

Reflective Multimode Interference Coupler

Co-Simulated by BeamPROP and FullWAVE

Introduction

Multimode Interference (MMI) couplers are common device in Photonics Integrated Circuits (PICs), facilitating the interconnect of various optical components such as modulators, filters and detectors on a single chip. Conventional MMIs, however, are typically long, posing challenges for integration into a PIC. To address this issue, a compact reflective MMI coupler with etched Total Internal Reflection (TIR) mirrors was proposed [1], which saves space and improves integration potential.

Simulating such a device presents challenges: the MMI structure is too large for the FullWAVE FDTD method, especially when 3-dimensional results are required, while BeamPROP BPM cannot handle the facet reflection from the TIR mirrors. RSoft Device tools offer a variety of photonics component simulation software, each tailored to solve specific problems. By decomposing the complex or big structure into smaller problems, we can use the appropriate suite of tools to simulate each part efficiently. In this application note, we outline a co-simulation approach that combines BeamPROP for the MMI region, FullWAVE for the TIR facets, and MOST for optimizing the MMI length.

Flow Description

The most effective approach involves combining BeamPROP BPM for forward and backward propagation in the MMI region and FullWAVE FDTD for light reflection at the facets. This approach leverages the speed of BPM and the omnidirectional nature of FDTD. RSoft Photonic Device tools are seamlessly integrated within the RSoft CAD Environment. Here is the flow chart described for the co-simulation process, as shown in Fig. 1 schematically.

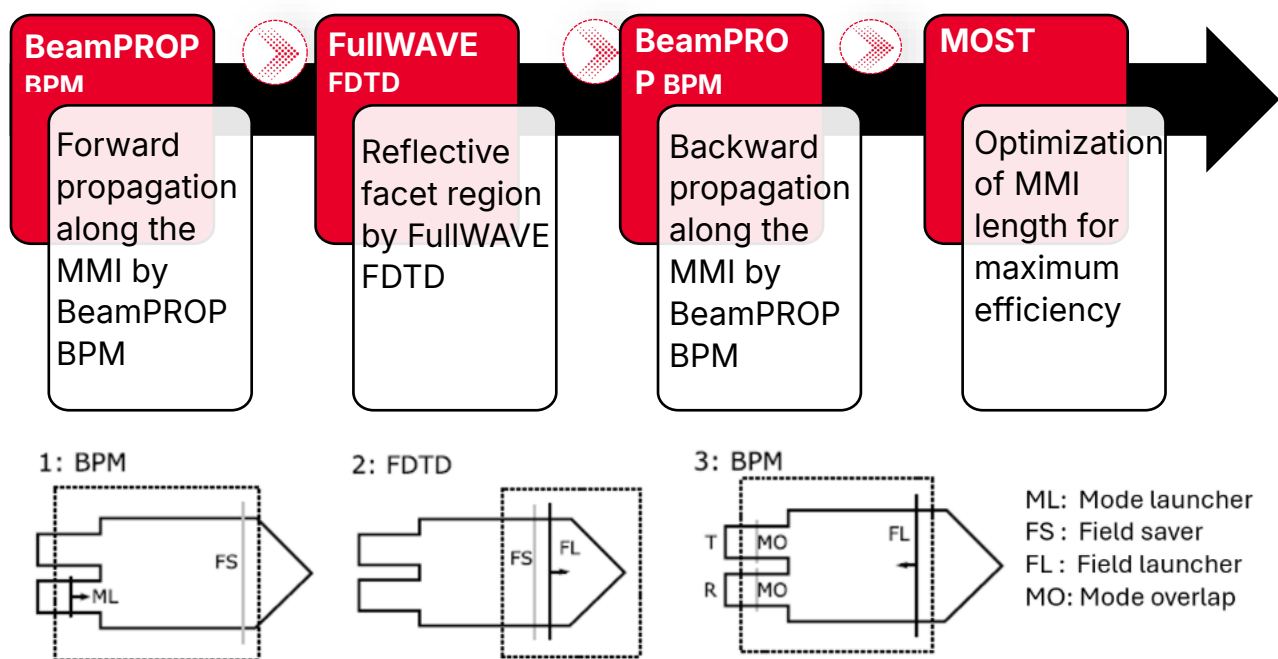


Figure 1. The co-simulation process flow for the reflective MMI coupler [1]. The dotted shape represents the area that is simulated during the different steps. The arrows indicate the direction of the launching field.

1: BPM

1. Build the geometry

We begin by building the optical waveguide by a multilayer structure type on an InP material platform. The waveguide is composed of four layers, with the corresponding indices and thickness for each layer depicted in Fig. 2 (a). The surrounding material is air, and the MMI waveguide also shares the same material profile.

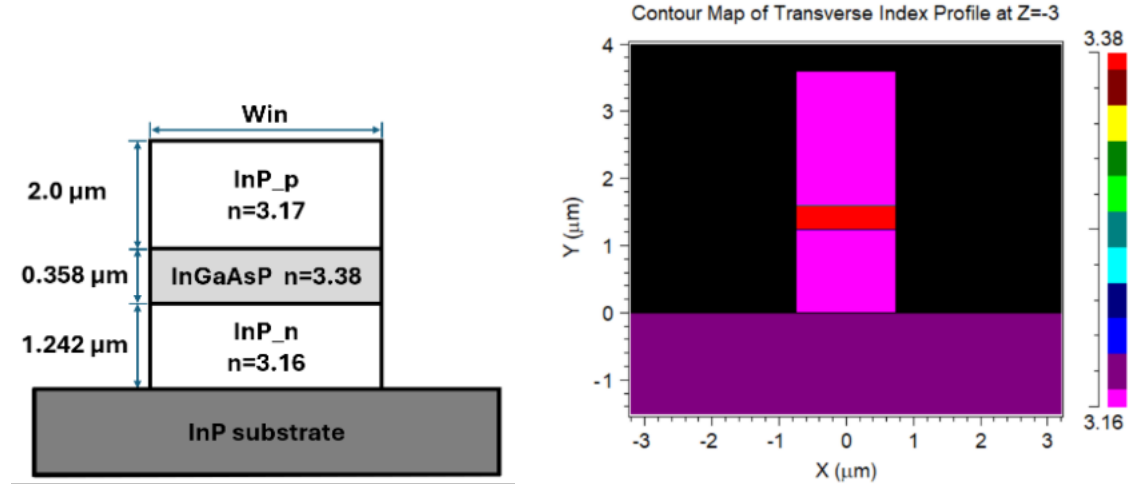


Figure 2. (a) Cross-section view of the waveguide at the input port. (b) Refractive index profile of the waveguide cross-section calculated at a wavelength of 1.55 μm in RSoft CAD.

The layout of the reflective MMI coupler, including the MMI waveguide and facet regions, is built in RSoft CAD. The MMI waveguide has a fixed height of 3.6 μm. The input waveguide has a width (W_{in}) of 1.5 μm and a length (L_{in}) of 3.0 μm. The parameters of W_{MMI} and L_{MMI} represent the width and length of the MMI waveguide, as shown in Fig. 3(a). A prism-shape geometry is added to the end of the MMI waveguide to act as the TIR mirror, with a linear taper from W_{MMI} to 0 μm over a length of $L_{tri} = 3.0$ μm.

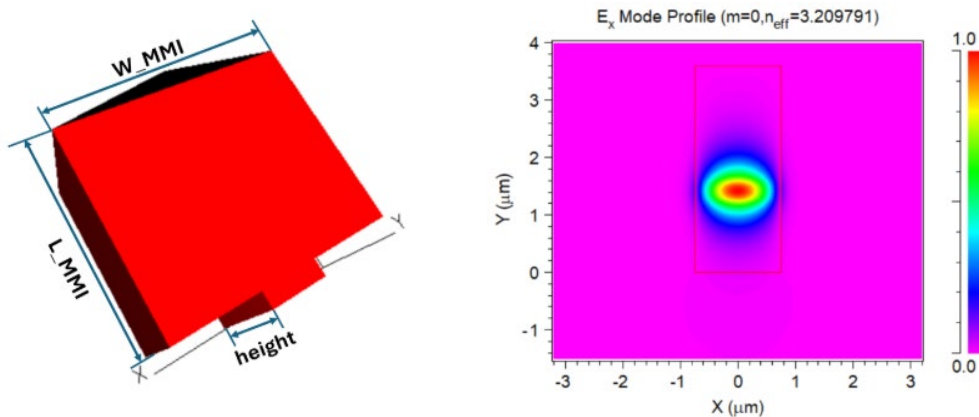


Figure 3. (a) 3D view of the reflective MMI coupler created in RSoft CAD with labeled design parameters. (b) TE polarized mode profile calculated at the input waveguide port by the BPM mode solver, used as a launching field for the forward propagation in BeamPROP.

The mode profile at the input port is calculated using either the BPM mode solver or the FemSIM tool (Fig. 3(b)). This fundamental mode profile is saved and can be served as the launching field for the input waveguide. By examining the mode field on a logarithmic scale, we can determine an appropriate simulation domain for the waveguide cross-section (Fig. 4).

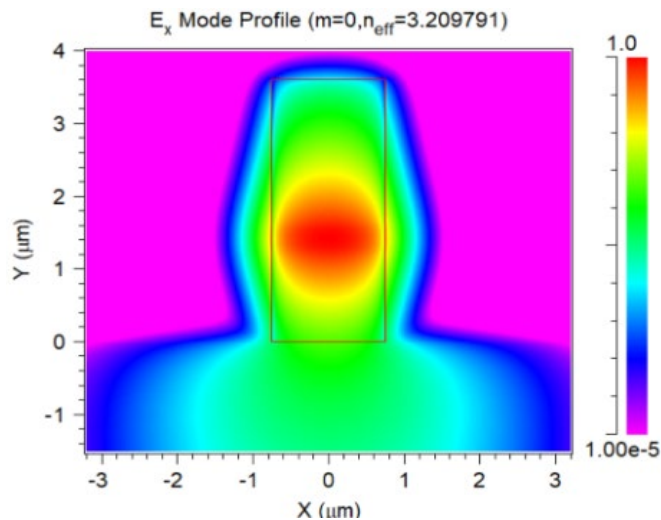


Figure 4. TE polarized mode profile on a logarithmic scale, converted from Fig. 3(b).

2. Simulation parameters for forward propagation

In terms of BeamPROP simulation, the TE polarization with the Semi-vector mode is utilized for the BPM options. The simulation domain in the X and Y directions are set based on the domain shown in Fig. 3, while along the z direction, the domain_Zmin is set to -3.0, and the domain_Zmax is equal to L_MMI.

3. Run the simulation and export results to FDTD

The first simulation run is to model the forward propagation from the input port to the facet region (Fig. 1- 1: BPM). Note that the final output field from the MMI region is stored and used as input for the next step, the FDTD simulation.

2: FDTD

FullWAVE FDTD is an omnidirectional numerical method capable of simulating the mirror structure with light reflection behavior. In this step, the TE polarized FDTD options is utilized with a continuous wave (CW) excitation at a wavelength of 1.55 μm . The saved field profile from the BPM step serves as the input launching field for the FDTD simulation (Fig. 1 – 2: FDTD). The reflected output field from the TIR mirror is stored and will be used for the subsequent BPM simulation.

3: BPM

In this step, BPM is used again to simulate the backward propagation of light reflected from the TIR mirror back toward the input ports (Fig. 1 – 3: BPM). The output field saved from the FDTD simulation step is launched into the MMI region for the current BPM run. The reflection efficiency at the input/output port is determined by evaluating the overlap between the reflected mode and the input fundamental mode. Figure 5 shows the mode field distribution profiles along the various positions of the reflective MMI coupler during the co-simulation process.

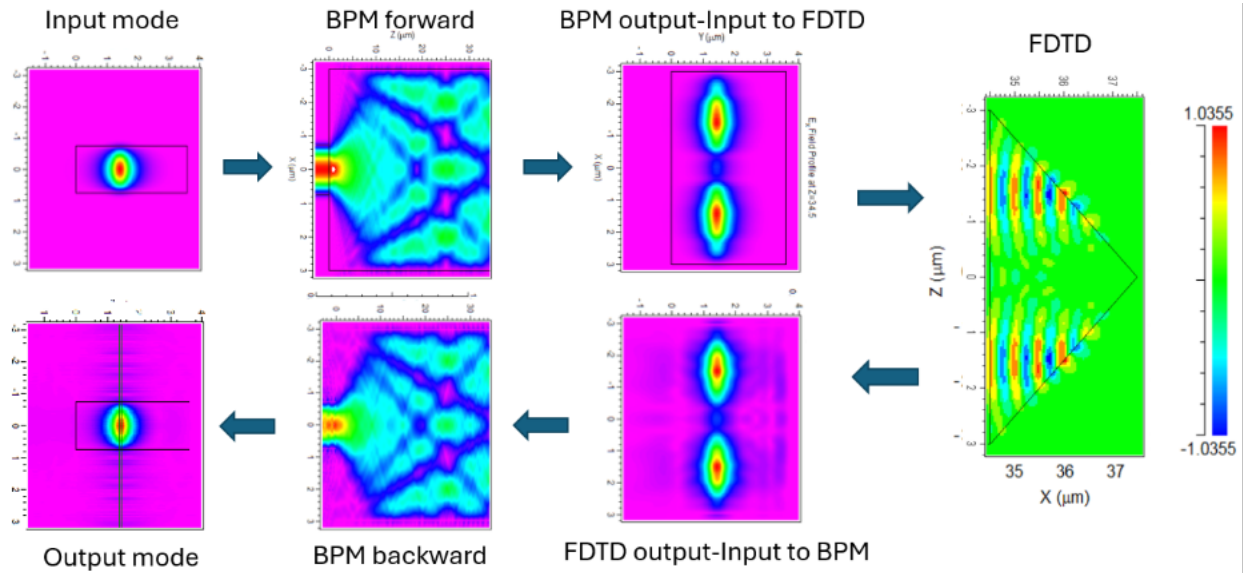


Figure 5. Mode field profiles evolution at the different positions of the reflective MMI coupler during the co-simulation process

4: MOST

MOST, RSoft's Multi-Variable Optimization and Scanning Tool, is used to optimize the MMI length with the Python scripted user-simulator and user-defined outputs. The optimal MMI length is found to be $\sim 34.7 \mu\text{m}$, achieving a maximum efficiency of $\sim 94.9\%$, as shown in Fig. 6. To highlight the advantage of the co-simulation process, we compare the computing resources and simulation time between the FullWAVE only and BeamPROP + FullWAVE co-simulation. The results are similar, but the FullWAVE only simulation requires ~ 20 hours on an 8-core computer with $\sim 20\text{GB}$ of RAM, whereas the co-simulation completes in ~ 10 minutes using 1.5 GB of RAM (Fig. 6).

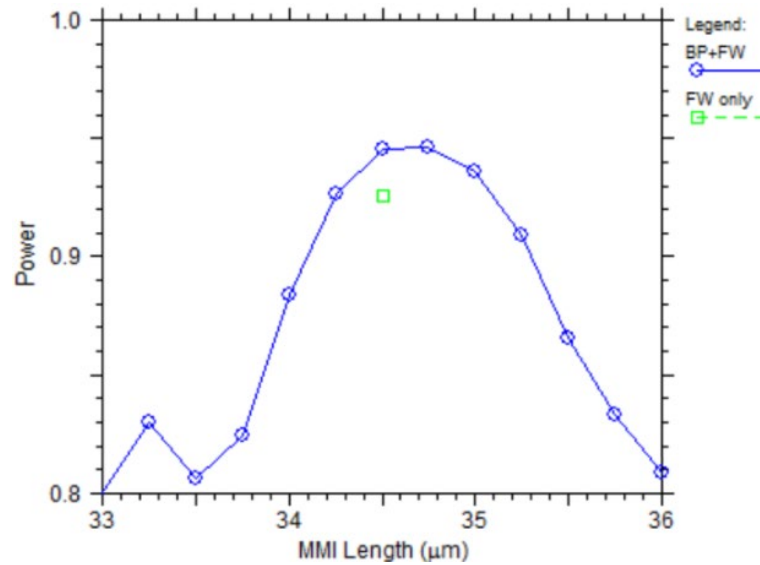


Figure 6. The normalized reflected power at the input port dependency on the MMI length

Note that we use a Python script-based User-Simulator to automate the co-simulation process. For instance, step 0 calculates the mode profile at the input port, step 1 runs the forward propagation in BeamPROP, and so on (Fig. 7).

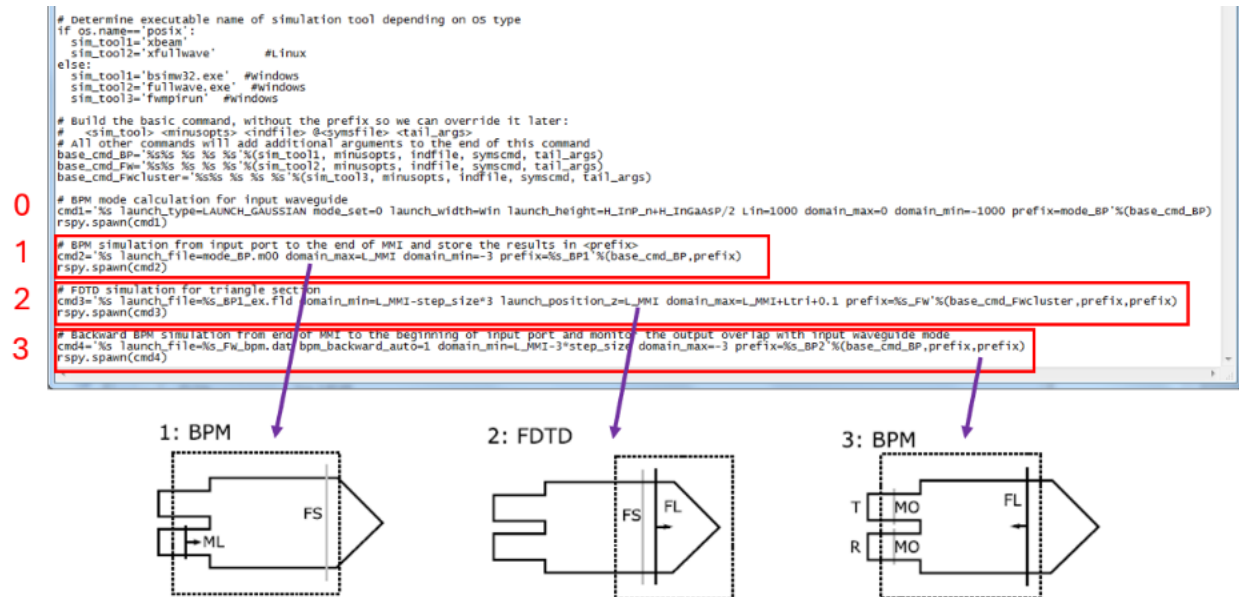


Figure 7. A Python script-based User-Simulator utilized to streamline the co-simulation process

Conclusion

We have demonstrated the procedure for simulating a reflective MMI coupler device by combining multiple RSoft component tools, such as BeamPROP, FullWAVE, and MOST. The co-simulation process takes full advantages of BPM's fast speed for a larger structure and FDTD's omnidirectional property for simulating the mirror facet. Compared to a FullWAVE-only simulation of the entire structure, the co-simulation method shows ~100 times faster in simulation time and requires ~13 times less RAM memory.

Reference

[1] E. Kleijn, M.K. Smit, and X.J.M. Leijtens, "Multimode interference reflectors: a new class of components for photonic integrated circuits." J. Light. Technol., Vol.31, No.18, pp.3055-3063 (2013).

Design files

Supporting Files for RSoft Application Note "Reflective Multimode Interference Coupler Co-simulated by BeamPROP and FullWAVE"