DEVELOPMENT OF FINITE-DIFFERENCE TIME-DOMAIN (FDTD)/ PERIODIC BOUNDARY CONDITION (PBC) SOFTWARE FOR MODELING MICROWAVE ABSORBER MATERIAL AT KU BAND FREQUENCY

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Specially dedicated to my parent, brothers, sisters and friends for the endless support, encouragement and understandings throughout this period.

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ABSTRACT

This thesis is writing about the project which is developing Finite Difference Time Domain (FDTD) / Periodic Boundary Condition (PBC) software. The developed software is for modeling microwave absorber material. This project implements the computational electromagnetic method in solving the electromagnetic problem via analysis. Besides that, the developed software is based on FDTD algorithm that well arranged in the Fortran software. Besides the FDTD concept, there are many other concepts that used in this project to properly simulate the microwave absorber material which are combined altogether to create software that able to model Radar Absorber Material (RAM) structure and doing analysis of that structure. The objective and scope of this project will be explained later in this thesis which state what is this project aim and what is the work scope which limits the project workload. All of the concepts involved in this project is written in the literature review part which gives explanation for all of the concepts and equations involved in developing the software. Then when the software is able to execute perfectly, some analysis were carried out. The analysis was done to two structures which are Frequency Selective Surface (FSS) and Radar Absorber Material (RAM) structure. For the FSS structure, the result obtained is the magnitude of transmission coefficient while for RAM structure, the result obtained is magnitude of reflection coefficient. The result obtained is validated by comparing it with the result from commercial software which is CST. Then, it was discussed related to the objective of this project. Lastly the project was concluded by relating the result discussed with respect to the objective stated.

ABSTRAK

Tesis ini adalah tentang projek pembinaan peisian Finite Difference Time Domain (FDTD) / Periodic Boundary Condition (PBC). Perisian yang dibina ini adalah untuk memodelkan bahan penyerap gelombang mikro. Projek ini menerapkan pengiraan elekromagnetik computer dalam menyelesaikan masalah elektromagnetik melalui analisa. Di samping itu, perisian yang dibina ini adalah berdasarkan algoritma FDTD yang disusun secara rapi di dalam perisian Fortran. Di samping konsep FDTD, terdapat banyak lagi konsep lain yang digunakan di dalam projek ini untuk mensimulasikan bahan penyerap gelombang mikro tersebut yang digabungkan semua sekali untuk mencipta satu perisian yang boleh memodel struktur Bahan Penyerap Radar (RAM) dan sekaligus melakukan analisis ke atas struktur tersebut. Objektif dan skop untuk projek ini akan diterangkan kemudian di dalam tesis ini dimana ia menyatakan apakah matlamat projek ini dan apakah skop pekerjaan yang memberikan had untuk beban kerja dalam projek ini. Semua konsep yang terlibat di dalam projek ini ditulis di dalam bahagian kajian literatur yang memberi penjelasan untuk semua konsep dan persamaan yang terlibat dalam pembinaan perisian. Kemudian apabila perisian boleh berjalan dengan sempurna, beberapa analisis telah dijalankan. Analisis tersebut dilakukan terhadap dua struktur iaitu struktur Permukaan Frekuensi Terpilih (FSS) dan sturktur Bahan Penyerap Radar (RAM). Untuk struktur FSS, keputusan yang diperoleh adalah magnitud pekali penghantaran manakala bagi struktur RAM, keputusan yang diperoleh adalah magnitud pekali pantulan. Keputusan yang diperoleh telah disahkan dengan membandingkan ia dengan keputusan dari perisian komersial iaitu CST. Kemudian, ia telah dibincangkan dengan mengaitkannya dengan objektif projek ini. Akhir sekali, projek ini telah disimpulkan dengan mengaitkan keputusan yang dibincangkan dengan objektif yang dinyatakan.

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LIST OF ABBREVIATIONS

FDTD	-	Finite-Different Time Domain
FSS	-	Frequency Selective Surface
RAM	-	Radar Absorbing Material
PEC	-	Perfect Electric Conductor
2D	-	Two Dimension
3D	-	Three Dimension
ABCs	-	Absorbing Boundary Conditions
PML	-	Perfectly Matched Layer
CPML	-	Convolutional Perfectly Matched Layer
PBC	-	Perfect Boundary Condition
FFT	-	Fast Fourier Transform
CST	-	Computer Simulation Technology
CEM	-	Computational Electromagnetic
GA	-	Genetic Algorithm
MOM	-	Method of Moment
GRM	-	Geometry Refinement Method
KU	-	K-under

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CHAPTER I

INTRODUCTION

In this chapter, the overall requirement that needed in implementing 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 radar absorbing material. These equations are being used to develop Finite Difference Time Domain (FDTD) algorithm for modeling full wave electromagnetic structure. The advantages of FDTD are simple to implement numerically and time based simulation method as a result better for wideband frequency response.

Radar absorbing material is used as the absorbing material. With implementation of Frequency Selective Surface on the radar absorbing material, the absorption characteristic is improved. The scattering parameter of the reflection coefficient S_{11} is obtained by implementing method of Fast Fourier Transform (FFT) to the result given by the program. Finally the reflection coefficient is analyzed by comparing it with the result given by commercial software for example CST software.

1.2 Objective

The objective of this project is:

a) To develop 3D Finite-Different Time-Domain (FDTD)/Periodic Boundary Condition (PBC) software for modeling the Radar Absorbing Material using Fortran language in KU band frequency.

Develop FDTD/PBC program is the main objective for this project. The main concern of the program is for modeling the Radar Absorbing Material. The FDTD program is to develop 3 dimensional structures and it based on Maxwell's equation as the basic equation. Fortran software is used to model the Radar Absorbing Material. Therefore Fortran algorithm need to be studied to relate the FDTD Maxwell's equation with the program that want to be developed. At the end of the simulation, parameter in analyzing the radar absorbing material which is the reflection coefficient can be calculated.

KU Band is one portion of electromagnetic spectrum in the microwave range of frequency. The value of frequency is from 12 until 18 GHz in radar application according to the formal definition of radar frequency band. This KU symbol is refers to "K-under" which is originally from German language "Kurz-unter".

1.3 Problem Statement

Experiment is the most common method used to perform analysis but it had introduced many disadvantages. This method is not the best option to be chosen since there is another option in this era millennium where people are more prefer to use the computational method rather than experiment. The disadvantage of experiment method is an entire process requires high cost. Besides that, the data obtained might be invaluable and consume a lot of time and man power to be done.

Today, with the existence of computer in doing works, there are some better technique and method that can be used to perform evaluation, analyzing and designing analysis. For the analysis that involves too many numerical calculations to obtain result such as in designing the electromagnetic device or structure, computer can be powerful tools since the design process is hard to be done manually [3].

The usage of computer in doing analysis about electromagnetic problem can be called as Computational Electromagnetic (CEM) method. This method will overcome the disadvantage of experimental method by reducing the cost in solving the problem. Besides, this method is versatile and accurate. The CEM method consists of integral and differential equation in time domain. The example integral equation is Method of Moment (MoM) and for differential is Finite-Difference Time-Domain (FDTD) [3].

The FDTD method has high popularity as a tool in solving Maxwell's equations which related to electromagnetic problem [2]. Since FDTD is important for people to make analysis, some of the people develop software which has the function to solve FDTD problem [1]. The developed software is then commercialized where the developer may gain profit by selling the software. Although the software is commercialized to be used by public, there is still some lack of functions in that software.

In term of solving Radar Absorbing Material (RAM) problem, the commercial software has limitation in function of creating the shape of Frequency Selective Surface (FSS). In the commercial software, random shape cannot be made for the FSS. User only can set the shape according to the options available in the software and cannot set to the shape as what they wanted. Since complex shape cannot be set, the simulation cannot be carried out and makes the user fail to fulfill their task.

Besides that, the other disadvantage of using commercial software is the result cannot be viewed when the software not installed in a computer. So when there is no software, simulation cannot be carried out and the result cannot be obtained. This will give huge impact to people that always travel to present their project to other people.

These kinds of people need to carry their heavy laptop wherever they go in order to show the result of their project. Therefore, new software needs to be developed which implements function of viewing the result without requires any software.

Normally commercial software is sold by developer with a very high price. For normal people, it is too expensive and some of them cannot effort to buy it. People will find easier way to use the commercial software which is by using pirate license that obtained from internet. This is unethical action whereas if they get caught by the developer, they might be sued by the developer.

Some of the commercial software can be downloaded from the internet with free trial version. This trial version has too many limitations and only most basic function is allowed to be used. Besides, users only had given a certain period of time to use the software which is too short. After the trial period end, the user is unable to use the software anymore and this will get them in trouble.

For students, it might be impossible for them to buy the license of the commercial software. Some of them really need the software to do their assignment and project. Therefore they need to go to laboratory that provides licensed commercial software for them to use in order to finish up their project. If the project needs very long period to be solved, this will be a problem to them as they have to go to the laboratory at every time they want to do the project. Besides they cannot do it after office hour since the laboratory only gives service during office hour.

1.4 Scope

The scope of work for this project is mainly about the Finite-Difference Time-Domain (FDTD) method for 3D modeling. FDTD method is one of the computational electromagnetic (CEM) methods besides Method of Moment (MOM), Finite Element Method (FEM) and many more. This project only focusing on the FDTD method so the other CEM method is not covered. Finite-Difference Time- Domain (FDTD) method carries numerical calculation in time domain.

This method is also related to the time domain Maxwell's equations that can be divided into two which are Faraday Maxwell Law and Ampere Maxwell Law. Therefore this report will not cover numerical calculation in frequency domain but only focusing in time domain calculation since all equation and concept used are in time domain.

There are six scalar equations of Maxwell's curl equation which has been used in developing 3D modeling that represented in a Cartesian coordinate system which consists of x, y, and z component. All these equations came from the basic equation of Ampere Maxwell Law and Faraday Maxwell Law before discretization. In mathematics, discretization concerns process transfer of continuous models and equations into discrete counterparts. For the FDTD part, this report only focusing on these two equations and these equations are then derived to obtain the discretized equations [1].

Besides FDTD, the other major part in this project is Radar Absorbing Material (RAM) and Frequency Selective Surface (FSS). This project is only focusing to model the Radar Absorbing Material. The FSS is a layer that implemented on the RAM which acts like a filter and improving absorption characteristic of RAM. Before begins writing the program, the characteristics of radar absorbing material need to be studied so that any output shown is expected.

The Radar Absorbing Material is a lossy material and any signal that comes into it will attenuate at rate depends on the material characteristic. The material does not fully attenuate the wave but small amount of wave will pass through the material. Then the reflection coefficient of the wave is calculated in order to know how much is the wave absorbed by the radar absorbing material.

In modeling the Radar Absorbing Material, Fortran software is used. This means that this project will not use other software to model the RAM. Therefore, the understanding of Fortran language is required because the command might be different from other programming language. But the language is still easy to understand since the command is very direct and does not require any complex coding.

CHAPTER II

LITERATURE REVIEW

This chapter will describe the fundamental concept and theory of the FDTD methods in solving Maxwell's curl equation in time domain. The derivations of the equations are also shown for the electric and magnetic field. The Absorbing Boundary Condition (ABC) and Frequency Selective Surface (FSS) for Radar Absorbing Material (RAM) also will be explained. Finally, the Periodic Boundary Condition (PBC) and Perfect Electric Conductor (PEC) also summarized related to this project.

2.1 Finite-Difference Time-Domain (FDTD)

Finite Difference Time Domain (FDTD) is one of the methods for computational electromagnetic (CEM) applications. FDTD is a tool for solving Maxwell's equations and the calculations made are in time domain. Therefore FDTD is very suitable to solve the differential time domain Maxwell's equation which used in this project. FDTD is also related to numerical analysis that implements numerical calculation method in solving problems.

There are some advantages in using FDTD which the first is if based on simple formulation that do not require complex asymptotic or Green's function. Second advantage is FDTD can solve problem in time domain but the frequency domain response still can be obtained in wide range by using Fast Fourier Transform method. Third is FDTD can easily handle composite geometries which consist different types of materials which such as dielectric, magnetic, nonlinear and anisotropic material [1], [2].

2.2 The Finite-Difference Time-Domain (FDTD) Basic Equation

To develop FDTD algorithm, first we must understand its equation. FDTD is using Maxwell's time-domain equation as the starting point. There are two basic equations that we use in here which are Ampere Maxwell's equation and Faraday Maxwell's equation [1].

1) Ampere Maxwell's Law

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H} - \vec{J} \tag{2.1}$$

2) Faraday Maxwell's Law

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \vec{E} - \vec{M} \tag{2.2}$$

Where the symbols are defined as:

D = electric flux density (C/m^2)

H = magnetic field (A/m)

J = electric current density (A/m^2)

B = magnetic field density (V/m^2)

E = electric field (V/m)

M = magnetic current density (V/m^2)

2.2.1 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 is 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 [8]. It means that each of electric and magnetic field dependent on the neighbor field on each of time steps.

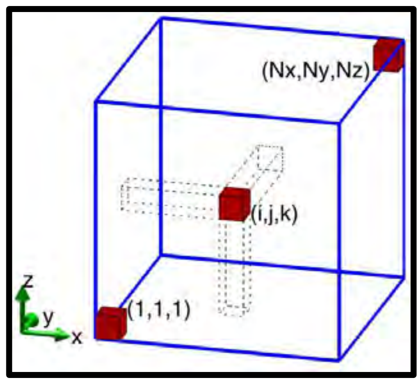

Figure 2.1: 3D FDTD Computational Space Composed of Yee's Cell [1]

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.