

Photonic Phased Array Design by Synthesis

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Abstract: We present a scalable photonic phased array design methodology based on synthesis of the array from a single element, decoupling simulation accuracy and time tradeoffs and enabling robust modeling of arbitrary array geometries and sizes.

1. Introduction

Integrated *Optical Phased Arrays* (OPAs) are rapidly becoming the critical building block for future LIDAR applications, thanks to their advantages in size, weight, and power consumption as compared to conventional solutions [1]. Recently, a 1024-element integrated OPA has been demonstrated using an SOI CMOS technology [2]. Large-scale OPAs can leverage high integration densities of electronic-photonic integrated circuit technology to generate finer beamwidth, better beamsteering control, and higher optical power [3]. Computational cost to accurately model large arrays with thousands to tens of thousands of elements rises exponentially at optical frequencies. Robust and efficient modeling is needed to meet design goals within simulation time and computer memory constraints. Large scale OPA designs also require a tightly integrated device-to-system co-design methodology to allow system-level optimization.

An OPA consists of three main components: an optical emitter array to couple light into free-space, an optical power splitting network to distribute light into each emitter, and a phase shifter network to control the collective radiation pattern [1]. The conventional approach relies on the Finite-Difference Time-Domain (FDTD) method and treats the OPA as a single photonic device [4]. At optical frequencies, the FDTD method is accurate at the expense of computational resources. Symmetric boundary conditions and 2D cross-sections may reduce computation cost while maintaining FDTD accuracy [5]. However, these cost-saving techniques do not scale well with asymmetric models or parameter sweep optimizations. In this work, we present an OPA design methodology which significantly relaxes the computational cost, time, and accuracy tradeoffs of phased array design at optical frequencies.

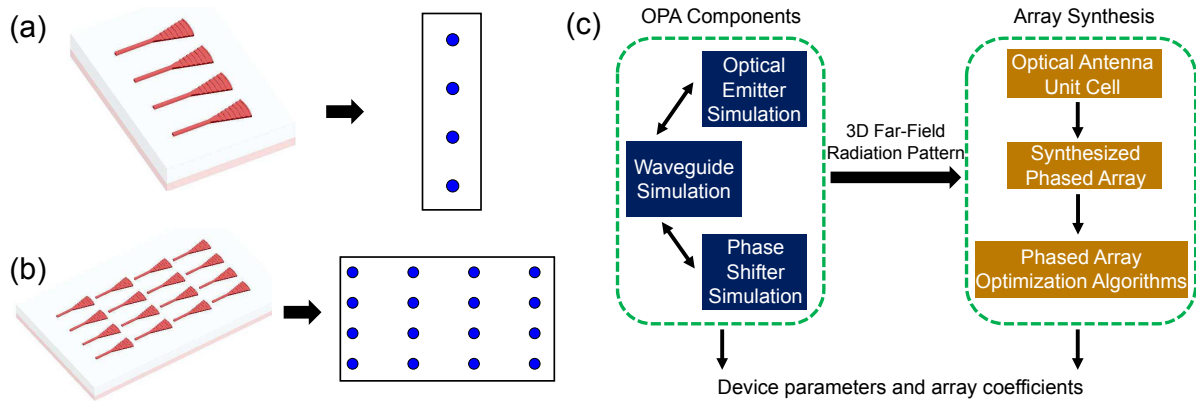


Fig. 1. (a) FDTD model of 1x4 focusing grating array converted to synthesized model. (b) 4x4 array FDTD model converted to synthesized model. (c) Proposed synthesized phased array design flow.

2. Design Methodology

We propose to use the radiation pattern of a single emitter element to synthesize the emitter array. As shown in Fig. 1(a)(b), instead of modeling an entire 1-D or 2-D emitter array using the FDTD method, this synthesis approach requires only a single emitter to be modeled using 3-D FDTD. A design flow based on the proposed phased array

synthesis is shown in Fig. 1(c). It allows accurate and robust modeling of arbitrary 1-D and 2-D OPAs, and enables optimization of device parameters and array coefficients across the device and system levels.

To demonstrate the proposed array synthesis method, we design two integrated OPAs with 1x4 and 4x4 emitter arrays, respectively, using standard silicon photonic technology on an SOI substrate (2- μm BOX and 220-nm top silicon layers). First, a parameterized model of a 3 μm ×5 μm focusing grating coupler was created. The model was simulated in FDTD with a mesh accuracy of 3 at 1.55 μm . Far-field radiation data was imported into the MATLAB Phased Array Toolbox as an element. 1x4 and 4x4 synthesized arrays were created from the element and far-field radiation profiles were generated. Direct FDTD simulation of the same arrays were also carried out for comparison.

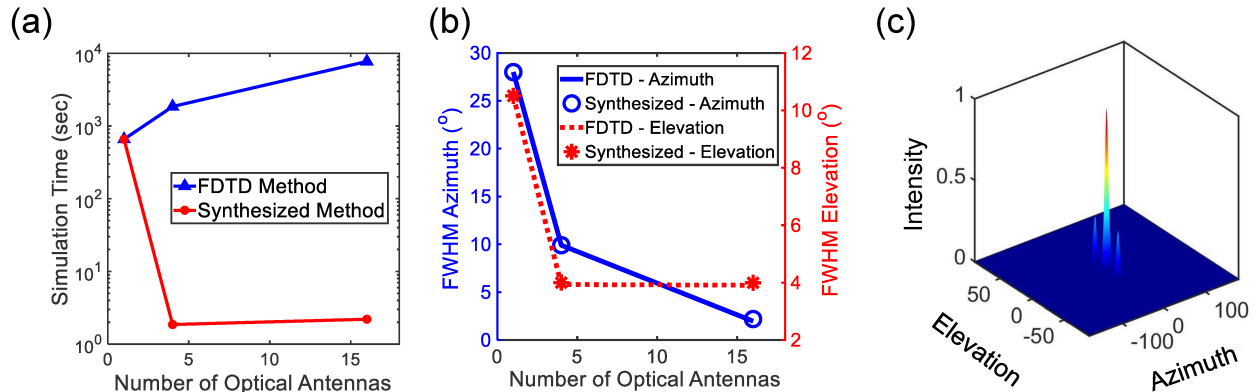


Fig. 2. Comparison of proposed synthesis method with FDTD: (a) Simulation time; (b) Full-Width Half Maximum (FWHM); (c) Example 3-D far-field radiation profile of 1x4 synthesized array.

Fig. 2(a) compares simulation times using FDTD and the proposed synthesis method. Fig. 2(b) compares beamwidth of the 3-D far-field main lobe across Azimuth (AZ) and Elevation (EL) planes, as shown in Fig. 2(c). FWHM is measured at 0.5 intensity. The FWHM in the Elevation plane is constant as the number of antennas is fixed along the array row, while the Azimuth FWHM decreases as linear rows of antennas are stacked into a 2D grid. Good agreement in beamwidth between the two methods is observed, with significantly reduced simulation time in the synthesis case.

Phased array optimization algorithms from the radar domain [6] are now accessible to the synthesized model. On the system level, parameter sweeps of arbitrarily sized and shaped arrays can be easily explored. Subarray geometries and taper windows can be applied for sidelobe management. Mature, RF control architectures can generate array weighting coefficients to guide optical phase shifter and splitter simulations in the photonic domain. The versatility afforded by the synthesis approach extends the capabilities of both stand-alone FDTD and RF array simulators.

3. Conclusion

We propose a new photonic phased array design methodology which largely removes the tradeoff in simulation time versus accuracy in conventional FDTD. After modeling a single emitter element using FDTD, synthesized phased arrays of arbitrary size and shape can be quickly and accurately modeled.

References

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