Title
The array scanning method (ASM)-FDTD algorithm and its application to the excitation of two-dimensional EBG materials and waveguides

ISBN
9781424408771

Authors
Qiang, Rui
Chen, Ji
Capolino, F
et al.

Publication Date
2007-06-01

DOI
10.1109/aps.2007.4396532

The Array Scanning Method (ASM)-FDTD Algorithm and its Application to the Excitation of Two-Dimensional EBG Materials and Waveguides

Rui Qiang* (1), Ji Chen (1), Filippo Capolino (2), and David R. Jackson(1)

(1) Dept. of ECE, University of Houston, Houston TX 77204, USA
E-mail: rqiang@mail.uh.edu

(2) Dept. of Information Engineering, University of Siena, 53100 Siena, Italy

Introduction

The finite-difference time-domain method (FDTD) has been successfully used to analyze the electromagnetic behaviors of many infinite periodic structures (such as EBG, FSS, metamaterial, etc.). To improve its computational efficiency, many different implementations of periodic boundary condition (PBC) have been proposed [1]. However, all of these proposed techniques are formulated based on a plane wave incidence. Consequently, these methods are restricted to applications where the plane-wave assumption is valid.

For problems involving finite-size source excitations (such as a dipole or line source) in the frequency domain, they can be analyzed using the PBC in combination with the spectral-domain transformation technique [2][3]. However, in the time domain, usually a "brute-force" FDTD simulation, which includes a large number of periodic elements in the simulation domain, has to be performed and this requires extensive computer memory and CPU time.

The purpose of this paper is to discuss a novel time-domain technique, which is based on the spectral-domain periodic FDTD method and the array scanning method (ASM), to study the electromagnetic behaviors of a two-dimensional EBG waveguide excited by an electric-current line source. This method requires the analysis of only a singe unit cell.

Methodology

The geometry of a two-dimensional EBG waveguide and the line-source location are shown in Fig. 1(a). The structure consists of an infinite periodic array of metallic rods of radius r_0 with a period a in the x direction, which is truncated along the y direction with a finite number of rows on either side of the propagation channel. A z-directed electric-current line source is placed at some point inside the propagation channel, formed from a missing row of rod elements. The same structure has been well discussed by using the frequency domain ASM method in [3]. However, in this paper, we use the ASM method technique in the time domain to re-examine this structure. The details of the procedure follow.

1-4244-0878-4/07/$20.00 ©2007 IEEE

Assuming there is no variation along the z axis, an impressed time-domain electric current line source located at (x_0, y_0) in the 0th unit cell, i.e. $x_0, y_0 \in [-a/2, a/2]$ in Fig. 1(a), can be written as

$$J_z^i(x', y', t) = \delta(x' - x_0)\,\delta(y' - y_0)\,J_z^i(t). \tag{1}$$

Following the ASM principle similar to [3], the original time-domain line source is represented by the integration over all possible wavenumber k_x in the first Brillouin zone as

$$J_z^i(x', y', t) = J_z^i(t)\frac{a}{2\pi}\int_{-\pi/a}^{\pi/a} J_z^{i,\infty}(x', y', k_x)\,dk_x\,, \tag{2}$$

where $J_z^{i,\infty}(x', y', k_x)$ denotes an infinite array of sources with a linear phase delay factor $e^{-jk_x a}$ along the x direction, so that

$$J_z^{i,\infty}(x', y', k_x) = \sum_{m=-\infty}^{\infty} \delta(x' - x_0 - ma)\delta(y' - y_0)e^{-jk_x ma}\ . \tag{3}$$

Therefore, the electric field $E(x, y, t)$ (denoting the z component of the field) in the 0th unit cell in Fig. 1(a) that is produced by the line source at (x_0, y_0) can be evaluated by first calculating the electric field $E^\infty(x, y, k_x, t)$ excited by an infinite phased array of line sources as shown in Fig. 1(b), and then using

$$E(x, y, t) = \frac{a}{2\pi}\int_{-\pi/a}^{\pi/a} E^\infty(x, y, k_x, t)\,dk_x\,, \tag{4}$$

where $E^\infty(x, y, k_x, t)$ is the solution obtained by modeling one unit cell as shown in Fig. 1(b), where for each value of k_x a simple periodic boundary condition is enforced, namely

$$E^\infty(x + a, y, k_x, t) = E^\infty(x, y, k_x, t)\,e^{-jk_x a}\,. \tag{5}$$

This periodic boundary condition is readily implemented in the complex domain by using the periodic spectral-FDTD method proposed in [4]. The electric field in a unit cell that is m cells away form the 0th cell can then be obtained by using

$$E(x + ma, y, t) = \frac{a}{2\pi}\int_{-\pi/a}^{\pi/a} E^\infty(x, y, k_x, t)\,e^{-jk_x ma}\,dk_x\,. \tag{6}$$

The corresponding frequency-domain electric field $E(x, y, \omega)$ can easily be obtained by applying an FFT operation on the known time domain solution.

Numerical Simulation Results

In the following example, the period a is chosen as $a/\lambda_0 = 0.3$. A sinusoidal 1A current is located at the origin, $(x, y) = (0, 0)$. The operating frequency of the current source is 5 GHz. This structure satisfies the first complete stop band condition of $0 < a/\lambda_0 < 0.48$. Therefore, there is no leakage into the EBG structure (with a metallic rod radius $r_0 = 0.2a$) that surrounds the channel. Figure 2 shows the electric field E_z distribution sampled at the center of each periodic cell along the x direction. Results from both the FDTD and ASM-FDTD methods are given for comparison. For this particular simulation, the mesh size of $dx = dy = 0.5\ mm$ was used in all directions. In order to minimize boundary reflections, 201 unit cells were included in the FDTD simulation domain and 200 spectral points were sampled in Eq. (5) for the ASM-FDTD computation. As shown in the figure, very good agreement between these two methods is observed. Both Figs. 2(a) and (b) clearly reveal a single dominant mode of propagation with a guided wavelength $\lambda_g = 8a$ in the channel, as predicted in [3].

Compared to the frequency-domain ASM technique, one distinct advantage of the ASM-FDTD method is its capability to simulate time domain responses. A Gaussian pulse, $\exp\left[-(t-t_0)/2\sigma^2\right]$, is launched in the same structure to investigate its time domain behavior, where $\sigma = 2.83\times10^{-11}\sqrt{s}$ and $t_0 = 1.13\times10^{-10}s$. All other simulation parameters were kept unchanged. The electric field E_z in the time domain at locations $(x,y)=(5a,0)$ and $(x,y)=(5a,1.5a)$ are shown in Fig. 3(a) and Fig. 3(b), respectively. It is noticed that the ASM-FDTD results match closely with those obtained form the FDTD method up to 9 ns. As expected, the electric field strength in the EBG structure at $(x,y)=(5a,1.5a)$ is only about 5% of that in the channel at $(x,y)=(5a,0)$. This further validates that the wave cannot propagate into the EBG structure and mainly exists inside the channel.

Conclusion

A novel FDTD scheme, called ASM-FDTD, has been used to analyze 2D EBG materials and waveguides with an electric current line-source excitation. It has been shown that by choosing proper simulation parameters, this method can obtain the same accuracy as that of the FDTD method but can dramatically reduce the required computational needs in terms of both memory and CPU time.

References

[1] Taflove A. *Computational Electrodynamics: The Finite Difference Time Domain Method.* Norwood, MA: Artech House, 2000.

[2] B. A. Munk, G. A. Burrell, “Plane-wave expansion for arrays of arbitrarily oriented piecewise linear elements and its application in determining the impedance of a single linear antenna in a lossy half-space,” *IEEE Trans. Antennas Propagat.*, vol. 27, pp. 331 - 343, May 1979.

[3] F. Capolino, D. R. Jackson and D. R. Wilton, “Mode excitation from sources in two-dimensional PBG waveguides using the array scanning method,” *IEEE Microwave and Wireless Components Letters*, vol. 15, no. 2, pp. 49-51, Feb. 2005.

[4] F. Yang, J. Chen, R. Qiang, and A. Elsherbeni, "FDTD analysis of periodic structures at arbitrary incidence angles: a simple and efficient implementation of the periodic boundary conditions", *IEEE Antennas and Propagation Society Intl. Symp.*, pp. 2715-2718, June 2006.

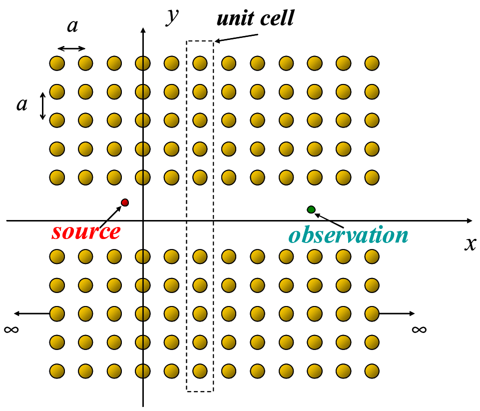

Figure 1(a). Geometry of the EBG waveguide and its excitation.

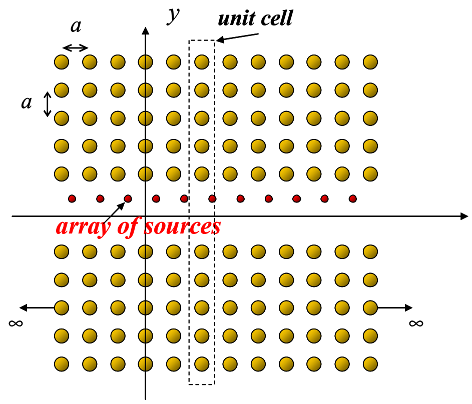

Figure 1(b). An infinite array of line sources in the same waveguide.

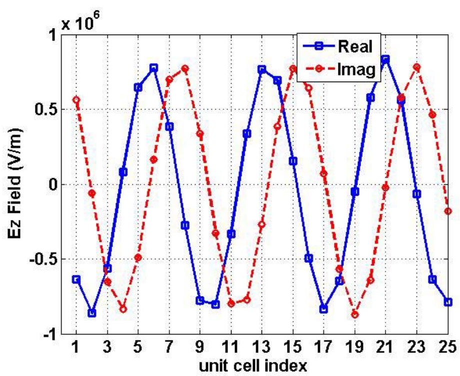

Figure. 2(a). Real and Imaginary parts of the electric field distribution in the channel the along *x* axis, by the FDTD method.

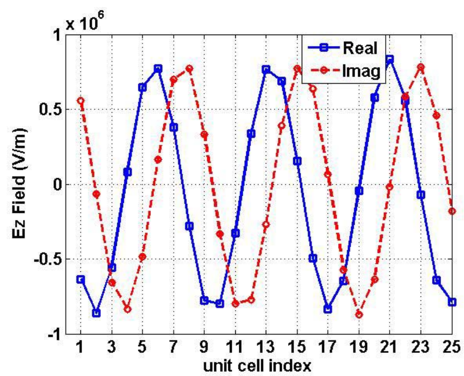

Figure 2(b). Real and Imaginary parts of the electric field distribution in the channel along *x* axis, by the ASM-FDTD method.

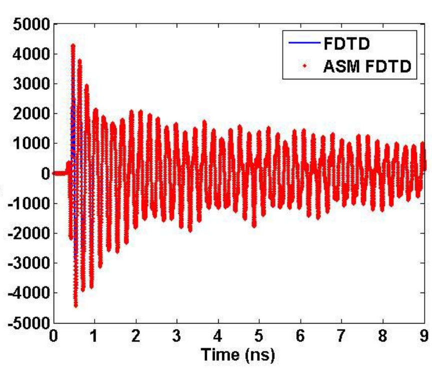

Figure 3(a). Time-domain responses, comparing the electric field at location $(x,y) = (5a,0)$, obtained from the FDTD and ASM-FDTD methods.

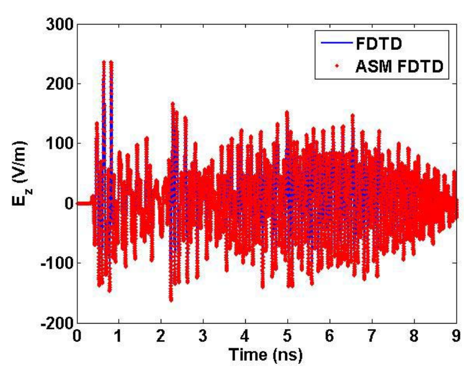

Figure 3(b). Time-domain responses, comparing the electric field at location $(x,y) = (5a,1.5a)$, obtained from the FDTD and ASM-FDTD methods.