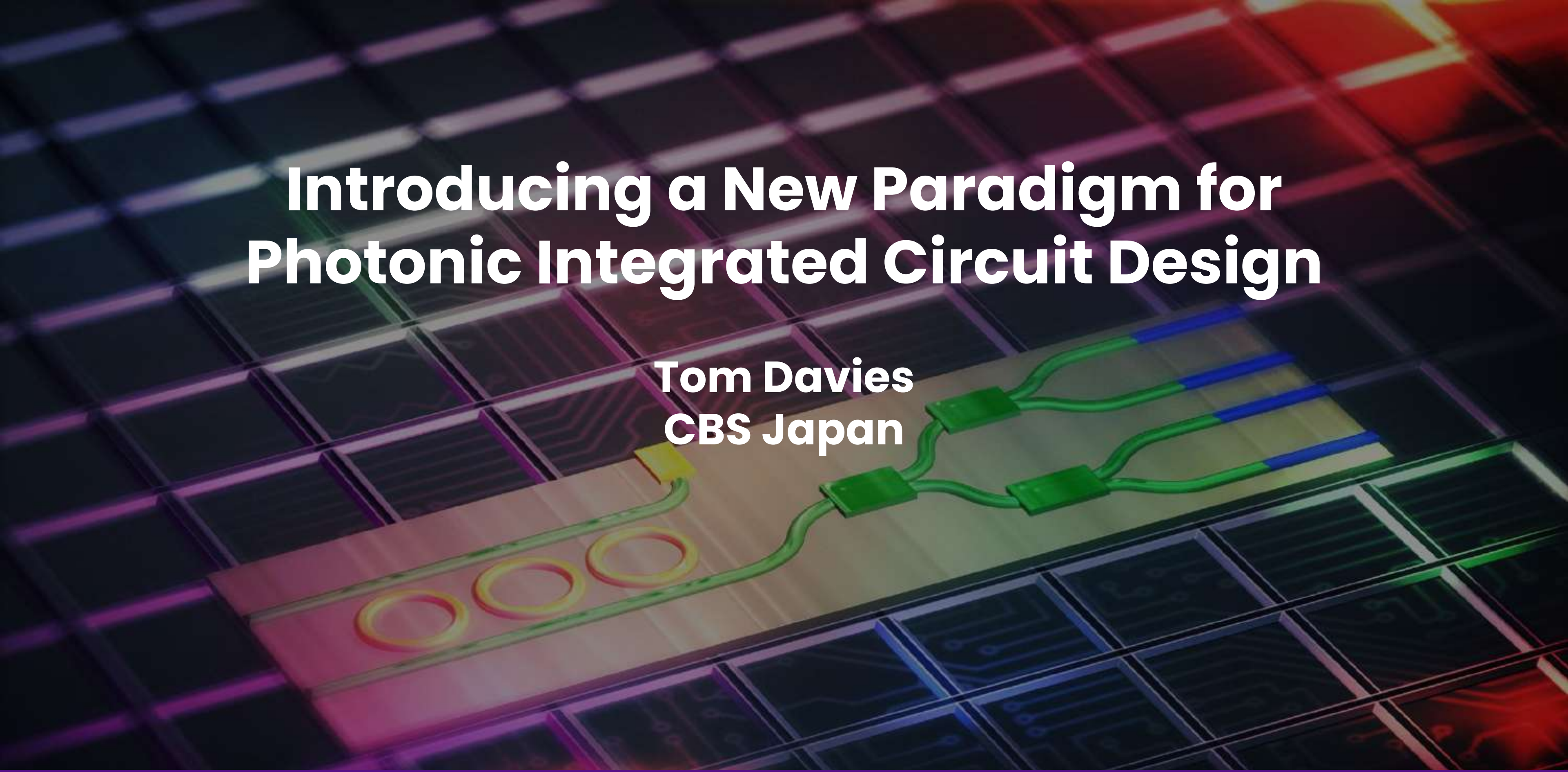


Introducing a New Paradigm for Photonic Integrated Circuit Design

Tom Davies
CBS Japan

About Us!

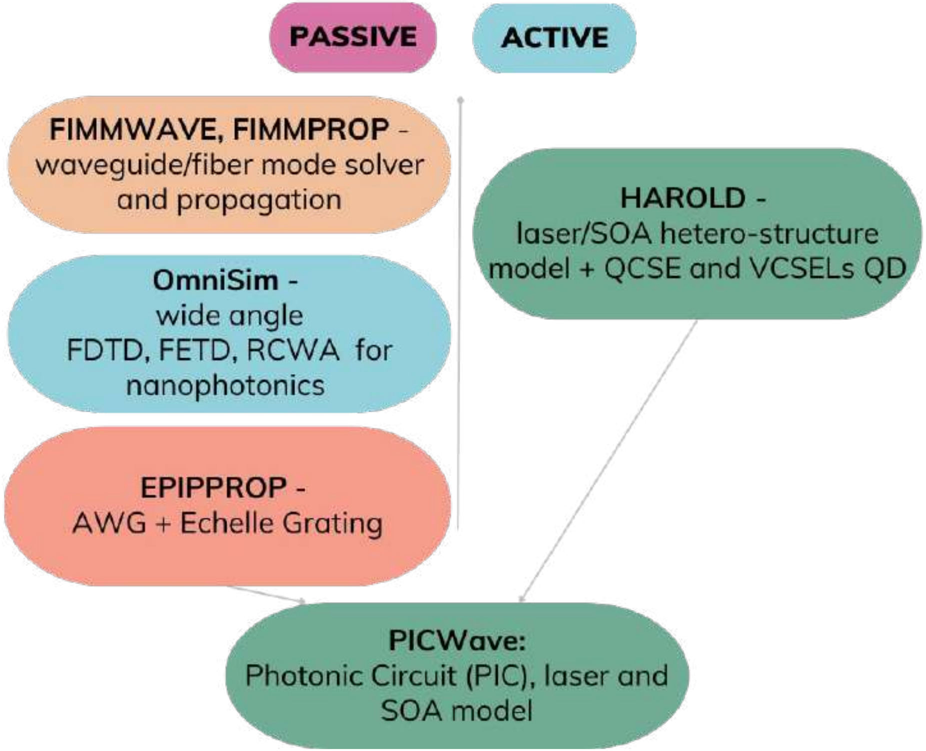
CBS Japan is the exclusive Japanese distributor of Photon Design CAD tools, specializing in modeling active and passive photonic components and optical circuits.

- Head Office: Canada, founded in 2006
- Branch Offices: CBS Japan (2006) & CBS Europe (2020)
- Additionally: We provide specialized tools for opto-mechanical simulation (FRED) and optical measurement systems (opsira) to support the full optical development cycle
- Today's Presenter: Tom Davies, COO

About Photon Design

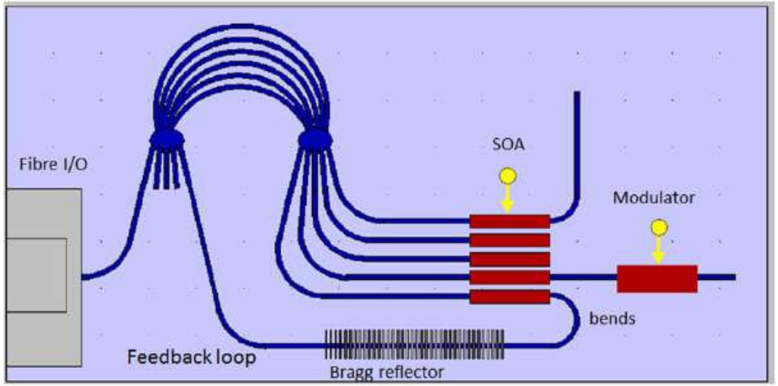
- Established in 1992
- Based in Oxford, United Kingdom
- Products used globally by most leading optical component manufacturers and academic institutions
- JePPIX member and partners in EuroPIC and PARADIGM projects (which developed InP generic foundry)

Photon Design Software Collection

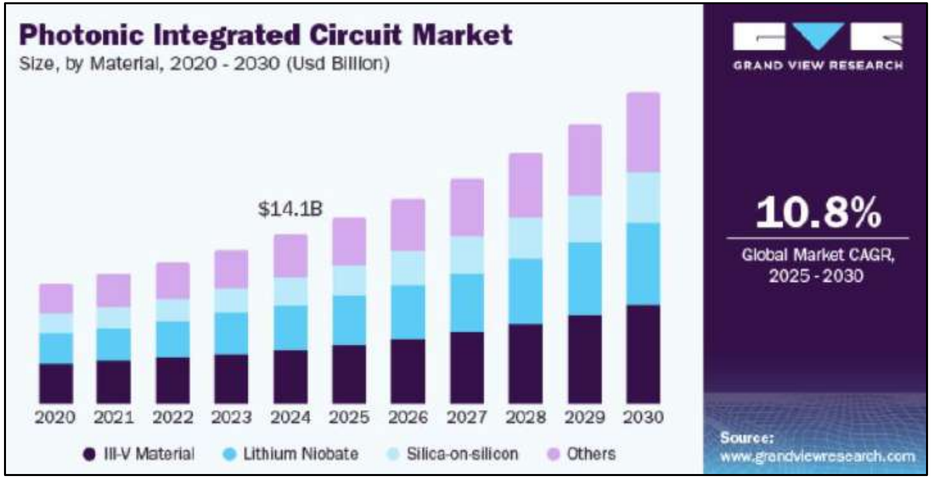


What is a PIC?

PIC = **Photonics Integrated Circuit.** Can often have both active and passive elements, and can have arbitrary topology. There is increasing demand for photonic integrated circuits (PICs) because of the superior capacities (bandwidth, speed) compared to electronic circuits.



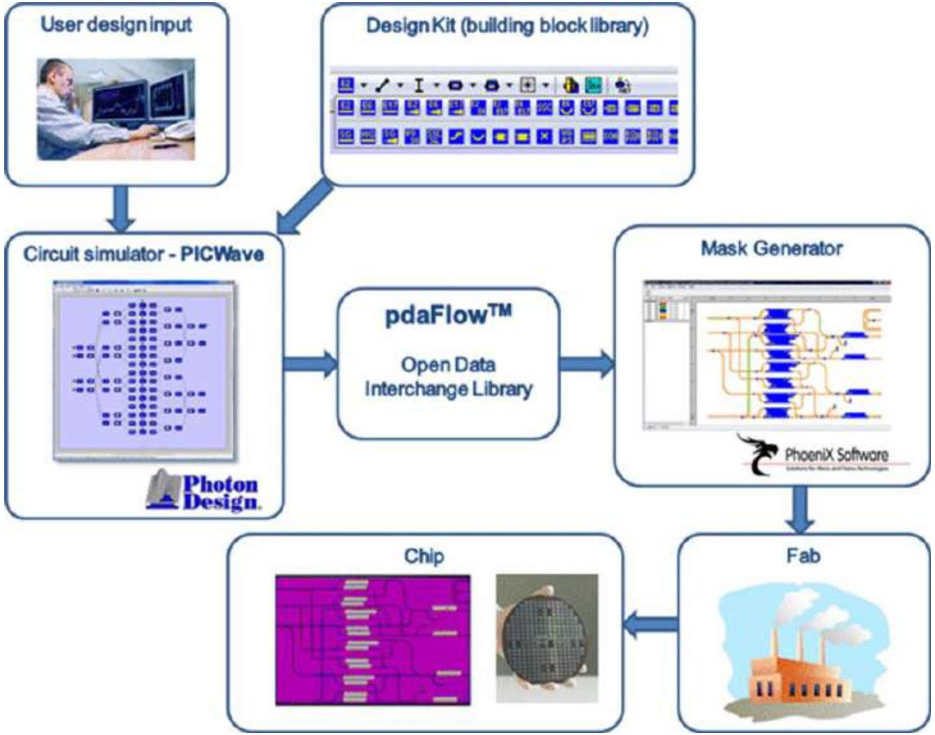
- Global Market: 14.1B USD
- Projected to grow at a CAGR of >10% from 2025 to 2030
- Common platforms: **III-V Material, Lithium Niobate, SOI**



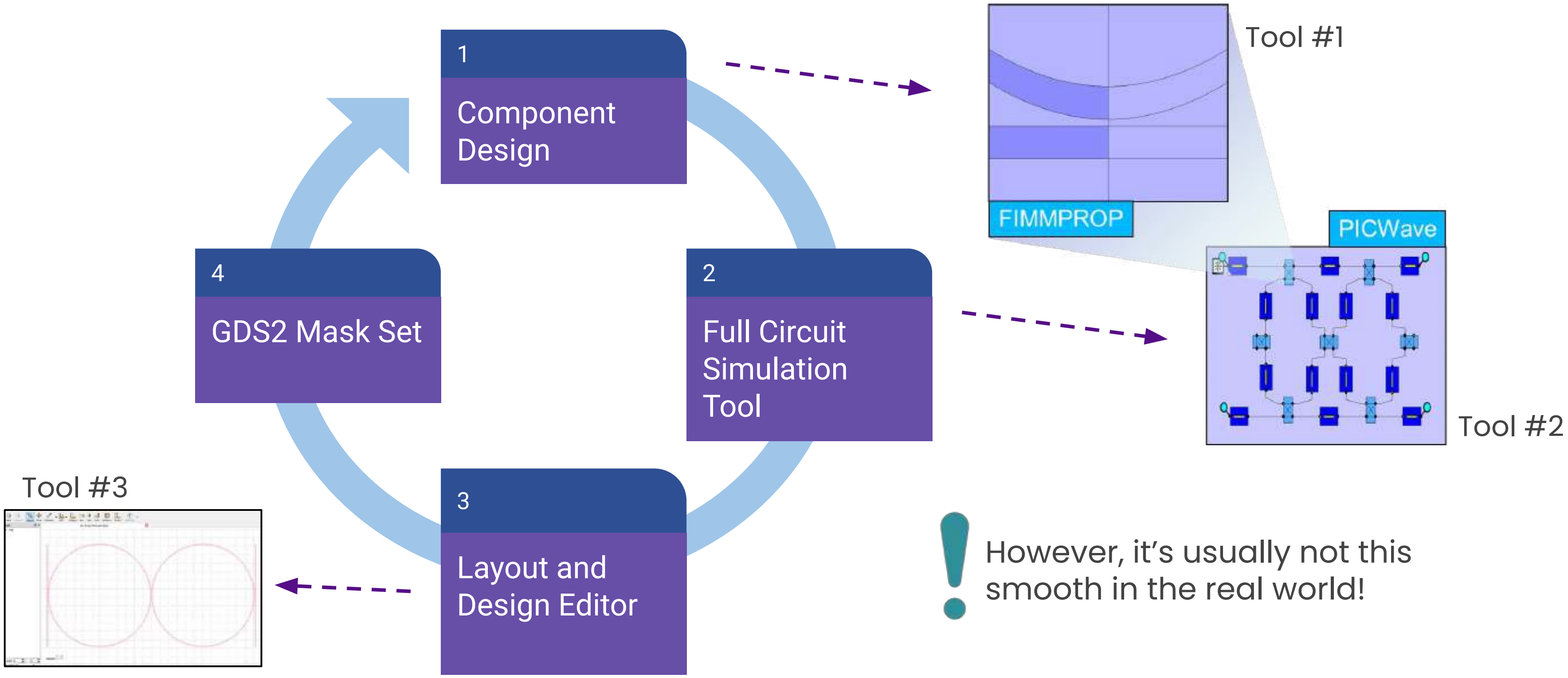
https://www.grandviewresearch.com/industry-analysis/photonic-integrated-circuit-ic-market

Manufacturing Platforms

Manufacturing platforms, such as those in **JePPIX** allow a design kit approach to circuit design, with libraries of characterised BBs (Building Blocks) specific to the platform.

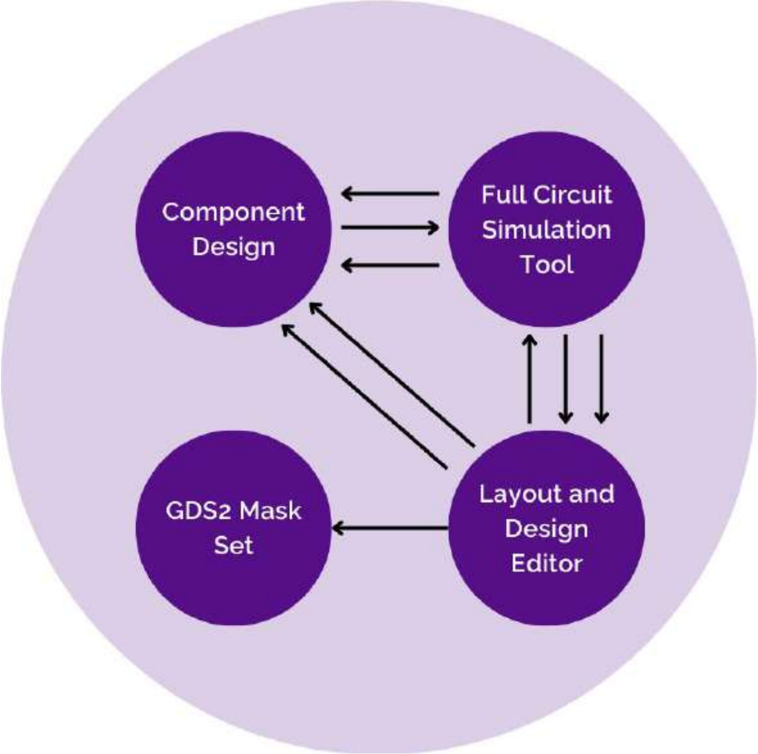


Ideal Design Process



However, it's usually not this smooth in the real world!

More Realistic Design Process



In the real world… it's often a more iterative process.

For example:

Components have to be redesigned after doing a Full Circuit Simulation

Or,

After creating the layout for the chip, the size of some parts need to be adjusted for manufacturing. This requires a redesign of the PIC, and also the components.

Switching between multiple tools is time consuming and troublesome.

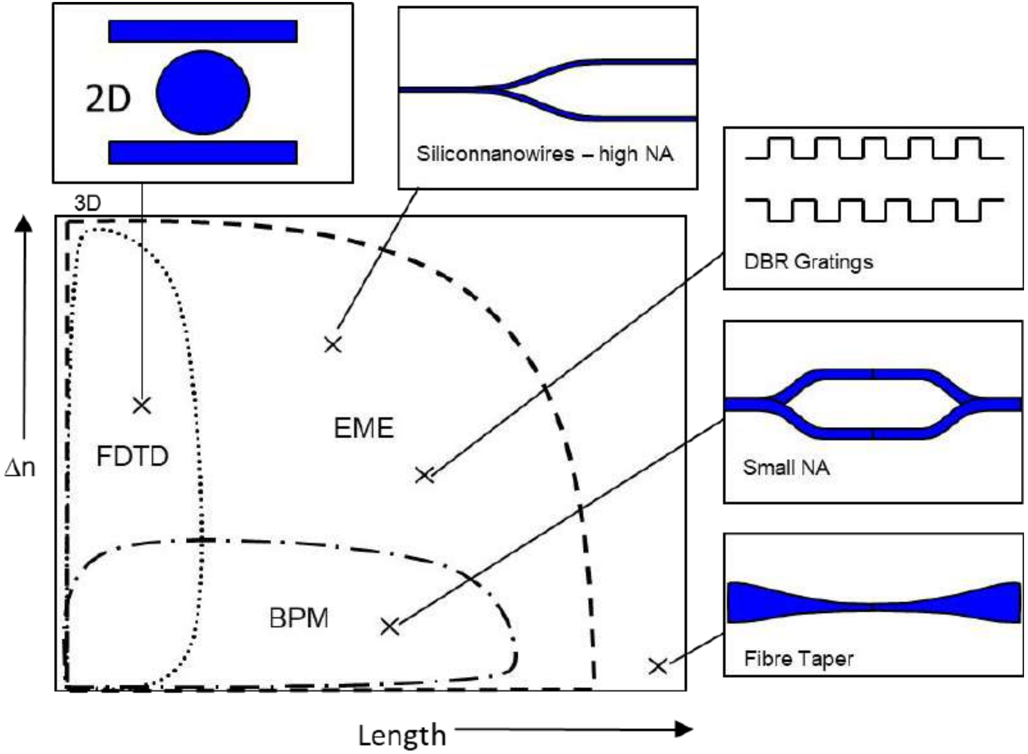
Photonics Simulation Algorithms

There are 3 commonly used methods in photonics:

- BPM
- FDTD
- EME

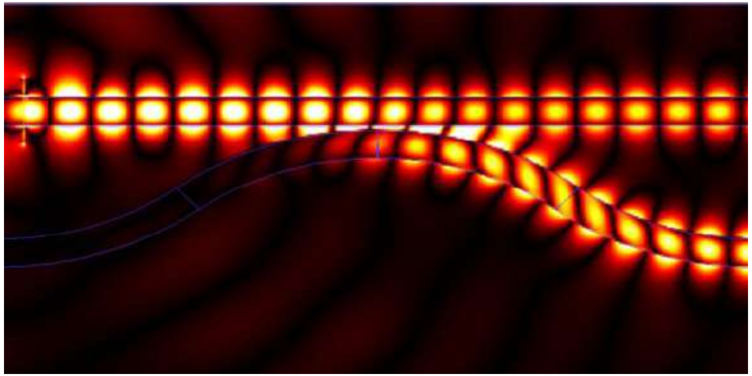
Each method has strengths and weaknesses.

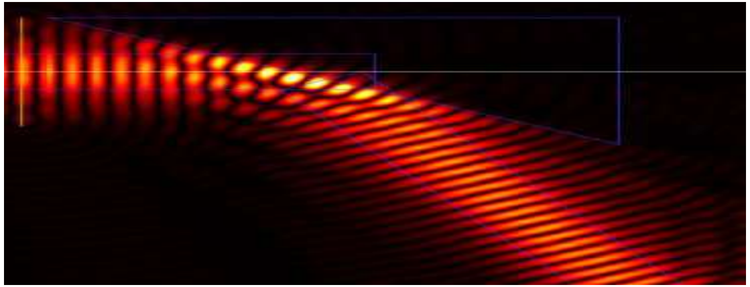
For high index structures such as Silicon Photonics and InP, FDTD and EME are most suitable.



FDTD Method – Overview

- Robust algorithm
- Can simulate light propagating at any angle
- Time domain algorithm - single simulation can provide steady state spectral results
- But requires **a lot** of computer power and RAM

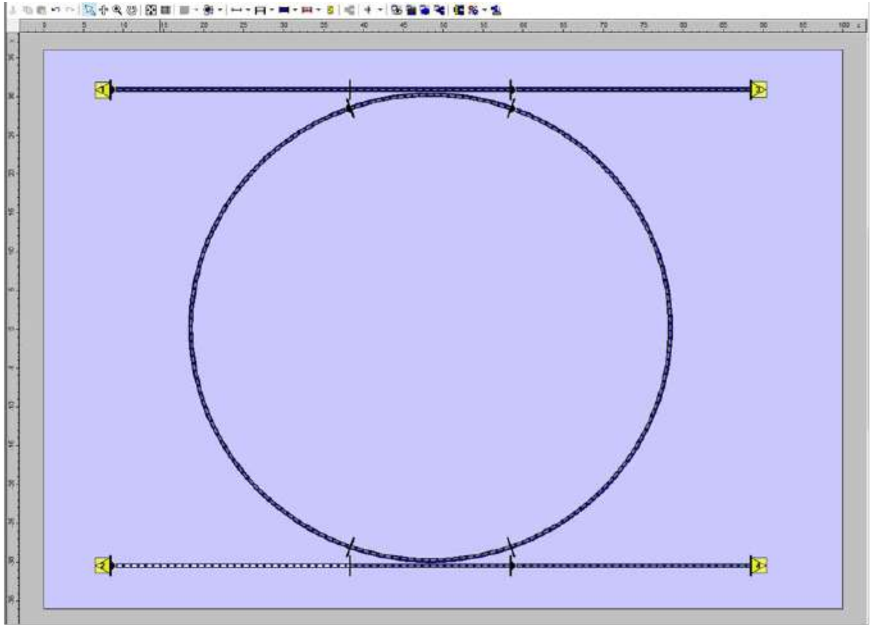




FDTD Method – Large Ring Resonator

Size (um)	100 x 70 x 2
Material	SOI
Dimension	3D

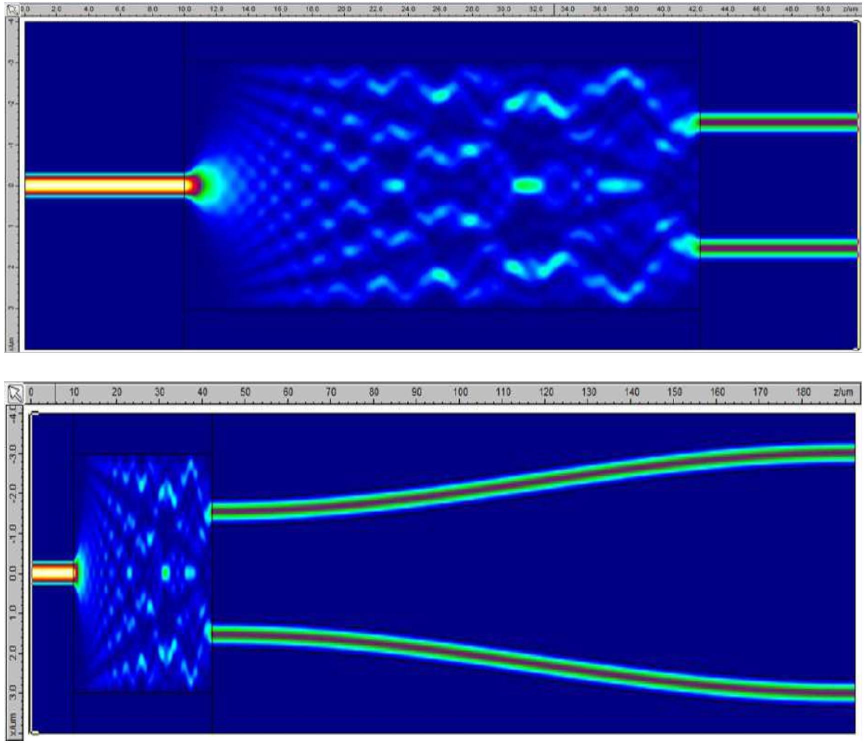
Spectral Resolution	Mesh (um)	Calculation Time (12 Cores i7, 2.6GHz)
5nm	0.02	>200 hours
2nm	0.02	>600 hours



! *Can't expand to modeling a PIC of multiple components.*

EME Method – Overview

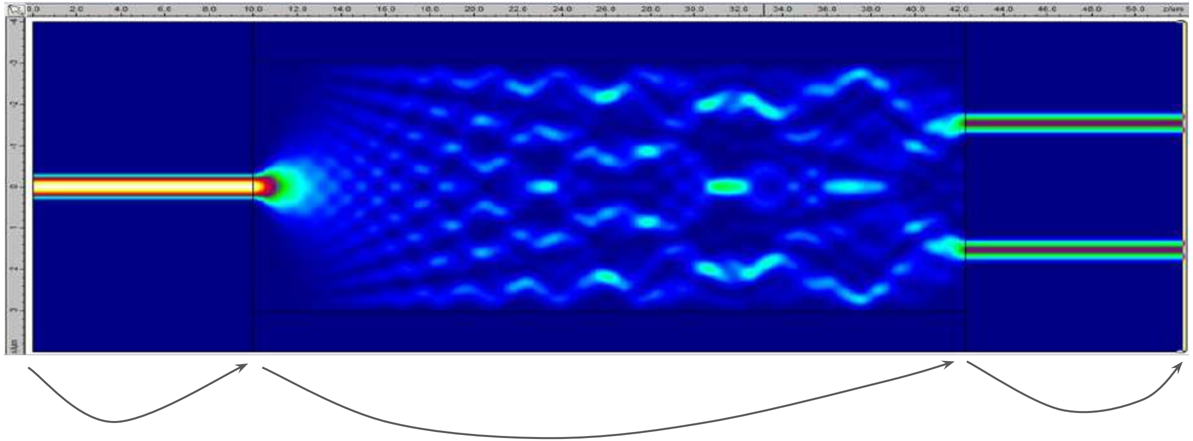
- Rigorous solution of Maxwell's Equations
- Full vectorial
- Bidirectional
- Much faster than BPM, FDTD or FEM for many applications
- Much more accurate in many cases too



EME Method – Overview

$$\Phi(x,y,z) = \psi_m(x,y)\cdot e^{i\beta z}$$

The modes of each cross-section are calculated and then propagated analytically. Coupling between modes is calculated at interfaces between sections.

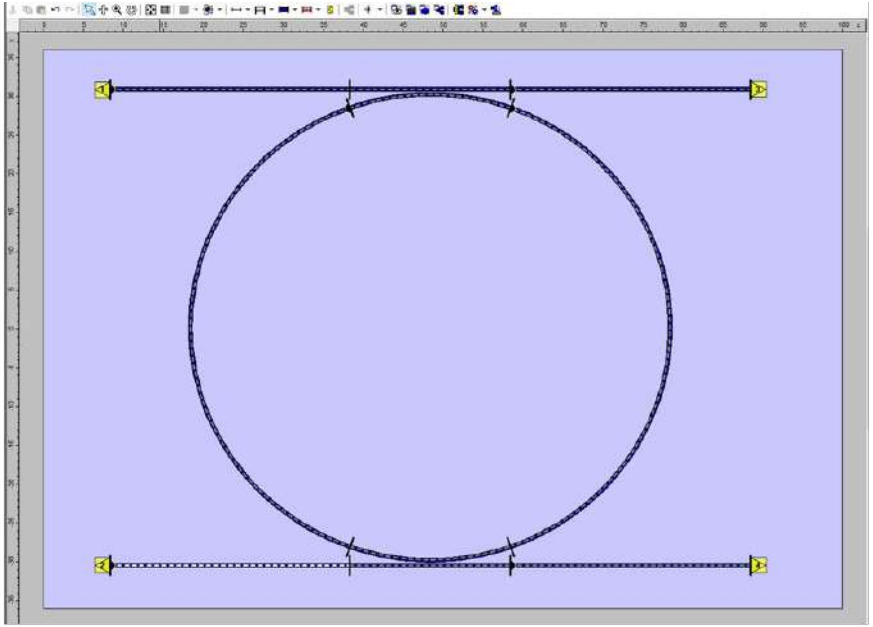


Unlike FDTD or BPM, EME only calculates one time per z-invariant section (Calculation time does not depend on length).
This is extremely efficient!

EME Method – Large Ring Resonator

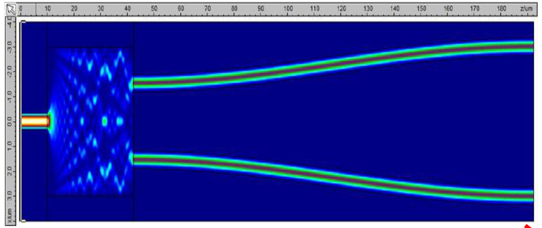
Size (um)	100 x 70 x 2
Material	SOI
Dimension	3D

3D simulation not possible in EME.

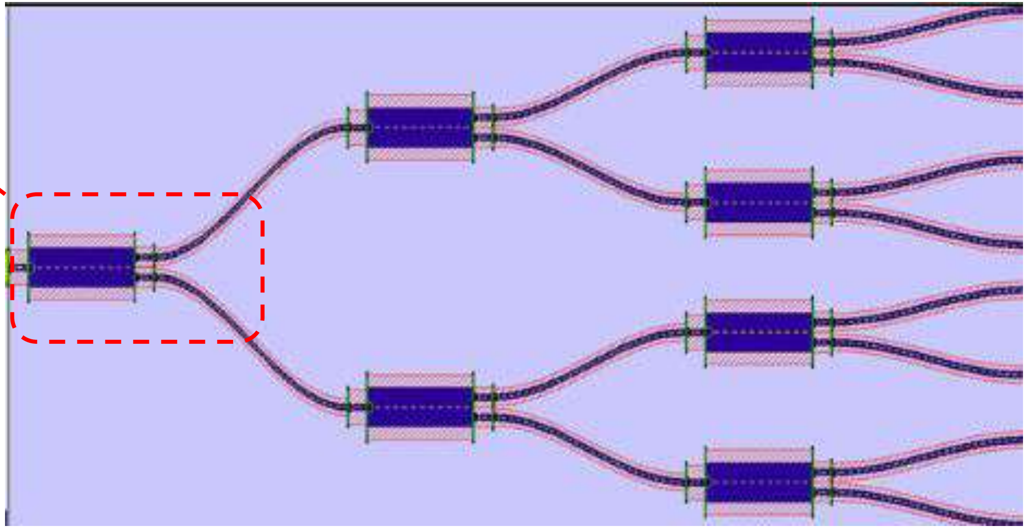


EME Method – Summary

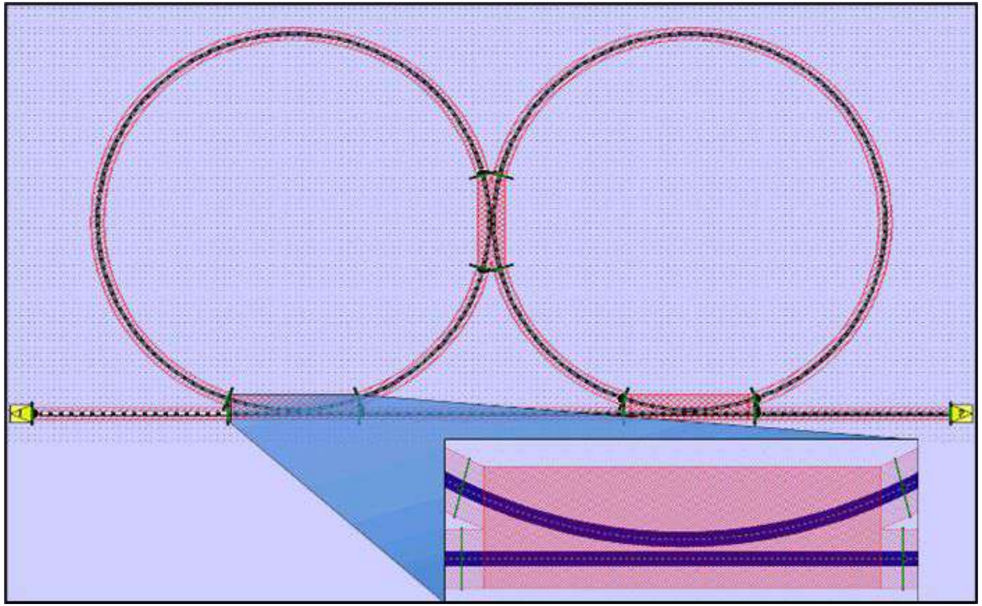
EME is the most efficient method for modeling this…



… but can't model this PIC…..(until now)



Introducing MT-FIMMPROP



MT-FIMMPROP (released Summer 2024) is a Layout Environment that uses EME method for the simulation of PICs.

MT-FIMMPROP is the only software where EME computation regions can be combined natively in a single layout environment

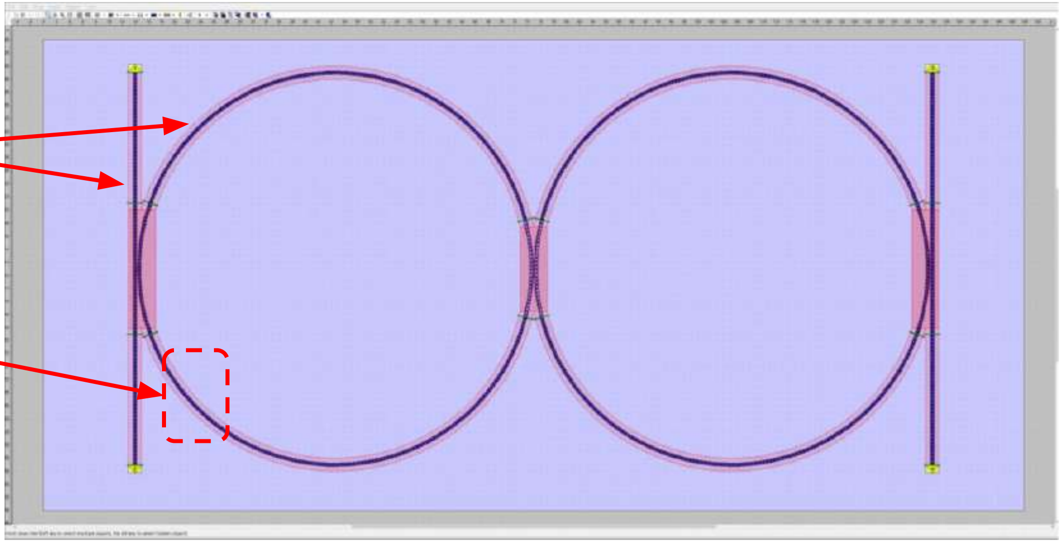
MT-FIMMPROP: “**M**ulti-**T**opology”

MT-FIMMPROP

Using MT-FIMMPROP we can construct the full ring resonator in a layout environment and simulate it there.

Simulation domain follows the path of the waveguides.

Only the red mesh area is calculated



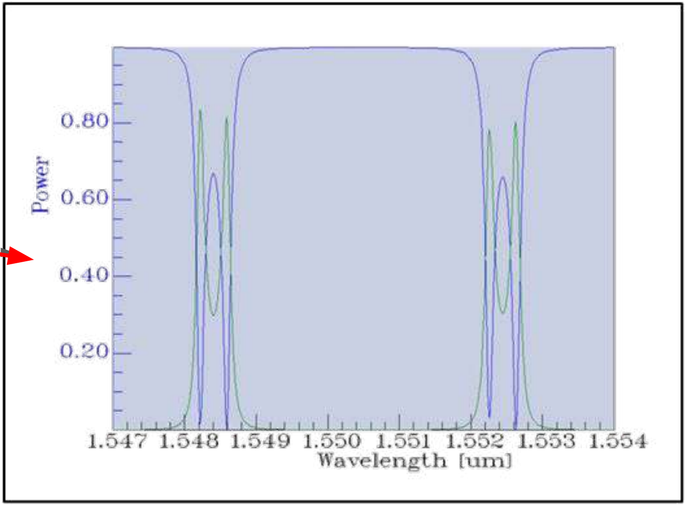
MT-FIMMPROP

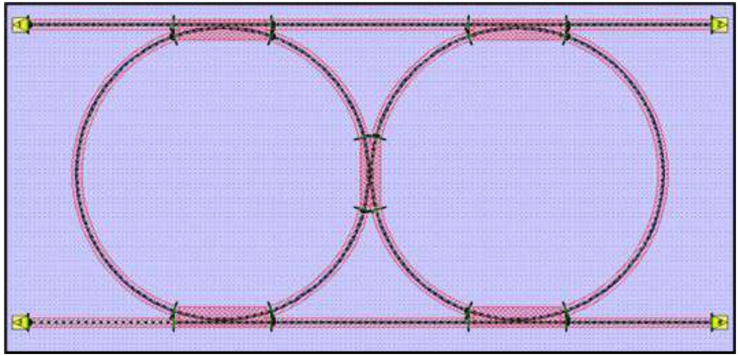
Because EME is a frequency domain method, (calculates the results for one wavelength at a time) the user has freedom to easily define the spectral resolution of the results.

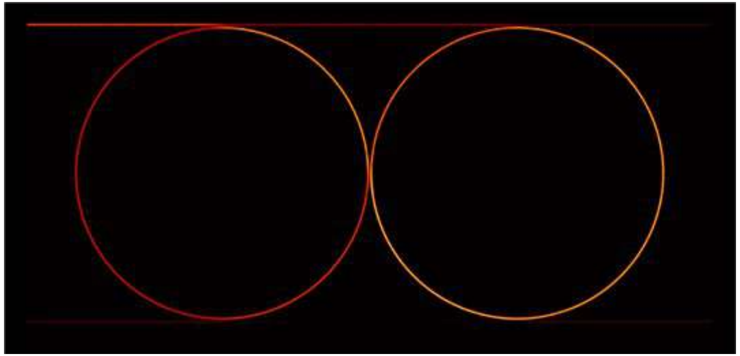
Example:

0.1nm resolution

(total: 80 data points)



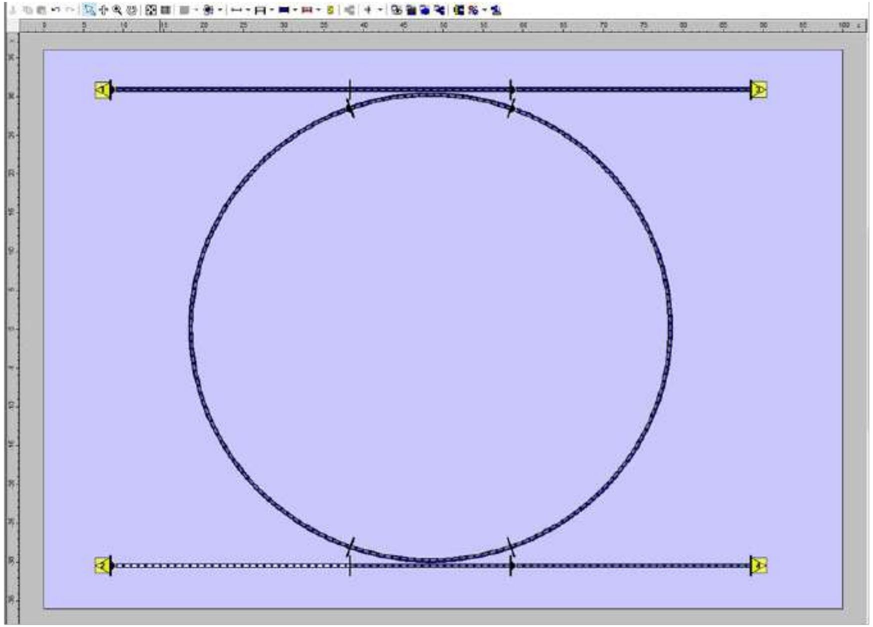




FDTD Method – Large Ring Resonator

Size (um)	100 x 70 x 2
Material	SOI
Dimension	3D

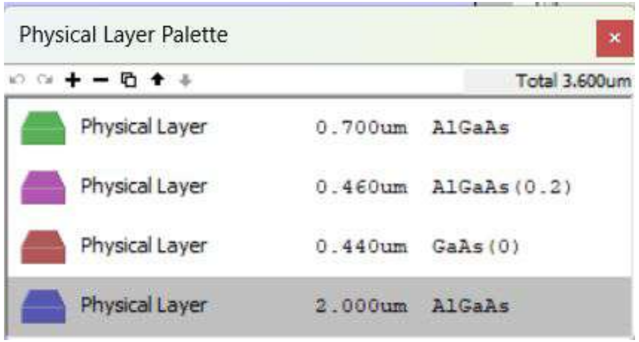
Spectral Resolution	Spectral range	Calculation Time
5nm	40nm	< 10 minutes
2nm	40nm	< 25 minutes



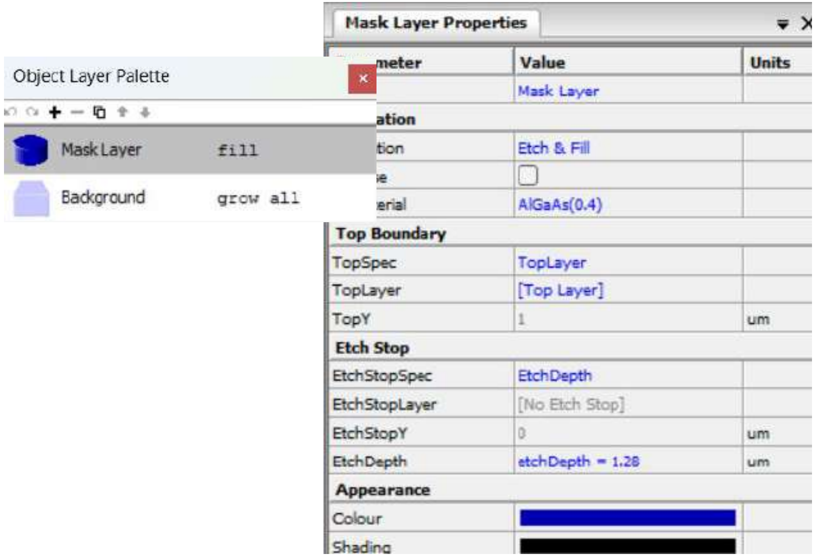
MT-FIMMPROP makes this large simulation easy

MT-FIMMPROP - Design Process

- First, define the epitaxial layer structure of the chip

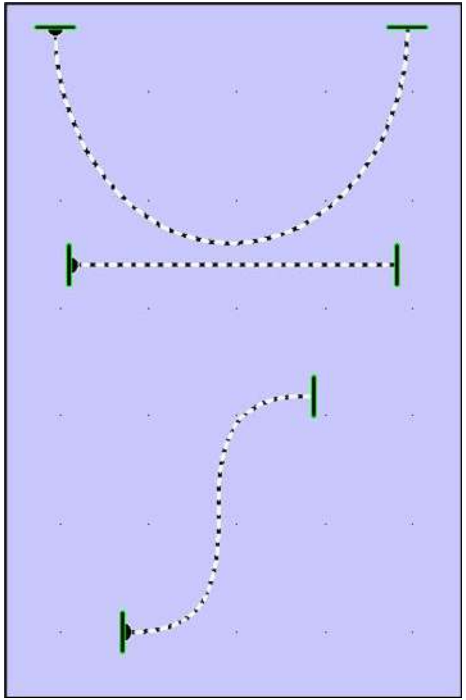


- Then, define the properties of the etching mask(s)



MT-FIMMPROP - Design Process

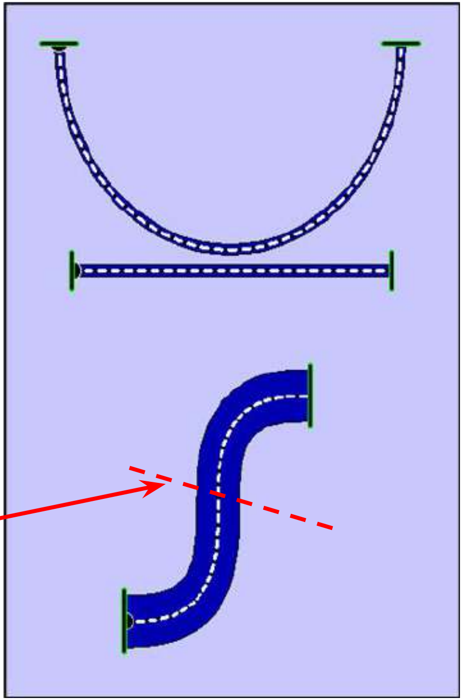
- Define paths to lay out the devices. Paths include:
  - Straight Paths
  - Constant Curvature Paths
  - S-Bends
  - Euler Bends
  - User-defined



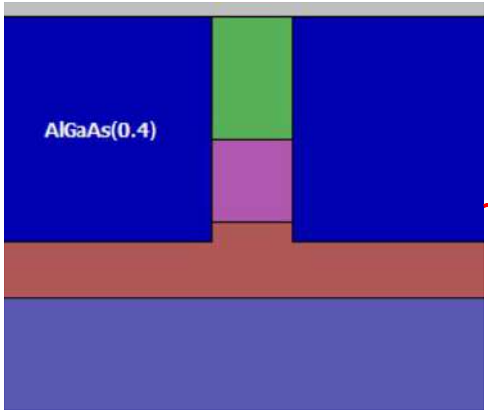
MT-FIMMPROP - Design Process

- Click and drag paths to attach a waveguide.

Widths can also vary along the path length allowing for tapers.



The etching of the waveguide path is already defined in the Mask properties

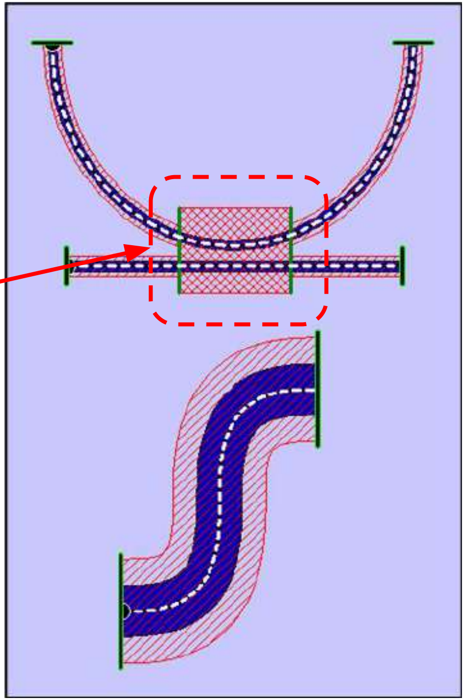


MT-FIMMPROP - Design Process

- Add Computational regions.

Computational regions will conform to the geometry of the waveguide.

Can span over multiple waveguide sections allowing you to simulate cross coupling.

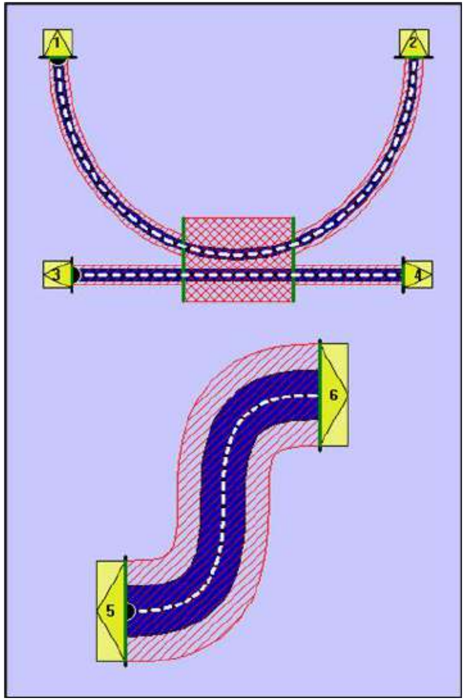


Key Point:
The only parts of the device that are simulated are the computational regions, allowing efficiencies by not simulating the whole area.

MT-FIMMPROP - Design Process

- Add input and output ports.

The output is the EME scattering matrix which shows how inputs at each port couple to all of the outputs.

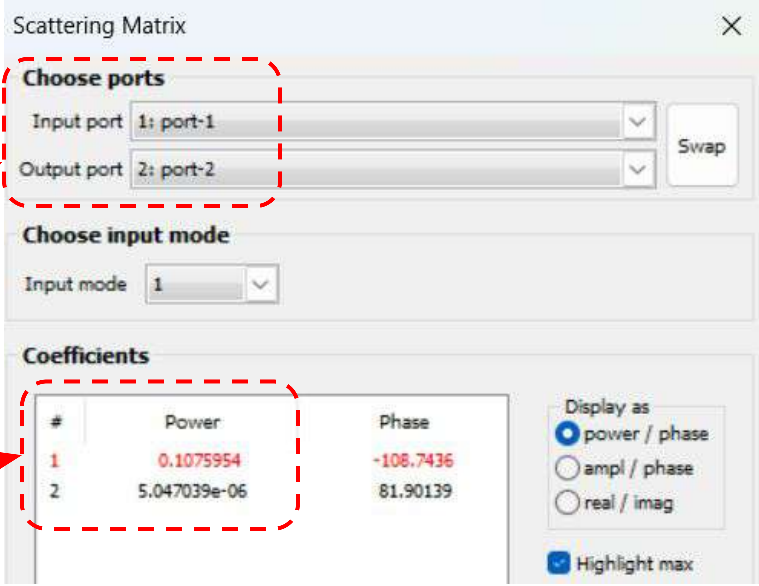


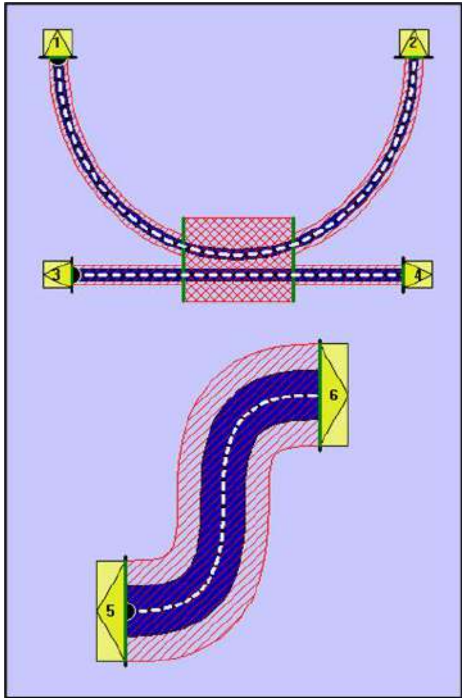
MT-FIMMPROP – Scattering Matrix

- View the Scattering Matrix results and output field data

Input: Port 1
Output: Port 2

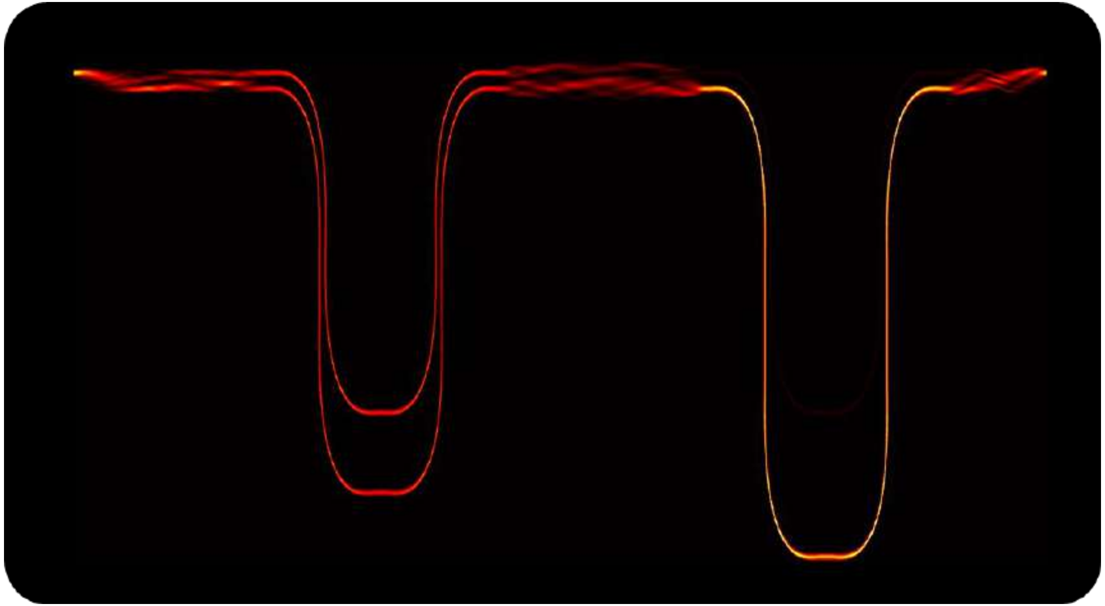
Output Power in fundamental mode:





Examples

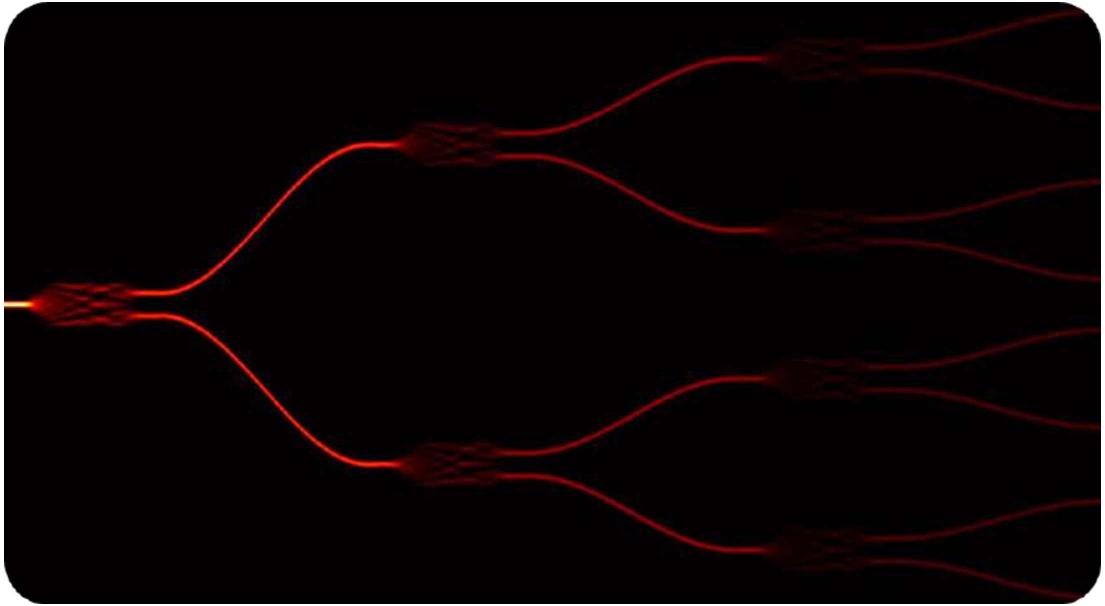
Long-Arm Mach-Zehnder Interferometer (MZI)



MT-FIMMPROP is used to model an interleaver design proposed by Cherchi et al. that is based on cascaded MZIs and multimode interferometers (MMIs) as power splitters.

M. Cherchi et al, Flat-top interleavers based on single MMIs, (2020) [https://arxiv.org/abs/2002.07521]

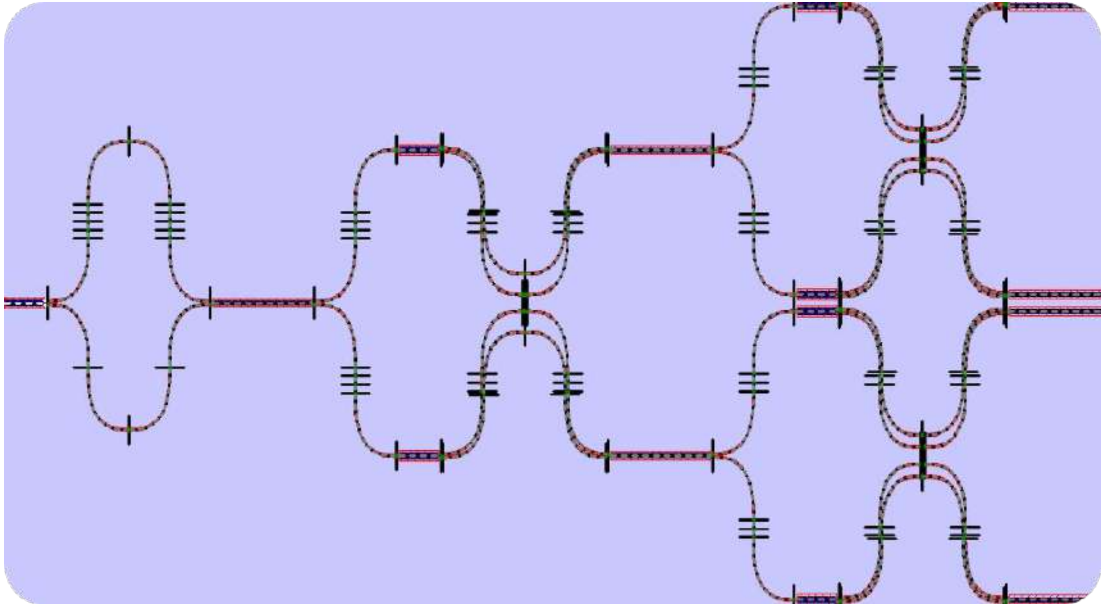
Cascaded MMIs / Optical Phased Arrays



MT-FIMMPROP is used to model cascaded MMIs.

Suitable for the design and layout of Optical Phased Arrays (OPAs) of any size.

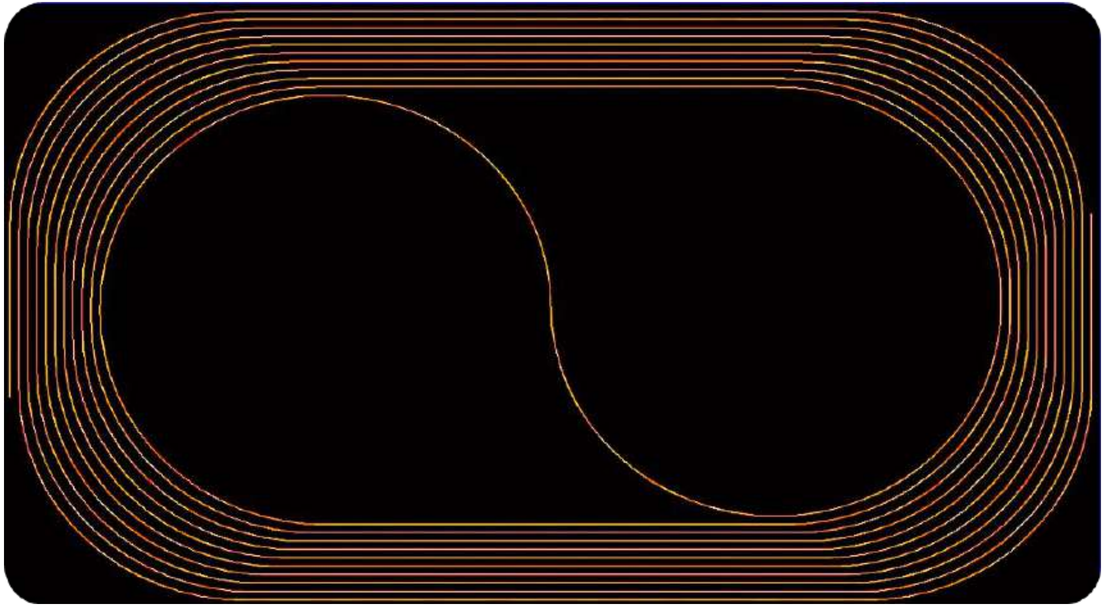
Cascaded MZI Wavelength Filters



MT-FIMMPROP is used to model cascaded Mach-Zehnder wavelength filters.

Suitable for application as WDM demultiplexers.

Delay Lines



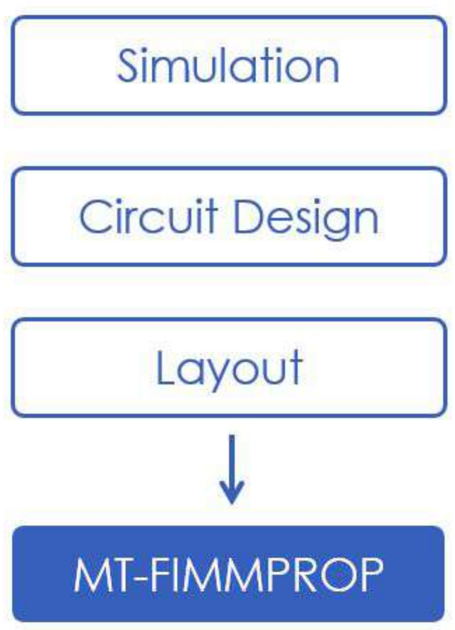
MT-FIMMPROP is used to model delay line constructed using constant bend and straight sections.

This example has a physical path length of ~11 cm and yet **simulates in <10s.**

MT-FIMMPROP is the first way to visualise field profiles of delay lines of this scale in a viable amount of time.

MT-FIMMPROP Summary

- MT-FIMMPROP replaces the 3 tools required in PIC design:
- Device design, PIC simulation and layout, all in one environment.
- Large complex devices can now be simulated for the first time.
- No compromise is performance, every part of the circuit is being solved by rigorous EME.
- Simple and intuitive in a visual environment, making errors easy to spot.



Thanks, and further Information and Support

ありがとうございました。

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