

Simulate Mode-Evolution-Based Polarization Rotator with High-Index Contrast

Products: FullWAVE FDTD, BeamPROP BPM

Applications: Silicon Photonics

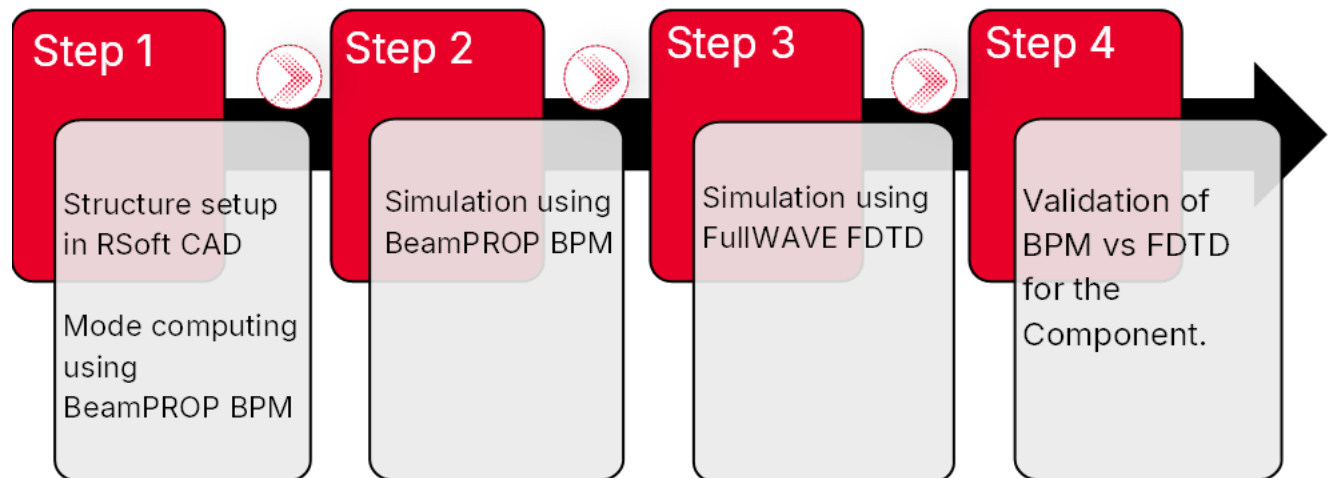
Introduction

High-index contrast dielectric waveguides exhibit strong confinement, making the TE and TM modes very different. As a result, device characteristics, such as propagation constant and coupling strength become strongly polarization dependent. Rotation of one of the polarization outputs allows a single polarization to be realized on-chip and the two paths to be operated on in parallel with identical structures. Mode-evolution-based polarization splitters and rotators have been proposed ¹.

Flow Description

One approach is to use the Finite-Difference Time Domain (FDTD) **FullWAVE FDTD** algorithm to model these devices, but FDTD is very computationally intensive and requires a lot of computer memory. In this article, we will demonstrate the simulation of a mode-evolution-based polarization rotator based with high-index contrast using the RSoft Beam Propagation Method (BPM) tool, **BeamPROP BPM**. The advantage of a BPM simulation when compared to an FDTD simulation is that it requires much less simulation time and memory (RAM).

In this application note, we will cover the implementation of the structure in **RSoft CAD**. Then simulate the converter using **BeamPROP BPM** and compare the simulation results obtained using **FullWAVE FDTD** and finally discuss the validation and compare the time memory usage of the two algorithms.



¹ Watts et al. "Integrated mode-evolution-based polarization rotators," *Optics Letters*, 30 (2005).

Step 1: Structure Setup

Figure 1 shows the proposed rotator structure. The polarization rotation can be created using only a pair of asymmetrically and oppositely tapered waveguide core layers. The core index material is silicon nitride and the cladding is silica. The principal axis of the structure and polarization state of the fundamental mode rotates in unison along the transition. Since we are going to investigate polarization state changes, a 3D full vector BPM calculation will be needed.

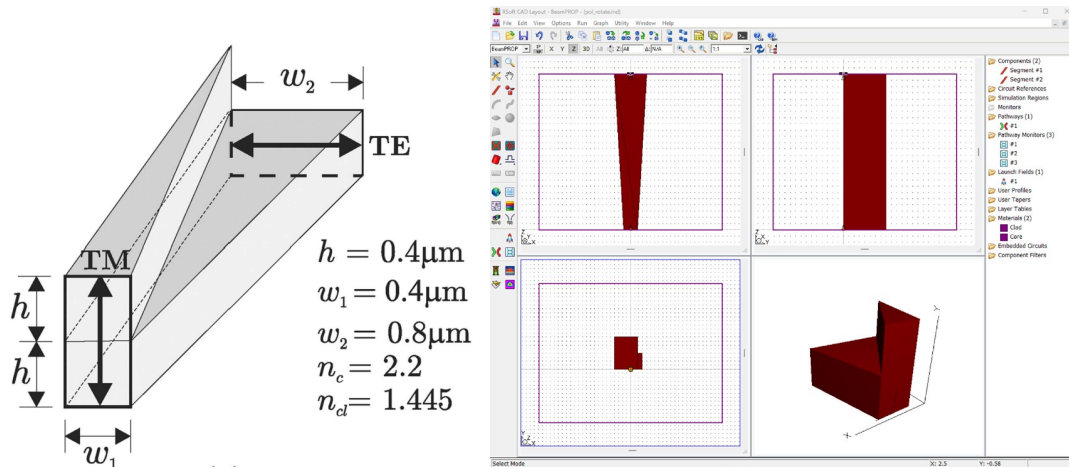


Figure 1. The schematic picture of the polarization rotator as shown in [1] and structure set up in RSoftCAD

Figure 2 shows the refractive index cross-sectional profiles at three different positions in the waveguide, for $z=0\mu\text{m}$, $z=L/2$ and $z=L$ ($L=25\mu\text{m}$)

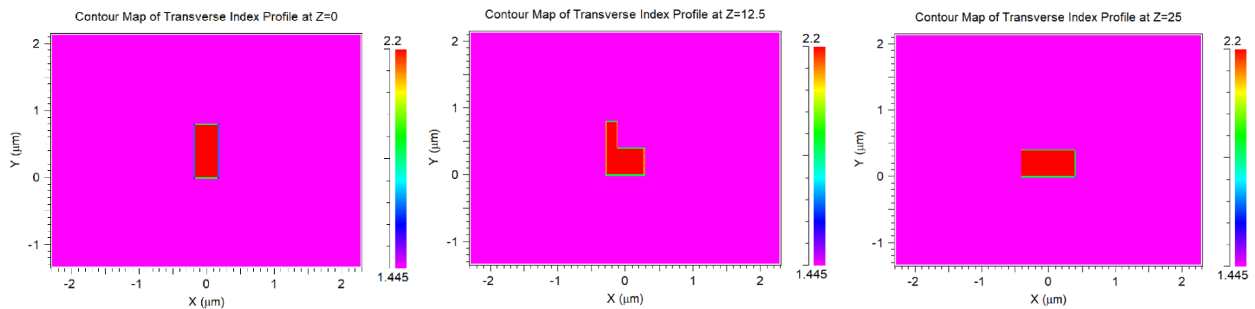


Figure 2. Index cross section profiles at several waveguide positions ($z=0$, $L/2$ and L)

We first calculate the TM fundamental mode at the input position ($z=0\mu\text{m}$) and then calculate both the TE and TM modes at the output position ($z=L$), as shown in Figure 3. Those mode computations have been performed using Beam Propagation Method mode solver in iterative method.

The iterative method is generally a faster approach for obtaining the field shape and propagation constant for the fundamental mode, as well as higher order modes, than the correlation method. The computations are performed using the so-called imaginary distance beam propagation method.

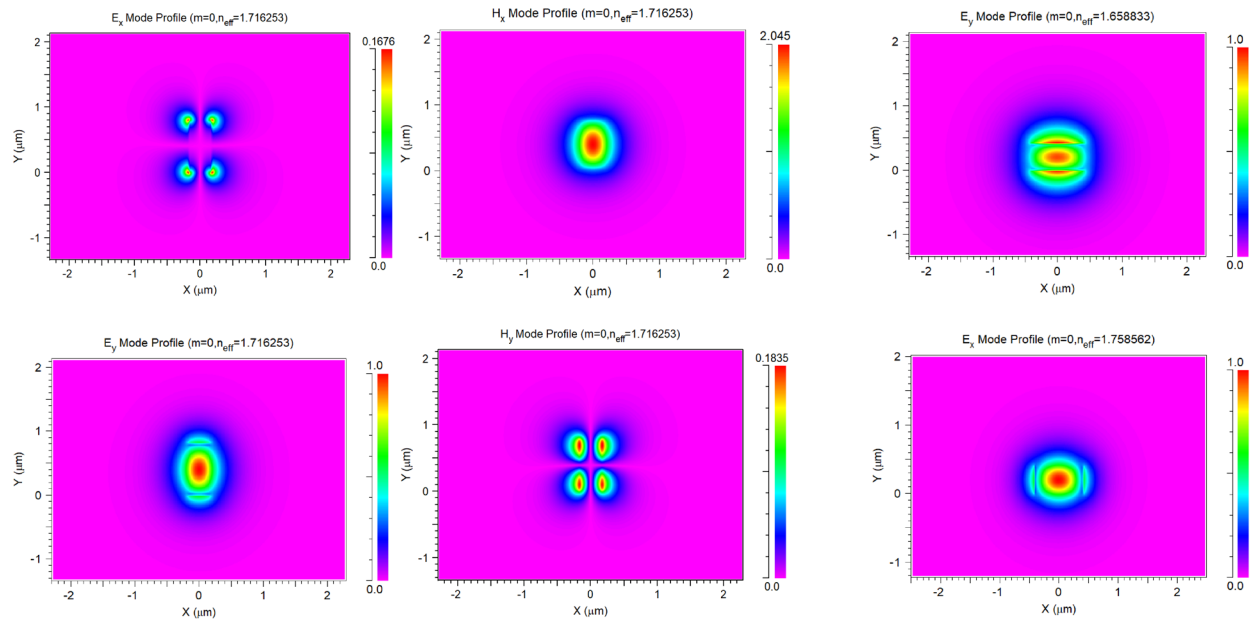


Figure 3. Modes calculated with BeamPROP mode solver
 (Left) Four field components of TM fundamental mode at input.
 (Right) Major E fields of TE and TM modes at output.

Step 2: Simulation using BPM

The TM mode is launched into the waveguide structure (as a launch field), and a full vector BPM propagation is performed. The input TM mode and output TE/TM modes are monitored along the propagation.

Figure 4 shows the propagation field and monitor values along the waveguide. It clearly shows how the input TM mode gradually evolves into the output TE and TM output modes, with $\approx 50\%$ power in the TE mode and $\approx 50\%$ in the TM mode at $25\mu\text{m}$ structure length.

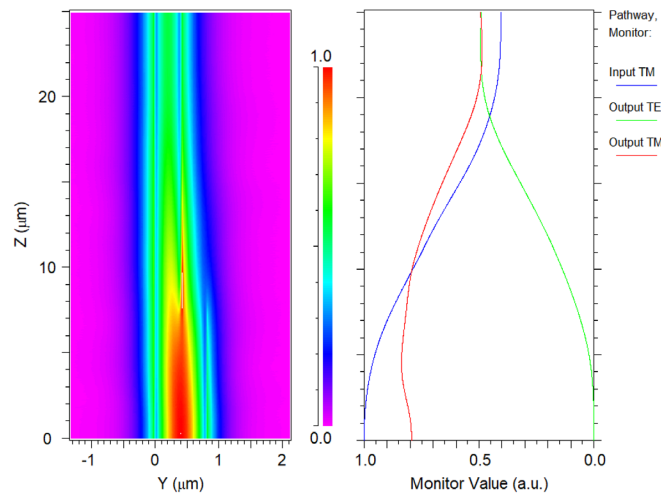


Figure 4. BPM propagation and monitor results along the waveguide

Step 3: Simulation using FDTD

For comparison, a FDTD simulation was performed with RSoft's FDTD tool, **FullWAVE FDTD**, for the same set up, as shown in Figure 1. Overlap monitors of TE and TM output modes have been added as equivalent figures of merit than the pathway monitors of the BPM simulation. Please note that the same grid size has been applied (vs BPM simulation). The results from the FDTD and BPM simulations have close agreement as we can see below:

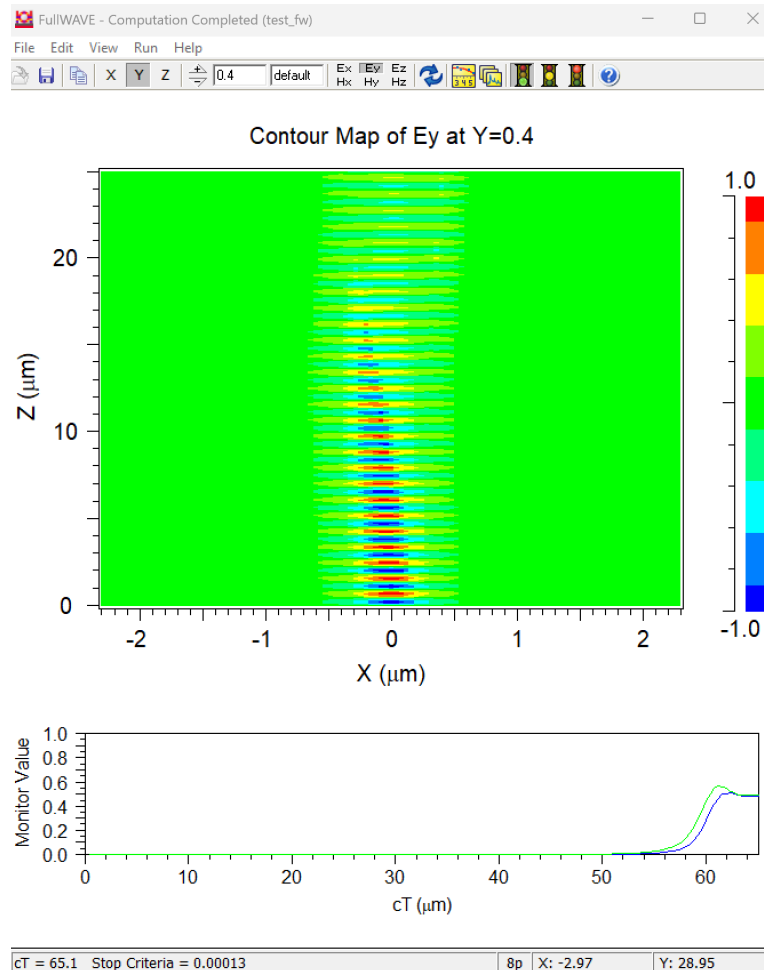


Figure 5. FDTD propagation and time monitor results

Step 4: Validation of the BPM vs FDTD

Finally, RSoft's **MOST** scanning and optimization utility was used to simulate the propagation for different waveguide length using **BeamPROP BPM** and **FullWAVE FDTD**. The results are shown in Figure 6. From Figure 6, we know polarization will completely convert to the opposite polarization state for a waveguide approximately 200 μm . Again, the BPM and FDTD results show excellent agreement.

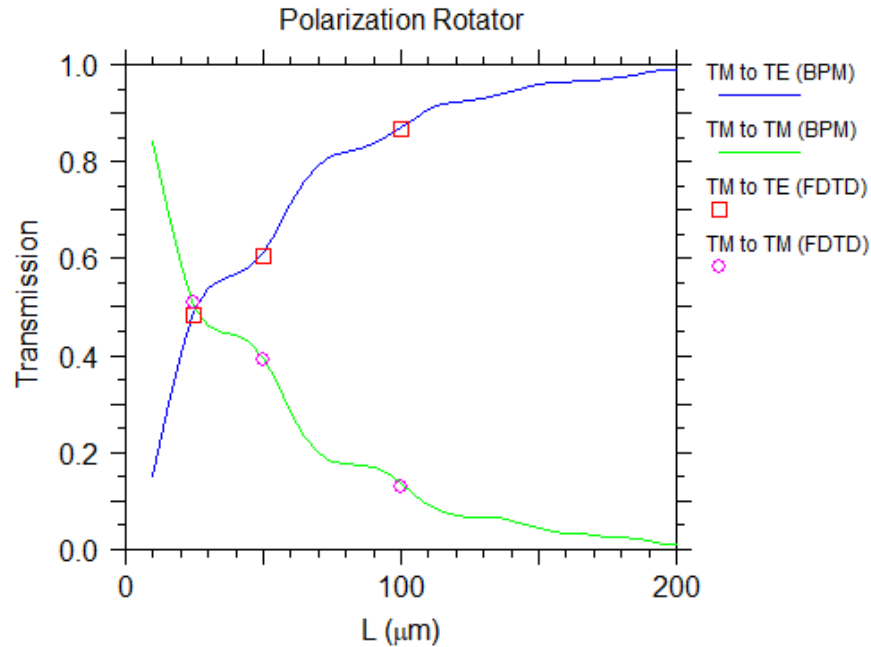


Figure 6. Polarization states of output field at different waveguide length for BPM and FDTD simulations

We also recorded the simulation time and memory cost for the above simulations, as shown in the table below. The simulations were performed on a single workstation with 2 x 10 core CPUs (E5-2650v3 @ 2.3GHz). To take advantage of the 20 cores, **FullWAVE FDTD** used multi-process clustering (20 processes) and **BeamPROP BPM** used multi-threading (20 threads). As can be seen, BPM runs many times faster with much less memory compared to FDTD.

L (μm)	FDTD (sec)	BPM (sec)	Speedup (BPM vs FDTD)
25	1150	22	52x
50	4380	45	97x
100	16560	84	197x

L (μm)	FDTD (sec)	BPM (sec)
25	5 GB	24
50	11 GB	24
100	22 GB	24

Note that the simulation time and RAM scale differently for BPM and FDTD. This is because the BPM equation is solved along the propagation axis, whereas the FDTD algorithm solves for all grid points at each time step during the simulation. Therefore, the simulation time for BPM is linear with the structure length, while for FDTD a 2x increase in length results in a 4x time increase. The required RAM for BPM is constant with structure length because the algorithm only saves field data over the cross-section; for FDTD, the required RAM increases linearly with the structure length since field data is saved over the entire structure.

GPU Acceleration

Since 2024.09 version, **FullWAVE FDTD** has been benefiting from the GPU acceleration.

Here is the simulation time on a modern laptop (using RSoft 2026 version)

- 8cores CPU 13th Gen Intel® Core™ i7-13850HX
- GPU Card : NVIDIA RTX 5000 Ada generation Laptop

L (μm)	FDTD (sec) CPU	FDTD GPU (sec)	BPM (sec)
25	1100	110	10
50	4063	390	21
100	13500	1470	42

Even if GPU is a huge speed up on this type of simulation, it remains more memory and time-consuming vs **BeamPROP BPM**.

Conclusion

In this application note, we demonstrate the benefit of Beam Propagation method for the simulation and study of a polarization rotator component. This component is based on high-index contrast that could be an issue for the BPM.

After a validation study, we can generate confidence that the BPM remains an accurate tool for the simulation of the component. This is a benefit of the RSoft Photonic Device Tools: it has multiple numerical approaches that can be improved significantly the efficiency of simulation and characterization flow for a photonic designer!

Example Files

Polarization Rotator Example