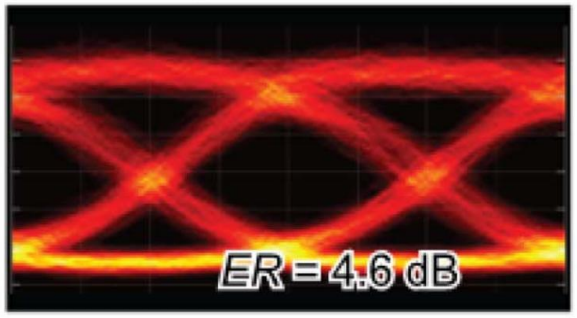




Simulation (50Gbps)



Measurement



Conclusion

Conclusion

EO Co-Design Reaches Practical Domain in 800G Systems

Challenge Accuracy of EO co-simulation was insufficient
RF modeling, noise modeling, experimetal verifications, ...

Results Experimentally verified up to 64 Gbaud, will be extended to >100 Gbaud

JMW
Paper
Link