# DEVELOPMENT OF 3D FINITE-DIFFERENCE TIME-DOMAIN (FDTD) ALGORITHM IN MATLAB FOR DIELECTRIC RESONATOR ANTENNA RADIATION STUDY

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# ABSTRACT

Ever since the development of computer in analyzing electromagnetic problem, it makes antenna study easier to accomplish. Today, the theoretical analysis in solving electromagnetic problems leads to the development of many different computational algorithms that also include FDTD. The Finite-Difference Time-Domain (FDTD) technique implements finite-difference approximations of Maxwell's equations in a discretized volume that permit accurate computation for the radiated field of Dielectric Resonator Antenna (DRA). In this thesis a brief introduction of the procedure for applying FDTD method to time-domain Maxwell equations is shown especially in the Yee’s algorithm that apply finite central approximation to obtain the equations. The starting point for the FDTD to simulate a structure begins with the constant value of permittivity, permeability, electric conductivity and magnetic conductivity of the material which produce electric and magnetic field on each Yee cells. This can be done by incorporating many important techniques in FDTD to develop a precise simulation of the DRA parameter in 3D such as Absorbing Boundary Conditions (ABCs) and Near-Field to Far-Field (NFFF) transforms. The result will illustrate in form of scattering parameter and radiation pattern in plane cut that consists of xy-plane, xz-plane and yz-plane. Then, the FDTD data generated from 3D models are compared with commercial software like CST and HFSS to verify the output data. Normally, prices of electromagnetic software packages especially antenna is quite expensive and license per year basis. Finally, this project also relevant and parallels with the latest technology in antenna design.

# ABSTRAK

Sejak pembangunan komputer dalam menganalisis masalah elektromagnet membuat kajian antena lebih mudah untuk dicapai. Hari ini, pengunaan teori dalam menganalisa sesuatu masalah elektromagnet telah membawa kepada pembangunan pelbagai pengiraan algoritma yang juga termasuk FDTD. "Finite-Difference Time-Domain" (FDTD) menggunakan penghampiran perbezaan-terhingga dalam persamaan Maxwell dalam pembahagian isipadu menghasilkan pengiraan yang lebih tepat dalam menentukan parameter Antena Dielektrik Pengetar (DRA). Dalam thesis ini pengenalan ringkas tentang prosedur penggunaan FDTD kaedah domain masa dalam persamaan Maxwell ditunjukkan terutamanya dalam algoritma yang juga menggunakan penghampiran pusat terhingga untuk mendapatkan persamaan Yee. Titik permulaan untuk FDTD membuat simulasi pada struktur bermula dengan nilai malar ketelusan, ketelapan, kekonduksian elektrik dan kekonduksian magnet bahan itu yang menghasilkan medan elektrik dan medan magnet pada setiap sel-sel Yee. Ini boleh dilakukan dengan menggabungkan pelbagai teknik penting dalam FDTD untuk membangunkan simulasi yang lebih tepat untuk parameter DRA dalam 3D seperti menyerap keadaan sempadan (ABC) dan pengubah "Near Field to Far Field (NFFF). Hasilnya akan ditunjukkan dalam bentuk parameter berselerak dan bentuk radiasi dalam bentuk keratan rentas yang terdiri daripada planar-xy, planar-xz dan planar-yz. Kemudian data FDTD dijana daripada model 3D akan berbanding dengan perisian komersial seperti CST dan HFSS untuk mengesahkan data keluaran. Kebiasaannya, harga pakej perisian elektromagnetik terutamanya antena adalah sangat mahalnya dan asas kepada tahun lesen. Akhir sekali, projek ini juga relevan dan selari dengan teknologi terkini dalam rekabentuk antena.

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| | | |
|---|---|---|
| FDTD | - | Finite-Different Time Domain |
| DRA | - | Dielectric Resonator Antenna |
| RDRA | - | Rectangular Dielectric Resonator Antenna |
| IEEE | - | Institute of Electrical and Electronics Engineers |
| 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 |
| FFT | - | Fast Fourier Transform |
| CST | - | Computer Simulation Technology |
| HSFF | - | High Frequency Structural Simulator |
| GUI | - | Graphical User Interface |

# LIST OF APPENDICES

# CHAPTER I

# INTRODUCTION

In this chapter, the overall requirement that needed in the implementing on this project will be explained briefly. It will include why and how this project will be done.

## 1.1. Project Overview

In this project, the fundamental and application of Finite-Difference Time-Domain (FDTD) method will be used to solve Maxwell’s equations of Cartesian coordinate to simulate dielectric resonator antenna. These equations are being used to develop Finite Difference Time Domain (FDTD) algorithm for modeling full wave electromagnetic structure. The benefits of this algorithm, it can be used as a fitness function of antenna optimization. The advantages of FDTD are simple to implement numerically and time based simulation method as a result better for wideband frequency response.

In finding the radiation for the region that far away from the antenna the near-field to far field (NFFF) transformation technique and also Fast Fourier Transform (FFT) will be implemented. By changing several parameters of the antenna radiation pattern can be visualized and studied. With the verify antenna radiation pattern of FDTD software it will be compared to commercial software either CST or HFSS.

## 1.2. Objective

The objective of this project consists of:

a) To implement the 3D Finite-Different Time-Domain method in modeling the Dielectric Resonator Antenna

b) To develop a program in modeling the Dielectric Resonator Antenna

c) To study the radiation pattern of Dielectric Resonator Antenna

The main objective of this project is to develop a program that capable of analyzing the radiation pattern of Dielectric Resonator Antenna (DRA) by implementing 3D Finite-Difference Time-Domain (FDTD) algorithm. This program will be able to analyze the approximate same result as the real analysis. At the end of the simulation, the parameter in analyzing the radiation pattern can be calculated including their scattering and directivity of the antenna.

## 1.3. Problem Statement

Now days there are several powerful techniques in evaluating, analyze and designing the electromagnetic devices or structures with the existence of computer as compared from previous analysis that mostly perform in the experimental method. There are drawbacks in using experimental method including higher cost for the entire process to be analyzed, the data from the measurement may be invaluable, and it also consumed a lot of time and manpower to be done. The implementation of Computational Electromagnetic (CEM) method for the analysis will overcome the disadvantages of experimental method by reducing the test cost and it also versatile and accurate [1]. The CEM method consists of integral and differential equation in time domain. The example integral equation is a Method of Moment (MoM) and for differential is Finite-Difference Time-Domain (FDTD). In MoM, the problem solve in frequency domain for electromagnetic boundary or a volume integral equation that include the matrix equation that may generate a complex equation [2]. In FDTD, its very straightforward since the problem solvers in time domain and easier to formulate and adapt in computer simulation. It also provides more physical insight to the characteristic problem.

Currently, FDTD has gained tremendous popularity as a tool in solving Maxwell’s Equation. The advantages in using FDTD method compared to other methods are it based on simple formulations that do not require complex asymptotic or Green's functions [2]. It can provide frequency-domain responses over a wide band using the Fourier transform [1]. It can easily handle composite geometries consisting of different types of materials including dielectric, magnetic, frequency-dependent, nonlinear, and anisotropic materials. The FDTD technique is easy to implement using parallel computation algorithms. This method is suitable in the study of radiation and scattering problems.

## 1.4. Scope of Works

The scope of this project includes the understanding of Finite-Difference Time-Domain (FDTD) equation for 3D modeling. There are six scalar equations of Maxwell's curl equation has been used in developing 3D modeling that represented in a Cartesian coordinate system that consists of x, y, and z component. All these equations came from the basic equation of ampere's and Faraday's law before discretization. In mathematics, discretization concerns process transfer of continuous models and equations into discrete counterparts. This process is usually carried out as a first step towards making those suitable for numerical assessment and implementation on computers.

Before beginning to write the program, the characteristics of Dielectric Resonator Antenna (DRA) need to studied so what the output might show. The DRA constructed from a dielectric medium with a high dielectric constant place on a ground plate plane that act as a conductive element and heat sink for the substrate [10]. The desired resonant mode can be archived by place the dielectric substrate carefully on the ground plane. The implementation of the dielectric on the antenna may overcome the limitation of metallic antenna that become lossy at higher frequencies. The radiation patterns of the DRA have many forms depend on the shape and feeding technique of the antenna.

In writing the program, the understanding of MATLAB programming required because the command might be different from other programming language. But MATLAB programming is very easy to use since the program is very direct and does not require any complex command.

# CHAPTER II

# LITERATURE REVIEW ON FDTD

This chapter will describe the fundamental concept and theory of the FDTD methods in solving Maxwell’s curl equation in time domain. The equations cover the in term of electric and magnetic field. The ABCs and NFFF transformations also will be explained. Finally, the overall processes of the FDTD are summarized.

## 2.1. Finite-Difference Time-Domain (FDTD)

The initial point of beginning of the FDTD algorithm is discretized the Maxwell’s time-domain equations. The differential time-domain Maxwell’s equations are needed to specify the field behavior over time.

### 2.1.1. The Finite-Difference Time-Domain basic equations

Only two basic equation use in this project that consist of Ampere’s and Faraday’s law and after adding the Maxwell’s equation, it becomes Ampere-Maxwell’s and Faraday-Maxwell’s law.

Ampere-Maxwell’s law

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H} - \vec{J} \tag{2.1.1a}$$

Faraday-Maxwell’s law

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \vec{E} - \vec{M} \tag{2.1.1b}$$

Where the following symbols are:-

H = magnetic field (A/m)
D = electric flux density (C/m$^2$)
J = electric current density (A/m$^2$)
E = electric field (V/m)
B = magnetic flux density (V/m$^2$)
M= magnetic current density (V/m$^2$)

### 2.1.2. Yee Cell’s

In FDTD technique, the problem space divided into small grid that called Yee cells that form a cube like segment. This technique that employs the second-order central difference formula that represented in discrete form of time and space. By applying this technique, the electric and magnetic fields can be solved in a leapfrog manner. It means that each of electric and magnetic field dependent on the neighbor field on each of time steps.

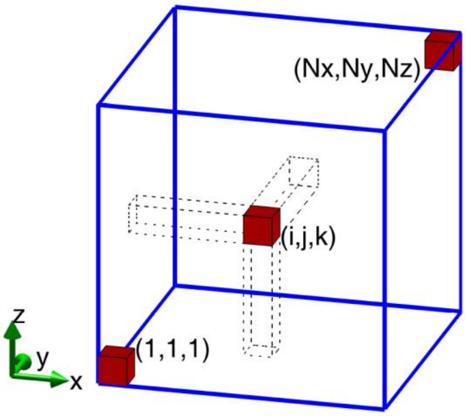

Figure 2.1: 3D FDTD Computational Space Composed of Yee's Cell [1]

From the figure 2.1, it shows how the cell grid composed with the $N_x$, $N_y$, and $N_z$ represent the maximum number of cells in the problem space. In designing the object geometry, the space resolution of the object set by the size of the unit cell and the material parameters including permittivity, permeability, electric and magnetic conductivity must be set to distinguish between object and free space.

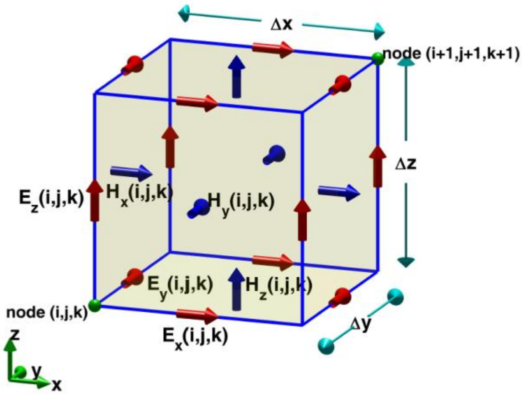

Figure 2.2: Arrangement of Field Component on Yee's Cell [1]

In the Yee cell scheme, the electric fields are located along the edges of the electrical elements while the magnetic fields are located at the center of the sample surface and the electrical elements are oriented normal to these surface that are consistent with the duality property of the electric and magnetic fields of Maxwell's equation.

After deriving the curl equation from 1.1a and 1.1b, we can get the 3D FDTD scalar equation in x, y and z component.

$$\frac{\partial H_x}{\partial t} = \frac{1}{\mu_x}\left[\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}\right] - \frac{1}{\mu_x}\left[M_{source_z} + \sigma_x^m H_x\right] \tag{2.1.2a}$$

$$\frac{\partial H_y}{\partial t} = \frac{1}{\mu_y}\left[\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}\right] - \frac{1}{\mu_y}\left[M_{source_y} + \sigma_y^m H_y\right] \tag{2.1.2b}$$

$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu_z}\left[\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y}\right] - \frac{1}{\mu_z}\left[M_{source_x} + \sigma_z^m H_x\right] \tag{2.1.2c}$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon_x}\left[\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z}\right] - \frac{1}{\varepsilon_x}\left[J_{source_z} + \sigma_x^e E_x\right] \tag{2.1.2d}$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon_y}\left[\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x}\right] - \frac{1}{\varepsilon_y}\left[J_{source_y} + \sigma_y^e E_y\right] \tag{2.1.2e}$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon_z}\left[\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right] - \frac{1}{\varepsilon_z}\left[J_{source_x} + \sigma_z^e E_z\right] \tag{2.1.2f}$$

Where the $\varepsilon_x, \varepsilon_y$ and $\varepsilon_z$ represent the permittivity of the material for each component that associated with the electric field component. Then the $\mu_x, \mu_y$ and $\mu_z$ represent the permeability of the material for each component that associated with the magnetic field component. The symbol of $\sigma^e$ and $\sigma^m$ will represent the conductivity for the electric and magnetic field respectively.