The Fourier modal method for aperiodic structures

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The Fourier modal method for aperiodic structures

by

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The Fourier modal method for aperiodic structures

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Summary
This paper extends the area of application of the Fourier modal method from periodic structures to non-periodic ones illuminated under arbitrary angles. This is achieved by placing perfectly matched layers at the lateral boundaries and reformulating the problem in terms of a contrast field.

Introduction

The Fourier modal method (FMM), also referred to as Rigorous Coupled-Wave Analysis (RCWA), has quite a long history in the field of rigorous diffraction modeling. It was first proposed by Moharam and Gaylord in 1981 [3]. Being based on Fourier-mode expansions, the method is inherently built for periodic structures such as diffraction gratings.

From periodic to isolated structures

Lalanne and his co-workers [4], [2] have applied the FMM to waveguide problems. The aperiodicity of the waveguide was dealt with by placing perfectly matched layers (PMLs) [1] on the margins of the computational cell (domain). PMLs can be seen as some fictitious absorbing and non-reflecting materials. In this way, artificial periodization is achieved, i.e. the structure of interest is repeated in space, but there is no electromagnetic coupling between neighboring cells.

The above approach, combining standard FMM with PMLs, is applicable only for the case of normal incidence of the incoming field, which is sufficient for waveguide problems. In this paper we show that for oblique incidence we need to reformulate the standard FMM such that the incident field is not part of the computed solution. We propose a decomposition of the total field into a background field (containing the incident field) and a contrast field. The problem is reformulated with the contrast field as the new unknown. The background field solves a corresponding background problem which has a simple analytical solution. The main effect of the reformulation is that the homogeneous system of second-order ODEs becomes non-homogeneous. The solution of this equation is derived in closed form, as required for the FMM algorithm.

Numerical example

We consider the problem of scattering from an isolated resist line in air with a width of 1 unit and a height of 0.2 units illuminated by a plane wave with a wavelength $\lambda = 2\pi$ units at normal and oblique incidence. The computational domain has a width $\Lambda = 5$ units and the lateral PMLs have a width of 1 unit. The geometry of the problem can be
seen in the top part of Figure 1. Note that the problem may be scaled in space and any fixed distance may be chosen as a unit. The permittivities of air and resist are given by $n_0 = 1, n_2 = 1.5$. For conciseness, the reformulated FMM with PMLs will be referred to as aFMM-CFF (aperiodic Fourier modal method in contrast-field formulation).

Figure 1 shows the total field computed with aFMM-CFF for oblique incidence, $\theta = \pi/6$. Solutions computed with supercell FMM (standard FMM with a large period $\Lambda$) are used as a reference. Clearly, in the limiting case $\Lambda \rightarrow \infty$, the solution of the periodic problem tends to the solution computed with aFMM-CFF. This enables us to draw two important conclusions: (1) the PML implementation is correct - it acts as a reflectionless absorbing layer, and (2) the amount of harmonics required to obtain a ‘good’ solution is much lower for aFMM-CFF than for supercell FMM.

In our example the aFMM-CFF requires 10 times less harmonics than the supercell FMM (20 instead of 200). In the view of the fact that the number of operations performed by the eigenvalue solver (which is the most demanding step in the method) scales cubically with the amount of harmonics, this results in a factor of $10^3$ difference in terms of computational time.
References


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