DEVELOPMENT EFFECTIVE PERMITTIVITY ALGORITHM FOR CONFORMAL STRUCTURE IN 3D FINITE DIFFERENT TIME DOMAIN (FDTD)

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For my beloved family.

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ABSTRACT

This thesis is about developing a conformal object using the finite difference time domain (FDTD) method. Theoretical analysis nowadays frequently uses to analyze problem regarding electromagnetic in computational algorithm. The FDTD method by numerically implemented and time based simulation results in better response of wide band frequency. In the FDTD there are several others principles that have been used in modelling the object; they are absorbing boundary condition (ABC), near Field Far Field (NFFF) and Scattering Parameter. This thesis also uses Radar Cross Section (RCS) characteristic to analyze the radiation pattern of the object at particular incident plane wave direction. The source of the plane wave was determined by the angle of phi and theta in the Matlab function. Once the simulation started, GUI immediately shows simulated object. After FDTD iteration completed the radiation pattern on the polar graph plotted in direction of xy-plane, xz-plane and yz-plane. This pattern can be used to analyze the object characteristic, regarding the frequency of the incident plane wave. From the radiation pattern, we can see that conformal (sphere) show less reflection than the cubical object as comparison.

ABSTRAK

Tesis ini adalah mengenai pembangunan objek konformal menggunakan kaedah beza terhingga masa domain (FDTD). Analisis teori masa kini sering digunakan untuk menganalisia masalah mengenai elektromagnet dalam pengiraan algoritma. Fungsi FDTD adalah dengan melaksanakan kaeda berangka dan simulasi berasaskan masa yang mengakibatkan tindak balas yang lebih baik kepada frekuensi jalur lebar. Dalam FDTD terdapat beberapa kaedah lain yang digunakan dalam membina objek, antaranya *Perfect Matched Layer* (PML), *Absorbing Boundary Condition* (ABC), *Near Field Far Field* (NFFF) dan *Scattering Parameter*. Tesis ini juga menggunakan ciri Radar Cross Seksyen (RCS) untuk menganalisis corak radiasi objek mengenai kejadian planar gelombang. Sumber gelombang pesawat telah ditentukan oleh sudut phi dan theta dalam fungsi Matlab. Selepas menjalankan simulasi, ia menunjukkan bentuk objek dan corak sinaran objek pada graf plot kutub pada arah planar-xy, planar-xz dan planar- yz. Corak ini boleh digunakan untuk menganalisis ciri-ciri objek, mengenai kekerapan gelombang pesawat kejadian. Dari corak sinaran, kita dapat melihat bahawa konformal (sfera) menunjukkan refleksi kurang daripada objek kubik sebagai perbandingan.

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FDTD - Finite-Different Time Domain
IEEE - Institute of Electrical and Electronics Engineers
HF - High Frequency
2D - Two Dimension
3D - Three Dimension
ABCs - Absorbing Boundary Conditions
PML - Perfectly Matched Layer
CPML - Convolutional Perfectly Matched Layer
NFFF - Near Field to Far Field
GUI - Graphical User Interface

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CHAPTER I

INTRODUCTION

1.1 Project Background

This project will be exposed to the differential time domain Maxwell equation of Cartesian coordinate to simulate object built by electromagnetic wave. The equations has been used in developing the finite difference time domain method for modeling full wave electromagnetic structure. The advantage of FDTD is simple; implementation of numerical and time based simulation method and resulting in better wide band frequency response.

The Maxwell’s equations have been discretized for the purpose of numerical electromagnetic modeling. Finite Different Time Domain (FDTD) can be used to investigate electromagnetic in propagation and scattering from infinite artificial periodic arrays with arbitrary electromagnetic source. FDTD has been used to solve numerous types of problem arising many applications including scattering parameter [2].

Since FDTD is grid based numerical modeling, the simplest technique to build the conformal structure is staircase approximation but it is happening numerical spurious as a result in accurate scattering or radiation characteristic. For instance, to model the curved surface conformal structure like a subcell model and contour path model were proposed. This project will implement the Yu-Mittra model in FDTD algorithm.

1.2 Objective

The objective of this project is:

1. To understand the 3D FDTD method.
2. To model a curve object using 3D FDTD method.
3. To understand and apply the Yu-Mittra theory (CFDTD).

The main objective of this project is to model conformal curve object, where it is more accurate than those generated by the conventional staircasing approach. The staircasing approaches that analyze the objects with curved metallic surfaces using Yee algorithm not only generate spurious solutions, but also introduce errors [3] due to inaccurate approximation of the geometry.

1.3 Problem Statement

Nowadays, to designing the scattering parameter using the experimental method based on the perfect electric conductor and perfect magnetic conductor that required high cost of the single periodic unit based. For analytical method it required more on theoretical and derivation where more time to study the fundamental equation thus the numerical modeling need will be used to develop this model where the numerical modeling is mathematical models that use some sort of numerical time-stepping procedure to obtain the models behavior over time.

The mathematical solution is represented by a generated table and or graph. Since this is numerical modeling, the FDTD can simulate the structure results algorithms with built-in optimization that allows for rapid virtual prototyping to reduce costly physical prototypes. FDTD is the tool to simulate structure that required and easy to fabricated. The FDTD technique is easy to implement using parallel computation algorithms.

The approach to analyzing objects with curved surfaces using the Yee algorithm is to resort the staircasing to model these surfaces. However, these procedures not only generate spurious solution, but can also introduce errors due to inaccurate approximation of the geometry. Many approaches have been proposed to overcome these difficulties; employing a globally curvilinear grid to model the geometry is one of the solutions. But, it may be may be difficult to generate for an arbitrary shape for the explicit algorithm on these grids requires a special type of mesh. Using the contour path finite difference time domain (CFDTD) scheme is another strategy for handling curved surfaces [4] by deforming the grid only locally to accommodate the curvature of the surface. In this scheme, by using the conventional FDTD procedure certain electric field edges are available and can be updated, while the values of other electric field edge are borrowed from their nearest available collinear edges.

1.4 Scope of works

1. To study application of Maxwell and familiarize Maxwell equation to apply in 3D FDTD. This equation below is representing vector equation.
   - *Faraday's law*

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E} - \vec{M} \qquad (1.4.1a)$$

B is represent magnetic fields

E is represent magnetic fields

- *Ampere's Maxwell law*

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H} - \vec{J} \tag{1.4.1b}$$

D is represent electric displacement fields

H is represent magnetizing fields

- *6 scalar Maxwell's equations for 3D FDTD*

i. $$\frac{\partial H_x}{\partial t} = -\frac{1}{\mu}\left[\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{dz}\right] - \frac{1}{\mu}\left[M_{source_x} + \sigma^* H_x\right] \tag{1.4.2a}$$

ii. $$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu}\left[\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{dx}\right] - \frac{1}{\mu}\left[M_{source_y} + \sigma^* H_y\right] \tag{1.4.2b}$$

iii. $$\frac{\partial H_z}{\partial t} = -\frac{1}{\mu}\left[\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{dy}\right] - \frac{1}{\mu}\left[M_{source_z} + \sigma^* H_z\right] \tag{1.4.2c}$$

iv. $$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{dz}\right] - \frac{1}{\varepsilon}\left[J_{source_x} + \sigma E_x\right] \tag{1.4.2d}$$

v. $$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{dx}\right] - \frac{1}{\varepsilon}\left[J_{source_y} + \sigma E_y\right] \tag{1.4.2e}$$

vi. $$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{dy}\right] - \frac{1}{\varepsilon}\left[J_{source_z} + \sigma E_z\right] \tag{1.4.2f}$$

Where the symbol are define as $\vec{E}$ is the electric field strength vector in volts per meter, $\vec{H}$ is the magnetic field strength vector in amperes per meter, $\vec{J}$ is the electric current density vector in amperes per square meter, $\vec{M}$ is the magnetic current density vector in volts per square meter.

From the above equation, the Maxwell's will discretized where it analyzed related to time dependent Maxwell's equation that introduce by Yee cell. In this method, the partial spatial and time derivates are replaced by a finite difference time domain because in FDTD no matrix operations have to be used. The spatial domain is discritized by two dual orthogonal regular Cartesian grids based on bricks that divide to Δx, Δy, Δz and the time domain is intervals of Δt.

- *Disretization of Maxwell's curls equations in time and space.*

i.

$$\frac{H_x\big|_{i,j,k}^{n+\frac{1}{2}} - H_x\big|_{i,j,k}^{n-\frac{1}{2}}}{\Delta t} = -\frac{1}{\mu_x\big|_{i,j,k}}\left[\frac{E_z\big|_{i,j,k}^{n} - E_z\big|_{i,j-1,k}^{n}}{\Delta y} - \frac{E_y\big|_{i,j,k}^{n} - E_y\big|_{i,j,k-1}^{n}}{\Delta z}\right] - \frac{1}{\mu_x\big|_{i,j,k}} M_{source_x}\big|_{i,j,k}^{n} - \frac{\sigma_x^*\big|_{i,j,k}}{\mu_x\big|_{i,j,k}} H_x\big|_{i,j,k}^{n} \tag{1.4.3a}$$

ii.

$$\frac{H_y\big|_{i,j,k}^{n+\frac{1}{2}} - H_y\big|_{i,j,k}^{n-\frac{1}{2}}}{\Delta t} = -\frac{1}{\mu_y\big|_{i,j,k}}\left[\frac{E_x\big|_{i,j,k}^{n} - E_x\big|_{i,j,k-1}^{n}}{\Delta z} - \frac{E_z\big|_{i,j,k}^{n} - E_z\big|_{i-1,j,k}^{n}}{\Delta x}\right] - \frac{1}{\mu_y\big|_{i,j,k}} M_{source_y}\big|_{i,j,k}^{n} - \frac{\sigma_y^*\big|_{i,j,k}}{\mu_y\big|_{i,j,k}} H_y\big|_{i,j,k}^{n} \tag{1.4.3b}$$

iii.

$$\frac{H_z\big|_{i,j,k}^{n+\frac{1}{2}} - H_z\big|_{i,j,k}^{n-\frac{1}{2}}}{\Delta t} = -\frac{1}{\mu_z\big|_{i,j,k}}\left[\frac{E_y\big|_{i,j,k}^{n} - E_y\big|_{i-1,j,k}^{n}}{\Delta x} - \frac{E_x\big|_{i,j,k}^{n} - E_x\big|_{i,j-1,k}^{n}}{\Delta y}\right] - \frac{1}{\mu_z\big|_{i,j,k}} M_{source_z}\big|_{i,j,k}^{n} - \frac{\sigma_z^*\big|_{i,j,k}}{\mu_z\big|_{i,j,k}} H_z\big|_{i,j,k}^{n} \tag{1.4.3c}$$

iv.

$$\frac{E_x\big|_{i,j,k}^{n+1} - E_x\big|_{i,j,k}^{n}}{\Delta t} = \frac{1}{\varepsilon_x\big|_{i,j,k}}\left[\frac{H_z\big|_{i,j,k}^{n+\frac{1}{2}} - H_z\big|_{i,j-1,k}^{n+\frac{1}{2}}}{\Delta y} - \frac{H_y\big|_{i,j,k}^{n+\frac{1}{2}} - H_y\big|_{i,j,k-1}^{n+\frac{1}{2}}}{\Delta z}\right] - \frac{1}{\varepsilon_x\big|_{i,j,k}} J_{source_x}\Big|_{i,j,k}^{n+\frac{1}{2}} - \frac{\sigma_x\big|_{i,j,k}}{\varepsilon_x\big|_{i,j,k}} E_x\big|_{i,j,k}^{n+\frac{1}{2}} \tag{1.4.3d}$$

v.

$$\frac{E_y\big|_{i,j,k}^{n+1} - E_y\big|_{i,j,k}^{n}}{\Delta t} = \frac{1}{\varepsilon_y\big|_{i,j,k}}\left[\frac{H_x\big|_{i,j,k}^{n+\frac{1}{2}} - H_x\big|_{i,j,k-1}^{n+\frac{1}{2}}}{\Delta z} - \frac{H_z\big|_{i,j,k}^{n+\frac{1}{2}} - H_z\big|_{i-1,j,k}^{n+\frac{1}{2}}}{\Delta x}\right] - \frac{1}{\varepsilon_y\big|_{i,j,k}} J_{source_y}\Big|_{i,j,k}^{n+\frac{1}{2}} - \frac{\sigma_y\big|_{i,j,k}}{\varepsilon_y\big|_{i,j,k}} E_y\big|_{i,j,k}^{n+\frac{1}{2}} \tag{1.4.3e}$$

vi.

$$\frac{E_z\big|_{i,j,k}^{n+1} - E_z\big|_{i,j,k}^{n}}{\Delta t} = \frac{1}{\varepsilon_z\big|_{i,j,k}}\left[\frac{H_y\big|_{i,j,k}^{n+\frac{1}{2}} - H_y\big|_{i-1,j,k}^{n+\frac{1}{2}}}{\Delta x} - \frac{H_x\big|_{i,j,k}^{n+\frac{1}{2}} - H_x\big|_{i,j-1,k}^{n+\frac{1}{2}}}{\Delta y}\right] - \frac{1}{\varepsilon_z\big|_{i,j,k}} J_{source_z}\Big|_{i,j,k}^{n+\frac{1}{2}} - \frac{\sigma_z\big|_{i,j,k}}{\varepsilon_z\big|_{i,j,k}} E_z\big|_{i,j,k}^{n+\frac{1}{2}} \tag{1.4.3f}$$

Where:

n represents time iteration and i,j,k represents index of Yee cell (lattice) position along axis –x,-y, and z of spatial domain respectively.

Figure 1.1.1 shows the top and bottom of the structure is the PEC where is refer as the electric field in polarization axis-x. For the magnetic field is located in the right and left of the structure as the axis- y for perfect magnetic conductor (PMC). Convolution perfect matched layer on the structure located at the front and back act as the boundary condition.

-*Structure modeling boundary layer*

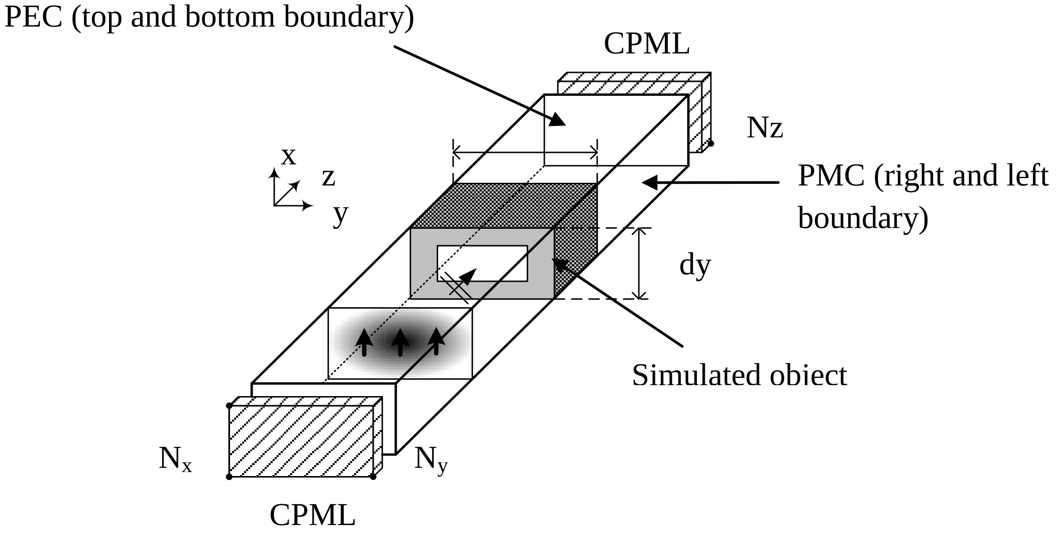

Figure 1.1.1: Structure modeling boundary condition

Where the PEC is Perfect Electric Conductor and PMC is Perfect Magnetic Conductor. Nx,Ny and Nz represent the finite value of the structure that unknown.

1. To write 3D FDTD software in MATLAB program using the discretize Maxwell's equation consist of the Faraday's Law and Ampere's Law.
2. Analyze output of the program where is define scattering parameter output for structure in MATLAB software. The output analyzed of the reflection coefficient (S_{11}) is obtained by the simulation in FDTD program.
3. The scattering parameter result will compare with the CST software to compare the reflection coefficient (S_{11}) on the application of the Frequency Selective Surfaces (FSS).