A Methodology of Hybrid PE and FDTD method for Electromagnetic Wave Propagation and Coupling

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Abstract—A methodology of hybrid PE and FDTD method for solving electromagnetic wave propagating over large area and coupling of specific objects is presented. Parabolic Equation (PE) and Finite Difference Time Domain (FDTD) method is employed to solve the EM wave propagation and coupling respectively. A plane wave spectrum(PWS) method is applied as boundary condition to connecting the fields between two solution zones to produce a consistent result. A numerical example of EM wave propagating through city region and coupling of buildings is presented to demonstrate the solution accuracy and feasibility of this hybrid methodology.

Keywords-coupling, propagation, FDTD, PE, PWS

I. INTRODUCTION

The propagation of electromagnetic waves among large area e.g. cities and coupling of objects e.g. buildings is important to electromagnetic environment effects analysis. This multi-scale issue involves scale of kilometer for the propagation area and centimeter for coupling objects, which cannot be solved by single numeric method. PE method is appropriate for solving propagation over complex terrain[1], while FDTD method is suitable for relatively small objects coupling and scattering problems. The key issue is the connecting between the two solution zones. A connecting boundary condition (CBC) using plane wave spectrum expansion[2] is presented to form the methodology of hybrid PE and FDTD method for solving electromagnetic wave propagation and coupling.

II. PARABOLIC EQUATION METHOD

A. Parabolic Equation Method

The Helmholtz equation can be written as

$$\partial_z^2 u + 2jk_0\partial_z u + (\partial_x^2 + \partial_y^2)u = 0 \qquad (1)$$

in which u represents either electric or magnetic field component. Apply the paraxiality condition, we get

$$\partial_z u \approx \frac{j}{2k_0}(\partial_x^2 + \partial_y^2)u \qquad (2)$$

This parabolic equation can be solve by Finite Difference (FD) or Split-Step Fourier Transform (SSFT) method. PE method has been proven to be capable of solving electromagnetic wave propagation over very large area and giving results with considerable accuracy.

B. Connecting boundary condition

Plane wave angular spectrum method is used to provide the connecting boundary condition between the parabolic equation solution zone and FDTD solution zone. The propagating electromagnetic wave on a virtual plane before the object is decomposed into combination of infinite number of plane waves with different amplitude and propagation constant. With a threshold for the amplitude, limited plane waves are chosen to reconstruct the propagating wave on the virtual plane with adequate accuracy because they contain most energy of the propagating wave. In FDTD solution process, these plane waves are excited simultaneously to perform an equivalent wave on the virtual plane.

III. NUMERICAL RESULTS

In this example, the propagation of plane wave with frequency of 10 MHz in a city is considered, as well as the coupling fields of a building located in this city. The dimension of the city is 6 km by 8 km, and 38m by 30m by 25m for the building. The field distribution of city is obtained by PE method. A virtual plane is set up 3 meters before the building, on which the field is decomposed and reconstructed by 288 plane waves, which contain 95.6% energy of the original wave. Then the plane waves are used as the excitation in FDTD method for building coupling simulation. The results are shown in Figure 2.

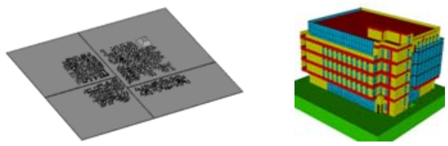
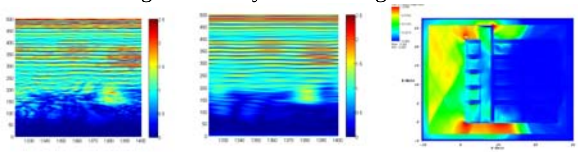


Figure 1. City and building model



(a) (b) (c)

Figure 2. (a) E-field on virtual plane simulated by PE method
(b) E-field reconstructed by 288 plane waves
(c) E-field coupled by the building simulated by FDTD

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