Inverse Design of Nanophotonic and Radio-Frequency Devices using Fast Maxwell Solvers

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Most electromagnetic devices arising from practical nanophotonic and radio-frequency (RF) applications require significant effort to model and design due to the lack of analytical solutions to Maxwell's equations for all but the simplest problems. Such systems usually require numerical simulation for analysis, but they often also pose serious challenges for electromagnetic simulation software due to being electrically large and/or having very fine features. The Finite-Difference Time-Domain (FDTD) method often turns out to be the only practical approach when dealing with extremely large, such as silicon photonic devices or large arrays of antennas. Frequency-domain methods that utilize volumetric meshes, such as the Finite Element Method (FEM) and the Finite-Difference Frequency-Domain (FDFD) method, produce large linear systems which have spectral conditioning properties that scale very poorly as the problem size increases. In this talk, we will introduce a fast high-order 3D boundary integral equation (BIE) solver based on the Nyström method, which we have used to efficiently simulate large devices in the frequency domain, including silicon photonic devices with semi-infinite input and output waveguides. We will discuss the most recent developments to our BIE solvers, including automated high-order meshing of planar structures, adaptive integration for automated error control, and a new way to launch one-directional modes in waveguides efficiently. Next, we will show how BIE-based solvers can be coupled with gradient-based optimization algorithms to inverse design high-performance nanophotonic devices, and we will derive the adjoint method for rapid computation of the objective function gradients in the context of boundary integral methods. Inverse design examples will be presented, including a 1:2 silicon photonic power splitter and a nonadiabatic taper.

We will also introduce our latest work on rapid algorithms for simulation and inverse design of planar metallic antenna structures and present a new approach that enables simulating candidate antenna topologies in less than a second per design after a fully parallelizable precomputation phase. Examples will be shown using this new framework to design high-gain and broadband antennas.

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