

Design of Photonic Integrated Circuits

Photonic Integrated Circuit Simulation

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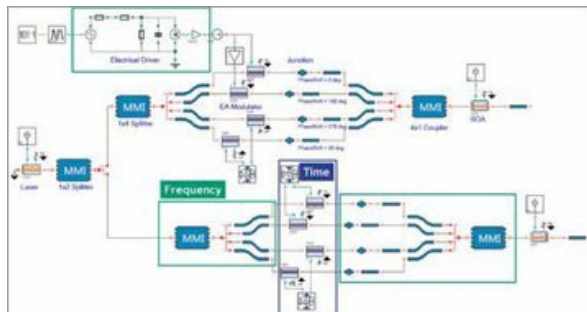
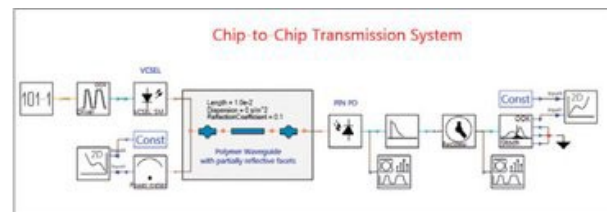
Keysight Photonic Integrated Circuit Simulation (VPIcomponentMaker Photonic Circuits) provides a focused modeling and simulation environment for experts in Photonic Integrated Circuit (PIC) design. It provides advanced libraries for modeling PICs comprising a mixture of hundreds of photonic, optoelectronic, and electrical elements. Circuit-level abstracted models facilitate rapid prototyping of complex large-scale structures independently from the dispersed technology process (Indium Phosphide, Silicon, Silicon Nitride, Polymer or any other materials).

The intelligent combination of time- and frequency-domain modeling techniques enables fast and accurate simulations of heterogeneous PICs, consisting of active and passive subelements. This approach allows the efficient modeling of multiscale PICs covering subelements of different length scales (from few μm to cm on the same circuit).

The Transmission-Line Laser Model (TLLM) handles the modeling of multisection semiconductor devices with bulk or MQW active mediums. This includes buried-hetero-structure lasers, amplifiers, electrooptic modulators, and distributed Bragg reflectors. The TLLM accounts for Kerr and two-photon absorption effects, DFB and DBR gratings, measured gain and absorption spectra, and carrier dynamics.

The S-matrix approach sustains the modeling of passive photonic and linear electrical elements such as passive waveguides, directional couplers, MMIs, star couplers, microring resonators, resistors, capacitors, inductors and voltage and current sources. This method provides support for frequency-dependent effective mode indices and attenuation.

Benefits



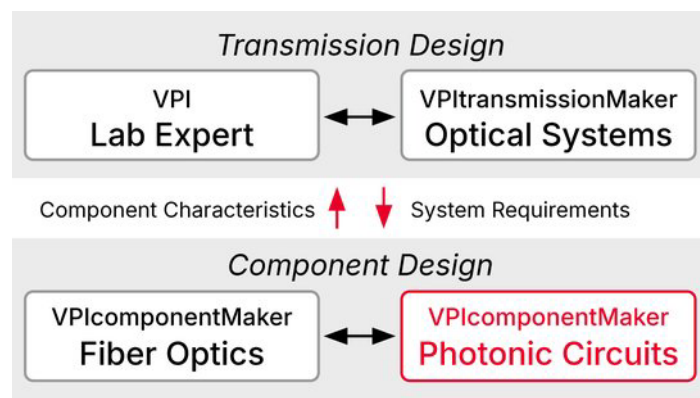
- Design and evaluate novel photonic circuits, integrated transmitters and receivers, tunable lasers, modulators, sensors, and electric circuits
- Build upwards from fundamental photonic elements, up to complex large-scale PICs
- Investigate device tolerances due to fabrication for a preliminary optimization of the device functionality
- Characterize large signal dynamics, tuning behavior, noise characteristics, side-mode suppression and others
- Model bidirectional signal and noise processes
- Find settings for stable laser operation, self-pulsation and mode-locking operation

Photonic Simulation Environment (VPIphotonics Design Suite)

VPIphotonics Design Suite embeds expert knowledge in one shared, flexible software environment to support requirements in design, analysis and optimization, providing the most powerful numerical algorithms as a professional solution for Photonic Design Automation (PDA). Beside *VPIcomponentMaker Photonic Circuits* the suite includes:

- Optical Transmission System Simulation (VPItransmissionMaker Optical Systems)
- Fiber Amplifier and Laser Simulation (VPIcomponentMaker Fiber Optics)
- Test Signal Generation and Analysis (VPIlabExpert)

VPIphotonics Design Suite

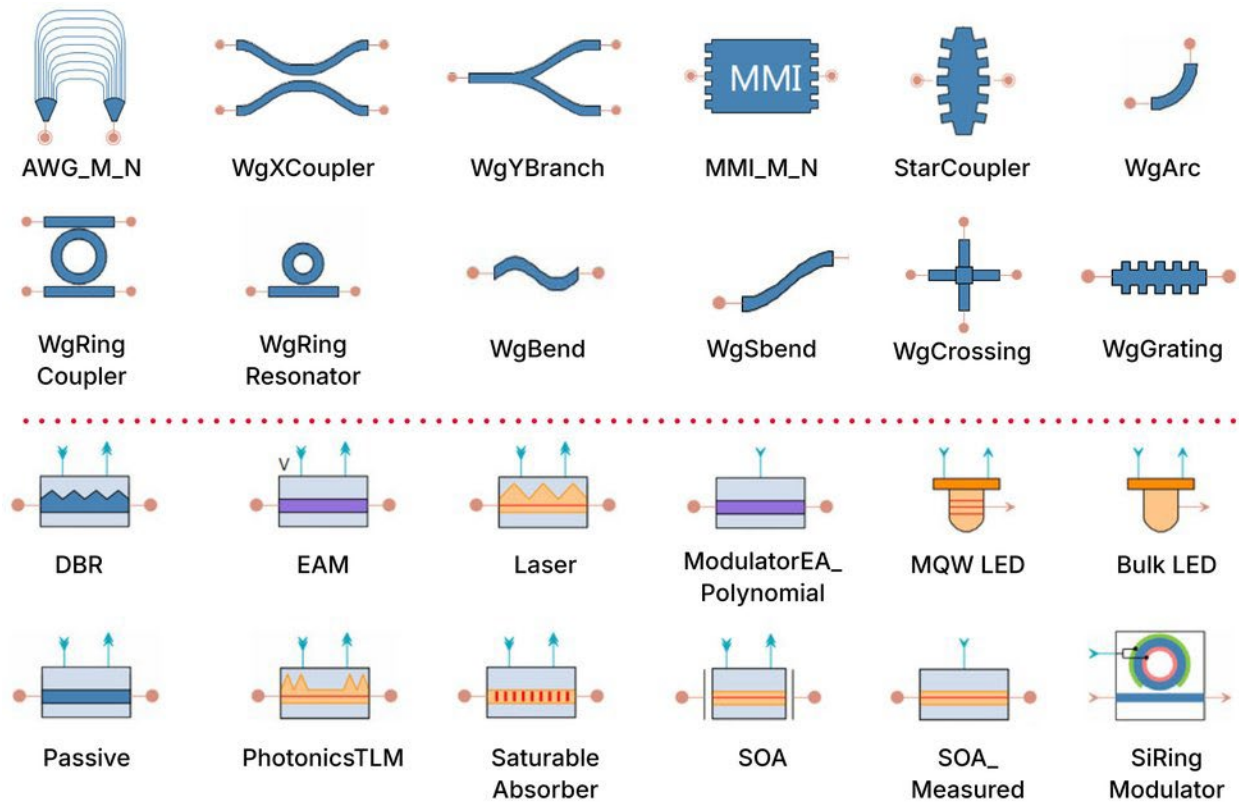


Applications

- Design and optimize active and passive PICs
- Model **dynamically tunable** passive components (optical filters, optical delay lines, phase shifters, interleavers)
- Design **microring-based photonic circuits** (add-drop filters, optical delay lines, ring modulators, polarization converters), with variable coupled rings
- Model **waveguide Bragg gratings** with individually specified index and loss coupling profiles (uniform, sampled, apodized and chirped)
- Design and optimize **MMI-based components** and visualization of MMI internal fields
- Build transmitters and receivers for **advanced modulation formats** (PSK, DPSK, DQPSK, mPSK, mQAM)
- Engineer **large-scale PICs** (reconfigurable cross-connects, add-drop multiplexed, optical interconnects)
- Model **multisection** semiconductor **lasers** with longitudinally dependent parameters (tapered or FBG-stabilized lasers) including MQW/Bulk, active/DFB/DBR/passive device sections and reflective interfaces

- Design **widely tunable and multichannel lasers** with sampled Bragg gratings, ring-resonator reflectors and AWGs
- Develop **electroabsorption** and **electrooptical modulators**, based on Franz-Keldysh, Stark, Pockels or Kerr effects
- Analyze active, passive, ring and hybrid mode-locked lasers to determine amplitude and timing stability of **ultrafast sources**
- Develop **2R and 3R regenerators** and optimize their speed, transfer characteristics and induced chirp
- Investigate **laser dynamics**: spectrum evolution, dynamic and adiabatic chirp, spectral-hole burning (SHB), turn-on jitter, mode hopping, intensity noise and data patterning
- Find optimum mixes of gain, loss and index coupling for power, spectral stability and feedback insensitivity in **high-power lasers**
- Enhance **modulation speed** using MQW materials, gain coupling and optimized drive waveforms
- Quantify antireflection coating specifications by simulating the full **interaction of laser and modulator**
- Develop fast switches, optical logic, modulators, detectors, edge detectors and gain flatteners
- Compare **wavelength conversion** based on XPM, XGM and FWM for speed, noise and conversion range
- Extract laser parameters from simple laboratory measurements, **explore design variations** based on the real device

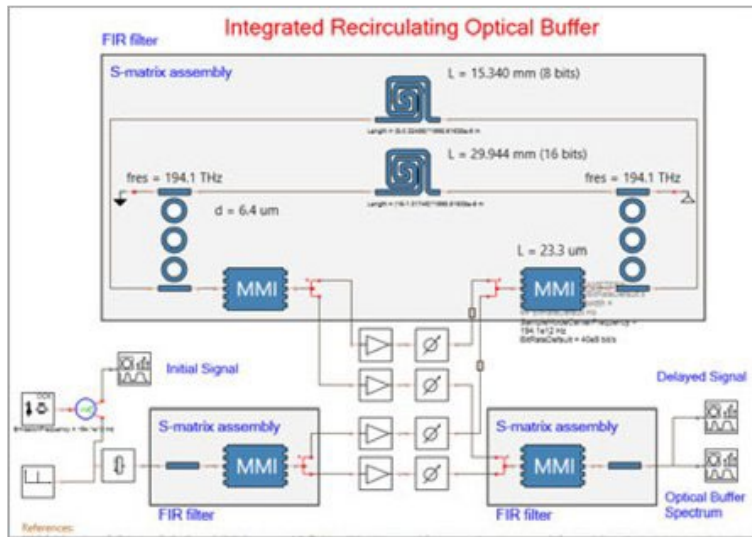
Building Blocks



Features

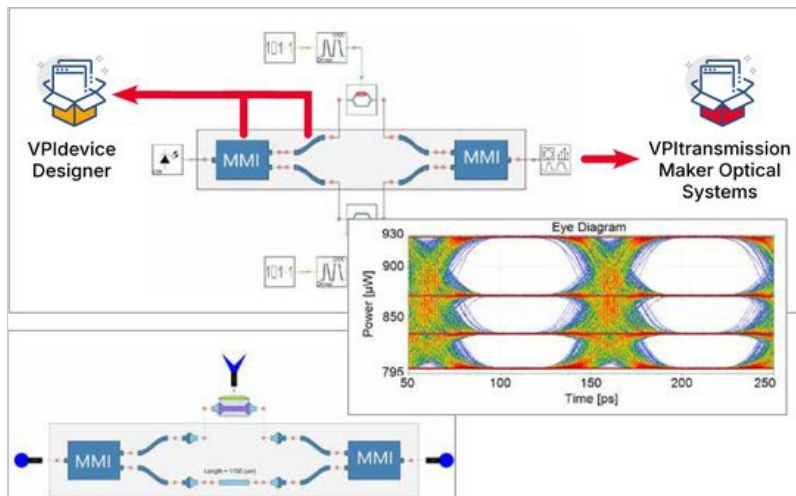
- Accurate analytical, behavioral, and measured models for standard passive photonic devices
- Advanced models for design of multisection optoelectronic devices: DFB, DBR, SOA, EAM
- Wide range of specialized optical modulators, optical sources and photodetectors
- Comprehensive and extensible library of linear electrical devices
- Support frequency-dependent effective mode indices and attenuations for TE- and TM-like modes
- Arbitrary carrier-dependent gain and voltage-dependent absorption spectra
- Efficient modeling of large-scale and multiscale PICs
- Flexible multiple signal representation with uni- and bidirectional signal flow
- DC, AC, and transient analysis of linear electric circuits
- Cosimulation interface for creating custom PIC elements
- Comprehensive tools for advanced signal processing
- Interactive simulations, simulation scripting, data import with automatic file format conversion
- Cosimulation with Keysight Advanced Design System (ADS) and standard programming languages (Python, Matlab, C, C++)

- Extensive set of documentation including over 200 exemplary design templates and application demonstrations



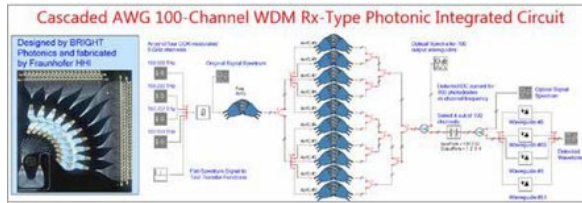
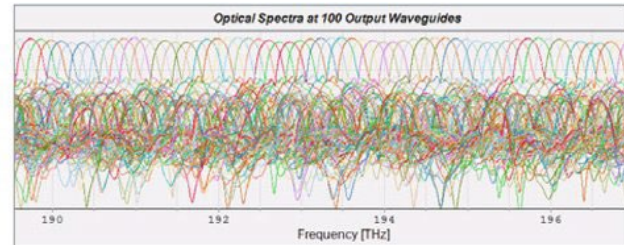
Design Examples

PAM4 Transmitter



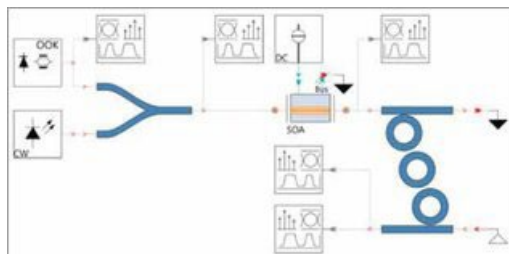
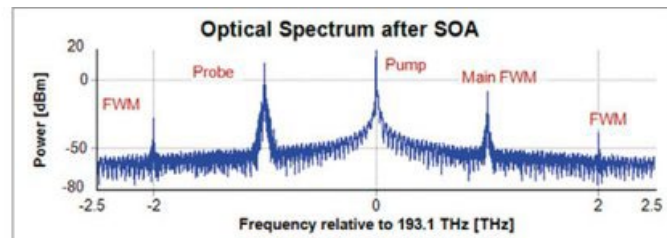
- Seamless integration with Photonic Device and Fiber Simulation (VPIdeviceDesigner) and VPItransmissionMaker Optical Systems
- S-matrix approach, frequency- and time-domain simulation modes
- Hierarchical designs
- Visualization of eye-diagrams
- Multiple simulation runs

Passive PICs



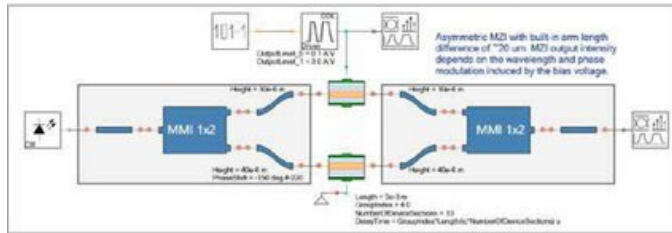
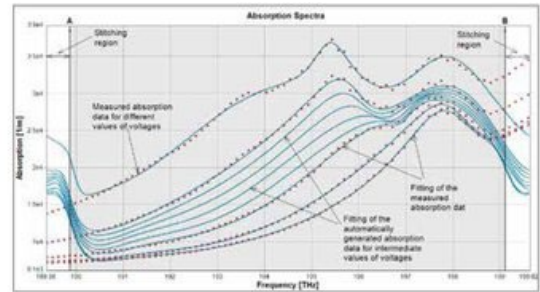
- Various modules: Directional, MMI, and star couplers, micro-rings, waveguides, and waveguide splitters
- Different modeling approaches: Analytical (coupled-mode theory, self-imaging MMI model, Fourier optics star coupler), behavioural, and measured models
- Birefringence, polarization coupling and dispersion effects

Optical Signal Processing



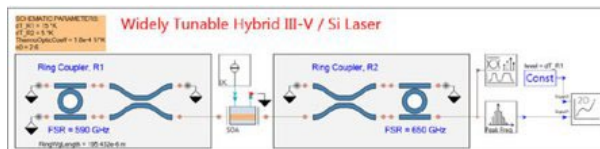
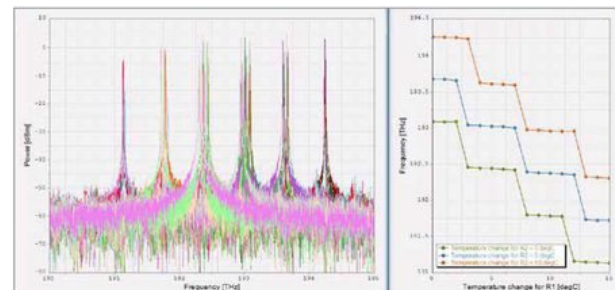
- Gain saturation and fast nonlinearities
- Model dynamics of ultrafast photonic circuits made from interacting elements
- Support of hierarchical designs for handling large-scale PICs consisting of linear and nonlinear blocks

High-Speed Integrated Modulators



- Electro-optical and electro-absorption
- Carrier injection and carrier depletion
- Signal retardation in both, distributed optical waveguides and traveling wave electrodes
- Voltage-dependent electro-absorption spectra automatically fitted by multi-Lorentzian IIR digital filters

Widely Tunable Lasers



- Wide tuning range, spectral purity, rapid tuning dynamics
- Carrier dynamics and nonlinear effects (spectral-hole burning, carrier heating, and four-wave mixing)
- Monitoring of temporal oscillations of the carrier density in MQW and SCH regions
- WDM transmitters to perform wavelength routing and conversion or modulation

Activation Unit for Deep Neural Network

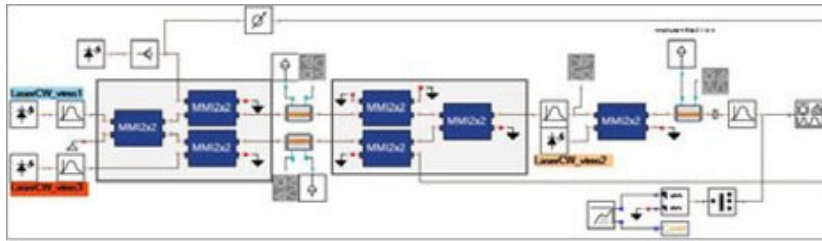


Figure 1. Fabrication tolerances

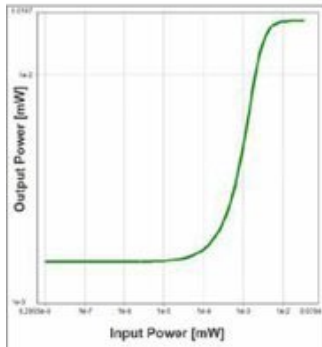


Figure 1a. Ideal case

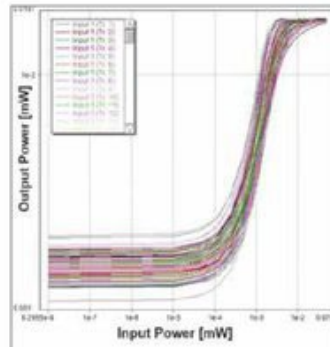


Figure 1b. With tolerances

- Design, optimization, and fabrication tolerance analysis of the PIC
- Sigmoid transfer function of activation unit
- Characterization of active and passive components
- Cosimulation techniques for Deep Neural Network modeling

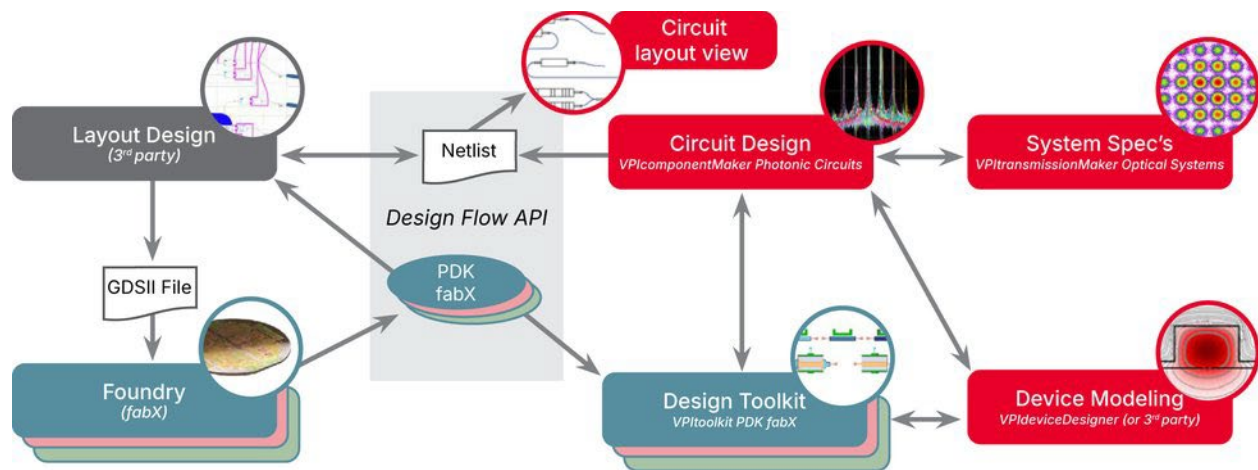
Design Kits for Photonics

Keysight offers a set of customized library extensions to VPIcomponentMaker Photonic Circuits enabling circuit-level support of a Process Design Kit (PDK) for various integrated photonics technologies (Indium Phosphide, Silicon, Silicon Nitride, Polymer) provided for instance by Fraunhofer HHI, SMART Photonics, LIGENITEC, LioniX International and Infinera foundries.

These pluggable Keysight Photonic Foundry PDK Library (VPItoolkit PDK <fab>) extensions allow the user to rapidly prototype application-specific photonic integrated circuits (ASICs) with prerequisite functionality using foundry-specific information without going deep into the details of device layout and fabrication process. The designer can choose photonic devices from a fixed list of standard Building Blocks (BBs) supported by the foundry. Each BB is represented with an adequate simulation model and only a few user-controllable parameters.

All the custom building blocks of such a design kit can be used alongside with a broad set of standard modules and instrumentation in VPIcomponentMaker Photonic Circuits.

VPItoolkit PDK <fab> implements the novel layout-aware schematic-driven PIC design methodology [1] enabling circuit-level simulations to account for exact physical locations and orientations of PDK BBs on the final layout and to connect subcircuits having fixed locations by smart elastic optical connectors. This functionality is enabled by the seamless integration with layout design tools (e.g., OptoDesigner, IPKISS, Nazca Design, L-Edit Photonics) allowing to combine graphical schematic capture and automated waveguide routing.



[1] PIC Magazine Issue 4 – “PIC Design: schematic or layout first? Both!”

Benefits

- Prototype integrated photonics and optoelectronics circuits with prerequisite functionality
- Account for layout information (physical locations, orientations) of BBs in the circuit design
- Utilize rich libraries of passive and active BBs which can be fabricated at the foundry
- Analyze fabrication tolerances and yield performance, and compare technology alternatives
- Build on adequate simulation models of BBs that are based on characterization data
- Export the circuit to JSON or Spice netlists, OptoDesigner, Nazca Design, L-Edit Photonics or IPKISS for layout, packaging and GDSII mask generation

Design Examples Using PDK Libraries

Widely Tunable Monolithically Integrated Laser

ASPIC design based on generic integration technology with SMART Photonics PDK building blocks for a widely tunable monolithically integrated CW laser [1].

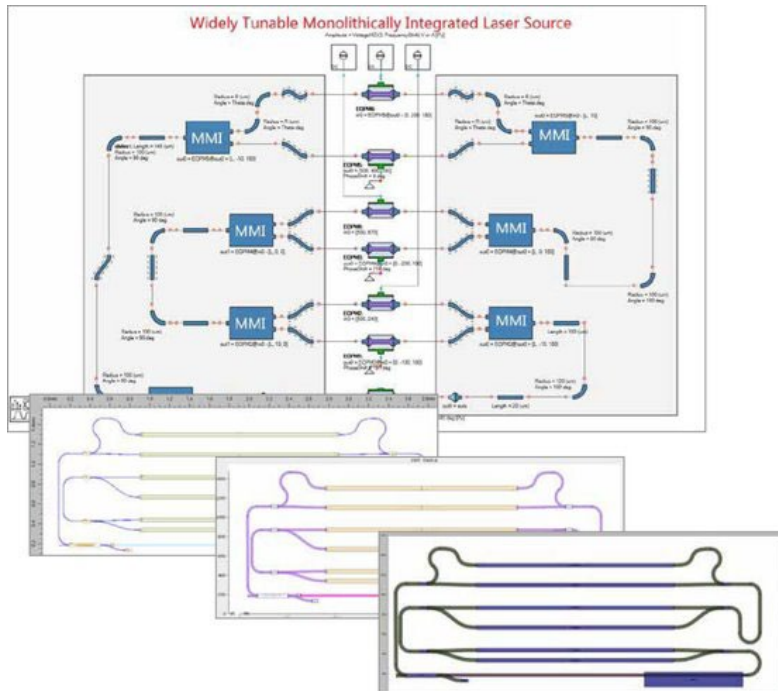


Figure 2. Circuit setup in VPIcomponentMaker Photonic Circuits and exported layout in OptoDesigner, Nazca, and IPKISS using VPItoolkit PDK SMART (from top to bottom).

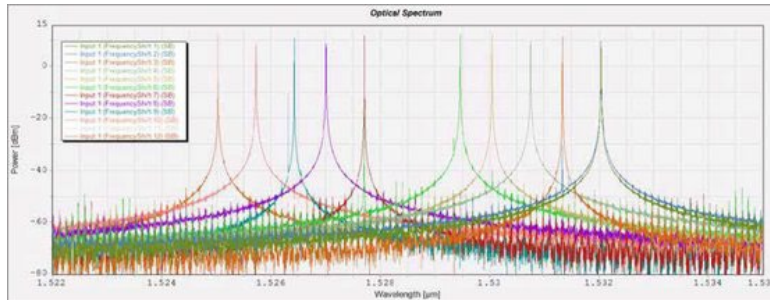


Figure 3. Exemplary simulation results of tuning characteristics

[1] S. Latkowski et al., "Novel Widely Tunable Monolithically Integrated Laser Source," *IEEE Photonics Journal*, vol. 7, No. 6, 1503709 (Dec 2015)

Optical Coherence Tomography (OCT)

Chip design based on [2] using LioniX PDK building blocks for the integrated optical waveguide technology TriPleX™ and exemplary simulation result: restored Sample after OCT.

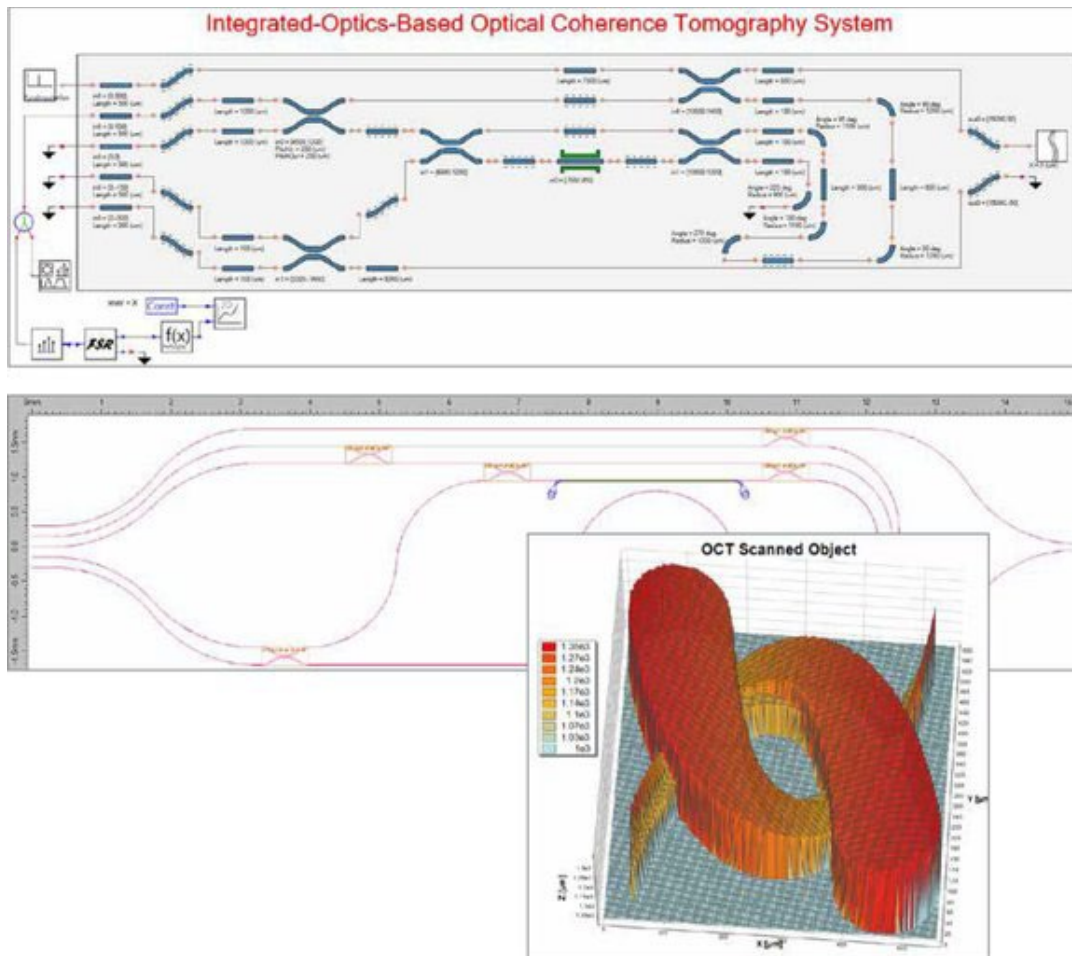


Figure 4. Circuit setup in VPIcomponentMaker Photonic Circuits and exported layout in Phoenix OptoDesigner using PDK LionIX

[2] K. Worhoff, R.G. Heideman, A. Leinse and M. Hoekman, "TriPleX: a versatile dielectric photonic platform", *Adv. Opt. Techn.* 4(2), 189–207 (2015).