WHITE PAPER

Accelerating Photonic Simulations with the Effective Index Method in RSoft Tools

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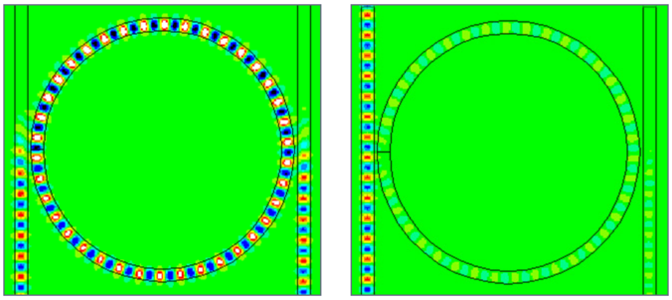
Introduction

The Effective Index Method (EIM) can be used in Synopsys RSoft™ photonic design software to greatly reduce the computation time and memory requirements of a simulation by converting a 3D structure into an approximate 2D structure [1]. This is also called an approximate 2.5D structure. Once a 3D structure has been reduced into a 2.5D structure using EIM, the propagation can be performed using one of numerous algorithms suitable for computational photonics, such as Finite Difference Time Domain (FDTD), Beam Propagation Method (BPM), Eigenmode Expansion (EME) and Rigorous Coupled Wave Analysis (RCWA). Most of the RSoft passive device modeling tools [2], including BeamPROP™, FullWAVE™, ModePROP™ and DiffractMOD™, all support EIM.

This white paper illustrates the performance and accuracy benefits of the EIM approach for two SOI-based structures: a ring resonator example and a 1x2 MMI example. The ring resonator example illustrates the use of EIM with FDTD-based FullWAVE and the necessity of taking EIM's frequency dependence into account when using such a time-domain technique. The MMI example compares three different numerical techniques and software tools available for modeling such devices in the RSoft photonic design toolset, including BPM-based BeamPROP, FDTD-based FullWAVE and EME-based ModePROP.

Validation of EIM to Model SOI-Based Ring Resonator

Ring resonators are critical components for silicon photonics applications such as wavelength channel add/drop multiplexing as well as for filtering operations. Resonant modes of the ring form at certain wavelengths (Figure 1(a)), when the wavelength of the light fits an integer number of times in the optical path length of the ring; conversely, the light that does not meet this resonant condition is transmitted through the bus waveguide (Figure 1(b)).



(a) (b)

Figure 1: Field distribution in the SOI based Ring Resonator (a) at resonance and (b) off resonance

When applying EIM to a time-domain technique such as FDTD, which can calculate the response over a broad frequency range in a single simulation, it is critical to include frequency dependence in the EIM method. If this is not done, it can lead to incorrect results as shown in Figure 2, which compares the through port response for an SOI-based ring resonator obtained through full 3D FDTD simulations versus the results from an EIM simulation not accounting for the frequency dependence. As can be seen, the Free Spectral Range (FSR) can differ substantially for the two cases: ~33 nm predicted by EIM versus ~26 nm predicted by a full 3D simulation.

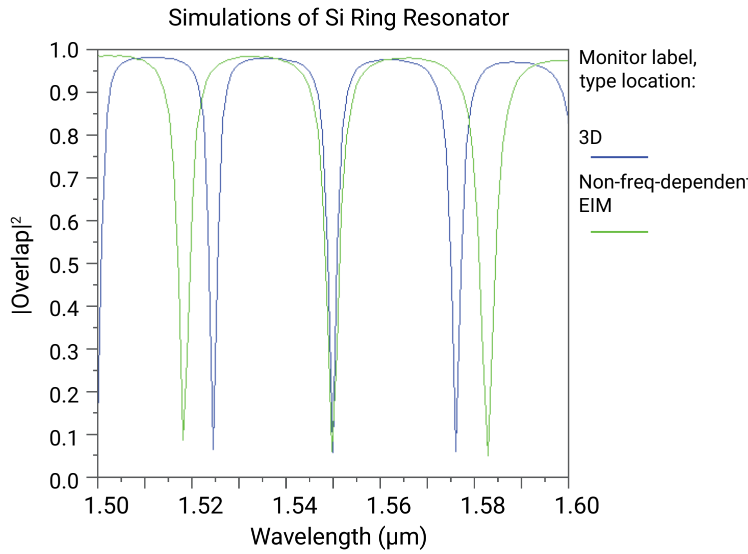


Figure 2: Results for SOI-based ring resonator: full 3D versus non-frequency-dependent EIM

However, when the frequency dependence is correctly accounted for in the EIM method, as is done in FullWAVE, the EIM results are in much closer agreement with the full 3D results. This is demonstrated in Figure 3, where the FSR predicted by EIM including frequency dependence is ~25.8 nm, which is very close to the ~26 nm predicted by the full 3D simulation. Moreover, the EIM simulation is ~300x faster than the full 3D simulation for this example.

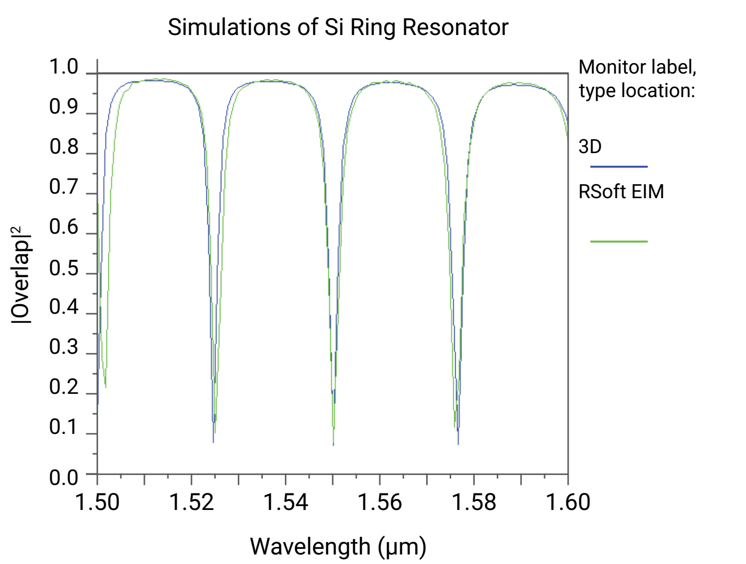


Figure 3: Results for SOI-based ring resonator: full 3D versus RSoft frequency-dependent EIM

Using EIM to Model SOI-Based 1X2 MMI

Multimode interference (MMI) devices have been utilized within photonic integrated optical circuits requiring power splitters, Mach Zehnder interferometers, and optical switches. MMIs can be fabricated on a wide range of material platforms including on CMOS compatible, SOI-based platforms for silicon photonic applications. Based on the number of ports and the nature of the self-imaging phenomena utilized by MMIs is such that these devices can be long. For example, increasing the number of ports by a factor of two requires a corresponding doubling of the MMI region width and a quadrupling of the device length. The use of EIM can provide a speed benefit for large structures when compared to full 3D simulation. In addition, the right choice of numeric technique can provide a substantial savings in design and simulation time.

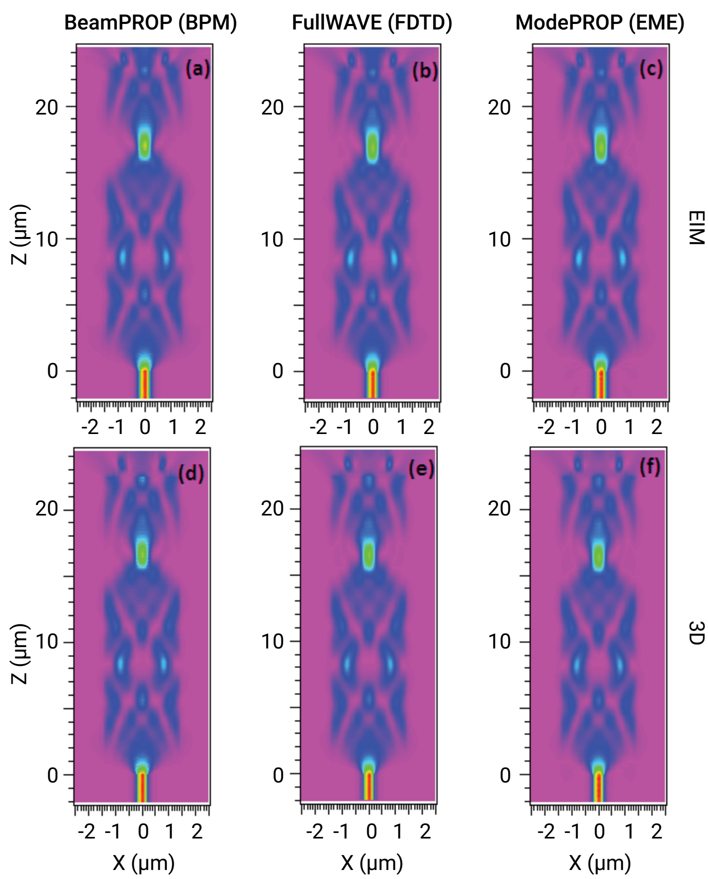


Figure 4: Field distributions in the SOI-based 1x2 MMI obtained using: (a) EIM BeamPROP; (b) EIM FullWAVE; (c) EIM ModePROP; (d) 3D BeamPROP; (e) 3D FullWAVE; and (f) 3D ModePROP

Here we analyze an SOI-based 1x2 MMI device using both EIM and full 3D analysis with three different techniques: BPM-based BeamPROP; FDTD-based FullWAVE; and EME-based ModePROP. We then present a comparison of the results and the computational times for each of these six cases. Figure 4 shows the final field results, obtained using BPM, FDTD and EME for both EIM and full 3D simulations. Table 1 tabulates the imaging length of the MMI obtained in each case. As can be seen from Figure 4 and Table 1, the final field distribution inside the MMI and the imaging length is very similar using any of the three numerical techniques (BPM, FDTD and EME). Moreover, as can be seen in this example, EIM applied to any of the techniques yields results comparable to 3D in all cases (~3% error for this structure).

	BeamPROP (BPM)	FullWAVE (FDTD)	ModePROP (EME)
EIM	17 .0	16.9	16.9
3D	16.6	16.5	16.4

Table 1: Results for the imaging length in μm found using the different numerical techniques

	BeamPROP (BPM)	FullWAVE (FDTD)	ModePROP (EME)
EIM	<~ 0.05	4.3	1.7
3D	68	1170	547

Table 2: Computational time (in sec) required for the different numerical techniques

Table 2 tabulates the computational times required in each of the six cases. EIM can save considerable time compared to full 3D for all three tools. Moreover, this example demonstrates that EME can be notably faster than FDTD (~2-3x). Furthermore, BPM is significantly faster than both FDTD (~20-80x) and EME (~8-30x) while maintaining similar accuracy (<1% error). Note that in order to get accurate results with BPM we used a rigorous wide angle BPM technique. If a traditional paraxial BPM scheme was used the error would have been higher but still only ~7%. Over an order of magnitude of savings in computation time obtainable by BPM, while maintaining acceptable accuracy levels, allows for rapid prototyping while designing a photonic component. This is extremely significant, since one of the biggest challenges in designing today's photonic systems is meeting computational resource requirements to perform the simulation, where in practice, a simulation can take hours, days or even weeks.

Summary

When applicable, the EIM technique can save orders of magnitude in computational time and memory compared to the full 3D simulation. When using the EIM method with a time-domain technique like FDTD, frequency dependence needs to be included in the EIM formulation; otherwise, it could lead to inaccurate results. RSoft FullWAVE implements such a frequency-dependent EIM technique; when applicable, this can provide accurate results compared to full 3D simulations as is shown for an SOI-based ring resonator. Most of the RSoft passive device design tools, including BeamPROP, FullWAVE, ModePROP and DiffractMOD, support EIM. By applying these three different numerical techniques to model a 1x2 SOI-based MMI, and comparing their results and computational requirements, it was demonstrated that the right choice of the numerical technique can lead to substantial savings in computational time and shorter design cycles through rapid prototyping.

References

[1] K. Chiang, "Dual effective-index method for the analysis of rectangular dielectric waveguides," *Appl. Opt.* 25, 2169-2174 (1986).

[2] *Synopsys RSoft CAD User Guide*, Synopsys, Inc., RSoft Products (2017).

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