# Simulation Methodology for LiDAR on Chip

**Chenglin Xu[1], Evan Heller[1], Maryvonne Chalony[2]**
[1]Synopsys, RSoft Design Group, 400 Executive Blvd, Ossining, NY 10562 USA
[2]Light Tech, 1128 Route de Toulon, 83400 Hyères, France
*e-mail: chenglin@synopsys.com*

**ABSTRACT**

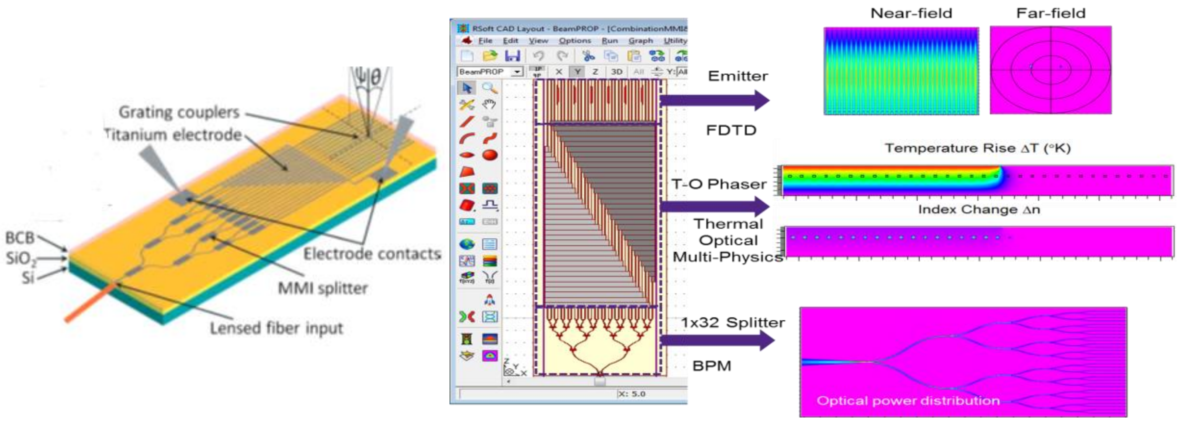
Simulation plays a critical role in the design and optimization of LiDAR on chip, but there is no single software tool that can completely handle such a complex device. In this paper, we present a simulation methodology that decomposes the complex structure into several simpler building blocks, and applies the appropriate algorithm to each. For example, the grating coupler, which is too big for a full FDTD simulation, can be treated through a coherent combination of individual grating simulation results. This provides a feasible solution which can be run on a typical PC.

**Keywords**: BPM, FDTD, multi-physics, LiDAR

## 1. INTRODUCTION

LiDAR (Light Detection and Ranging) is a critical device for self-driving cars. Currently, the LiDAR systems being tested in cars by various companies are based on discrete components. Aside from the bulky size and moving mechanical parts, the price can be even higher than that of the car itself, making it impossible to commercialize self-driving technology. Therefore, a cheap and reliable LiDAR is the key to making the self-driving car a viable consumer product. LiDAR built on photonic integrated chips could be a potential candidate for achieving this goal, as demonstrated by teams at Ghent University[1] and MIT[2].

Due to the low efficiency of the reported prototypes, the effective detecting range is only a few meters, well below the required 200 meters for practical applications. Therefore, design optimization of the LiDAR on chip is the major task and simulation plays an essential role. However, as reported by Prof. Baets' group and shown in Fig. 1(a), LiDAR on chip is a very big and complex device. There is no single design tool can handle the whole structure. Instead, we decompose it into a few functional blocks, as shown in Fig. 1(b), and each block is simulated by the most suitable tool from the RSoft product suite [3].




(a) (b)

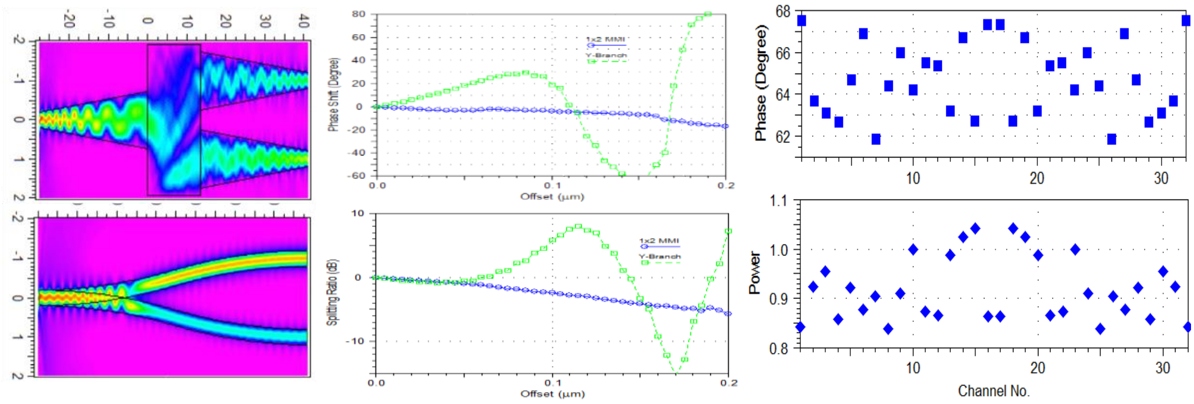
*Fig. 1. (a) The example structure reported in literature [1]; (b) Decomposition of the structure and simulation strategy*

Since there is little backward reflection in the power splitters, BPM (Beam Propagation Method) is the ideal algorithm for the individual 1x2 splitter and the cascaded 1x32 splitter. The following phase shifter requires a multi-physics solution to handle the combined thermal and optical problems. So, a thermal diffusion solver is used to provide the temperature dependent index perturbation of the structure, and BPM is used once again for the optical propagation. The final step is the emitter, which is typically implemented with a grating coupler. Since this involves omnidirectional light propagation, FDTD must be used. But this algorithm requires a long simulation time and significant computational resources, meaning that the emitter may be too large a problem to handle on a standard PC. To cope with this, we further decompose the problem into multiple inputs and coherently sum the output from each to obtain the final emitter response.

## 2. Detail Simulation Strategy

### 2.1 1x32 power splitter

The 1x32 power splitter used by most designers is comprised of 5 cascaded stages of 1x2 splitters. These 1x2 splitters can be either Y-branches or MMI's, each having its own pros and cons. In general, the Y-branch is simple, broadband, and polarization independent, but has a high insertion loss. The MMI is low loss but relatively complex, and is sensitive to both wavelength and polarization. These are all under the assumption of symmetric input. For the cascaded 1x32 splitter, however, the S-bends linking different stages inevitably create asymmetric input to the next stage, as shown in Fig.2(a). BPM simulation shows, in Fig. 2(b), that the MMI is more tolerant to asymmetric input and hence is a better candidate for the 1x2 splitter.



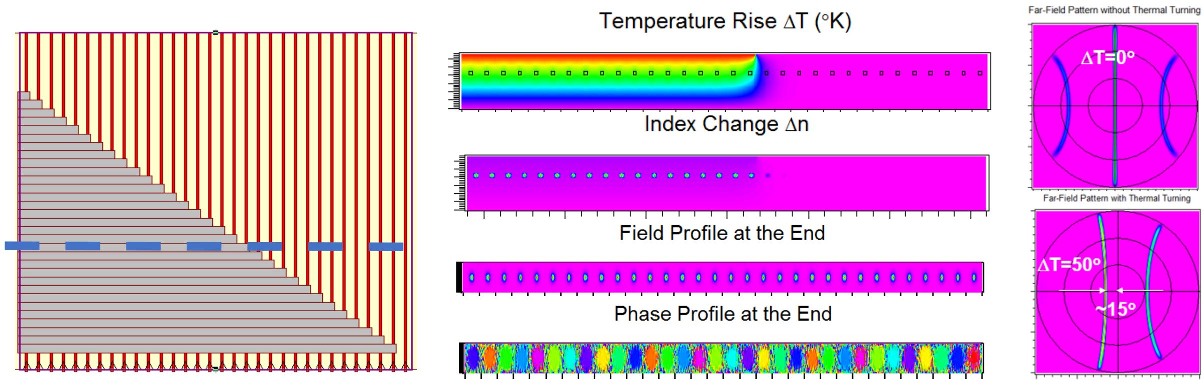

(a) (b) (c)

*Fig. 2. (a) Field patterns of both MMI and Y-branch under asymmetric input; (b) Sensitivity of phase difference and splitting ratio; (c) Non-uniformity of the cascaded 1x32 splitter in both phase and power.*

Although the MMI is less sensitive to asymmetric input, the effect still shows up as a non-uniformity in both power and phase of the final output, as shown in Fig. 2(c) for the 1x32 cascaded splitter with a 5º branch angle at the split. Obviously, non-uniformity can be reduced with a smaller angle at the expense of a longer device.

### 2.2 Thermal-optical phase shifter

Since silicon is not an electro-optic material, a thermally tuned phase shifter is used in the example, as shown in Fig. 3(a). We first solve the thermal diffusion equation to obtain the temperature distribution at each cross-section of the shifter. This profile is then converted into an index change by applying the thermo-optic coefficient. Finally, the propagating optical field is simulated with BPM to produce the complex (amplitude and phase) output field at the end of the device, as shown in Fig. 3(b). The exact phase shift can be examined from the far-field pattern, as shown in Fig. 3(c).




(a) (b) (c)

*Fig. 3. (a)Topview of the thermal phase shifter; (b)calculated temperature distribution, index change, amplitude and phase of the optical field at the end; (c) far-fields from the end without and with thermal tuning.*

The phase difference between adjacent waveguides is =120º for a temperature change of ΔT=50ºC. The BPM predicts a steering angle of 15º, which agrees exactly with the theoretical result $\psi = sin^{-1}(2\pi\Delta\Phi/\lambda) = 15^{o}$.

### 2.3 Beam Emitter

The beam emitter is a phase matched grating coupler which couples the in-plane optical wave from the waveguide nearly vertically into free space. A waveguide width grating[2]. was used in this example, although a waveguide height grating[1] could have been used, as well. To effectively out-couple the light with minimum divergence angle, the grating must be apodized properly, so that the light is out-coupled with a uniform distribution along the grating. After an FDTD optimization, we obtained an optimal tapered width grating function, normalized to grating length. Fig. 4 shown this optimized grating and the simulated field emission.

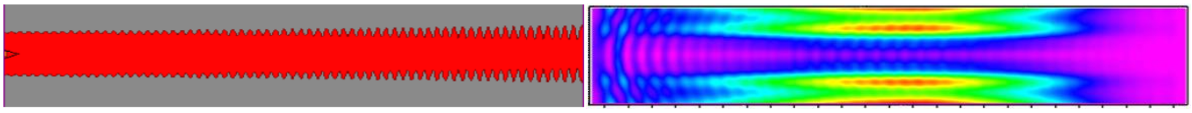


*Fig. 4. optimized grating and emitted field.*

Direct FDTD simulation of the 32-channel beam emitter requires about 100G RAM and a few days' computation time. So, instead of simulating the whole structure with all 32 inputs, we take an alternative approach. The input from each waveguide was simulated independently on a sufficiently large computational domain, which was determined to be about 5-waveguide widths. Each near-field above the grating, as shown in Fig. 5(a), was recorded. The total near-field, shown in Fig. 5(b), was obtained from the coherent sum of all the saved near-fields. Finally, we obtained the far-field, shown in Fig. 5(c), of the full emitter from the transform of the total near-field.

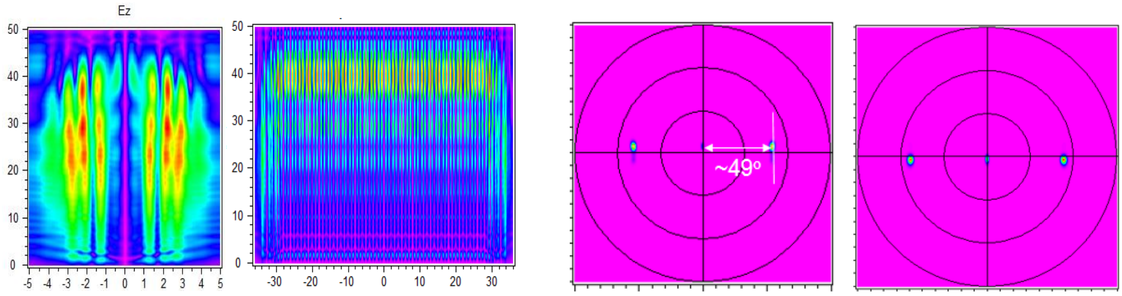



*Fig. 5. (a)Emitted near-field with input from a single waveguide; (b)Coherently combined near-field with inputs from every waveguide; (c)Emitted far-field; (d)Emitted far-field at a different wavelength.*

As shown in Fig. 5(c), the 1st order diffraction angle is ~49º, which is very close to the theoretical result $sin^{-1}(\lambda_0/D) = 50.8^{o}$. This result is obtained at ΔΦ=0º and λ=1.55μm. As we increase the phase difference ΔΦ between adjacent waveguides, the far-field pattern moves horizontally to the right. If we change the operating wavelength, the far-field pattern moves vertically as shown in Fig. 6(d). The calculated vertical angular variation is $\Delta\delta{\sim}18^{o}$ with the tuning range λ=1.5~1.6μm, and this agrees well with the theoretical result given by $\Delta\delta = \Delta n_{eff} - \Delta\lambda/\Lambda$, where Δ is the effective index variation and Λ is the grating period.

## 3. CONCLUSIONS

In summary, we have demonstrated a simulation methodology for LiDAR design by decomposing the full problem into several simple blocks, each simulated with a suitable algorithm. With the proposed strategy, where each part is optimized individually, LIDAR simulation becomes tractable on a standard PC.

## REFERENCES

[1] Van Acoleyen, Karel, Wim Bogaerts, Jana Jágerská, Nicolas Le Thomas, Romuald Houdré, and Roel Baets. "Off-chip beam steering with a one-dimensional optical phased array on silicon-on-insulator." *Optics letters* 34, no. 9 (2009): 1477-1479.

[2] Poulton, Christopher V., Ami Yaacobi, Zhan Su, Matthew J. Byrd, and Michael R. Watts. "Optical phased array with small spot size, high steering range and grouped cascaded phase shifters." In *Integrated Photonics Research, Silicon and Nanophotonics*, pp. IW1B-2. Optical Society of America, 2016.

[3] Synopsys RSoft products: *https://www.synopsys.com/optical-solutions/rsoft.html*