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

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ABSTRACT

This report is about developing Finite Difference Time Domain (FDTD) and Periodic Boundary Condition (PBC) software to model electromagnetic structure. There are two main structures that analyzed in this project which are Frequency Selective Surface (FSS) and Radar Absorber Material (RAM). This project implements the computational electromagnetic (CEM) method in doing the analysis. The main software used is Fortran besides the other supporting software like CST. This report consists of five chapters which are chapter one is introduction, chapter two is literature review, chapter three is methodology, chapter four is result, analysis and discussion and last chapter which is chapter five is conclusion and recommendation. Introduction in chapter one write about the explanation of why this project is carried out including the problem statement and objective of this project. In chapter two, all of the concept that involved in this project is reviewed which comprise the explanation of FDTD, PBC, FSS, RAM and many more. Chapter three shows the methodology on how this project is carried out. The method of gather information is explained and the flow charts of certain process are shown. Then in chapter four, result of this project is shown and it consists of FSS and RAM analysis. The validation is also done in this chapter where the result obtained from the developed software is compared with the commercial software's result. Lastly in chapter five, this project is concluded by relating the obtained result with the objective of this project. Some recommendations were given for the future improvement that can be made to this project especially to the developed software.

ABSTRAK

Laporan ini adalah mengenai pembinaan perisian Finite Difference Time Domain (FDTD) dan Periodic Boundary Condition (PBC) untuk memodel struktur elektromegnetik. Terdapat dua struktur utama yang dianalisa dalam projek ini iaitu Permukaan Frekuensi Terpilih (FSS) dan Bahan Penyerap Radar (RAM). Projek ini menggunakan cara pengiraan elekromagnetik komputer (CEM) dalam melakukan analisis. Perisian utama yang digunakan ialah Fortran disamping perisian lain yang mendukungnya seperti perisian CST. Laporan ini merangkumi lima bab iaitu bab satu ialah pengenalan, bab dua ialah kajian literatur, bab tiga ialah metodologi, bab empat ialah keputusan, analisis dan perbincangan, dan bab terakhir iaitu bab lima ialah kesimpulan dan cadangan. Pengenalan dalam bab satu menceritakan tentang penjelasan mengenai mengapa prijek ini dilakukan termasuklah penyataan masalah and objektif untuk projek ini. Dalam bab dua, semua konsep yang terlibat dalam projek ini telah ditunjukkan dimana ia mengandungi penerangan tentang FDTD, PBC, FSS, RAM dan banyak lagi. Bab tiga menunjukkan metodologi tentang bagaimana projek ini dilakukan. Cara-cara bagaimana maklumat dikumpulkan telah diterangkan dan carta aliran beberapa proses telah ditunjukkan. Selepas itu, dalam bab empat, keputusan dari projek ini telah ditunjukkan dan ia mengandungi analisis tentang FSS dan RAM. Proses pengesahan juga telah dilakukan dimana keputusan yang diperoleh daripada perisian yang dibina telah dibandingkan dengan keputusan dari perisian komersial. Akhir sekali dalam bab lima, projek ini telah disimpulkan dengan mengaitkan keputusan ysng diperoleh dengan objektif projek ini. Beberapa cadangan telah diberikan untuk penambahbaikan pada masa hadapan yang boleh dilakukan pada projek ini terutamanya pada perisian yang dibina.

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LIST OF ABBREVIATIONS

FDTD	-	Finite Difference Time Domain
PBC	-	Periodic Boundary Condition
FSS	-	Frequency Selective Surface
RAM	-	Radar Absorber Material
PEC	-	Perfect Electrical Conductor
ABC	-	Absorbing Boundary Condition
PML	-	Perfectly Matched Layer
CPML	-	Convolutional Perfectly Matched Layer
CST	-	Computer Simulation Technology
GRM	-	Geometry Refinement Method
FFT	-	Fast Fourier Transform
CEM	-	Computational Electromagnetic
GA	-	Genetic Algorithm
IEEE	-	Institute of Electrical and Electronics Engineers

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CHAPTER I

INTRODUCTION

This chapter will give brief explanation about this project. The overview in this chapter will explain overall concept of the project. Then objective is stated to show what is the project aim related to the problem statement explained. Scope part will explain what is covered and uncovered topic in this project.

1.1 Project Overview

This project will introduce about the Finite Difference Time Domain (FDTD) method that used to solve Maxwell's equation. The fundamental and application of the FDTD carries the numerical calculation of the Maxwell's equation in Cartesian coordinate system. These equations are used to develop Finite Difference Time Domain (FDTD) algorithm for modeling Radar Absorbing Material (RAM). Before implementation of Maxwell's equation into Finite Difference Time Domain (FDTD) algorithm, the equations were discretized to make sure that it is compatible to be use for modeling a full wave electromagnetic structure.

Finite Difference Time Domain (FDTD) method can be used to solve numerous types of problem for many types of applications including the scattering parameter problem. The FDTD which implements Yee Cell concept can easily understand and suitable method to be used by beginners in modeling projects. Besides FDTD, the Periodic Boundary Condition (PBC) concept is applied into this project to modeling the Radar Absorbing Material.

Using the combination of FDTD and PBC, only one unit cell need to be model and this can save more memory space of the computer compare to simulating the whole project that includes so many unit cells. Besides, the computational time taken will be more efficient when this method is done to simulate several periodic structures. The Frequency Selective Surface (FSS) that implemented on the Radar Absorbing Material (RAM) also can be considered as periodic structure since every unit cell has identical patch. The identical unit cell is repeating regularly for certain dimension length of the FSS structure.

Since the RAM structure implement the FSS concept for patch in front of it, the FSS will be analyzed first to see the effect of response when several parameters are changed. Then, with the guided of result obtained in FSS analysis, the RAM is designed and again the analysis is carried out to see how the value of parameters will affect the response of the structure to the electromagnetic wave that applied.

The FDTD iteration will obtain reflected wave values in voltage and ampere unit. Then the scattering parameter, which is the reflection coefficient of the wave is calculated after the FDTD iteration is finished with aid of Fast Fourier Transform (FFT). Scattering parameter (S1,1) is then plotted to see the response of the Radar Absorbing Material. The result obtained is finally compared to the result given by commercial software to see the accuracy.

1.2 Problem Statement

Previously in many years before, analysis are mostly performed by method of experiment which carries out in the laboratory. But this method has some drawbacks such as high cost for entire process to be analyzed, the measured data may be invaluable and it consumes a lot of time and manpower to be done. Therefore now day this experiment method is not the first choice anymore to do analysis on some topic.

In existence of computer, there are several powerful technique and method to be chosen from to perform evaluation, analyzing and designing analysis. This includes analysis that involves so many numerical calculations in determining the result such as designing the electromagnetic devices or structures. Since it is hard to do manually by experimental method, so modeling in computer software is the best method to be chosen.

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. This means that modeling in computer has many advantages. 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).

Currently, FDTD has gained tremendous popularity as a tool in solving Maxwell's Equation. Therefore some people developed software with function to solve Maxwell's equation problem. This software is then commercialized to be used by public and the developer may gain much profit on selling their commercial software. But, there is still some disadvantages exists in the commercial software.

The commercial software has limitation in its function. In term of solving Radar Absorbing Material (RAM) problem, the shape of the Frequency Selective Surface cannot be made randomly. User still can do whatever shape that they want. But, complex shape is very hard to be created which makes the designing process is very hard. Therefore it is harder when optimization process need to be carried out. A lot of time is consumed just to get the desired result of the project.

Besides that, the commercial software only can display result if the user has the software installed in their computer. If the software is not installed in the computer, simulation cannot be done and result cannot be viewed. This will introduce problem to a user that always present his project to people at many places. The user needs to bring his computer to anywhere he goes in order to simulate his project and obtain the result. Therefore, new software needs to be developed which implements function of viewing the result without requires any software to be installed.

The commercial software sold by developer is normally too expensive for normal people. Some people will find easy way by using pirate license to activate the software. But this is unethical action and the people that practice this might be sued by the developer. Some commercial software will give free trial period for the user to use and the software can be downloaded from the internet. But it only can be use in a limited time with limited usage of function inside the software. After the trial period end, user will be unable to use the software anymore.

For a student, it might be impossible for them to buy this expensive commercial software. Sometime they might have to go to laboratory which provides licensed commercial software for them to use. If their project takes very long time to finish, this can be a problem to them since they have to go to laboratory every time they want to do the project.

1.3 Objective

There is one objective for this project which is:

1. To develop 3D Finite Difference Time Domain (FDTD)/Periodic Boundary Condition (PBC) program for modeling Radar Absorbing Material using Fortran software in X-Band Frequency

The main objective in this project is to develop FDTD/PBC program. Therefore the concept of 3D Finite Difference Time Domain (FDTD) method which uses Maxwell's equation in the algorithm must be studied for understanding. Then using the FDTD, Radar Absorbing Material is modeled by developing program in Fortran software. The program is able to analyze the wave absorbed by the Radar Absorbing Material and the reflection coefficient is obtained at the end of the simulation. Lastly the scattering parameter of the reflection coefficient obtained is compared to the result given by commercial software.

X band is a part of the microwave frequency spectrum of the electromagnetic wave. For the radar engineering, the Institute of Electrical and Electronics Engineers (IEEE) has set the frequency range 8GHz to 12GHz. The name X band is given because frequency was a secret and used during world war 2. So in this project, the frequency of interest for the analysis of structure is in that given range.

1.4 Scope

There are some main theories and concepts that is taking under consideration in this project. Firstly the project is majorly applying 3D Finite Difference Time Domain (FDTD) concept to solve two types of Maxwell's equation which are Ampere Maxwell law and Faraday Maxwell law. The three dimension perspective is taken so that the modeling will produce real shape object which cannot be done in two dimensional view.

The two equations are derived in term of Cartesian coordinate until come to the discretization of the equation. By implementing Yee Cell's concept, the discretization will be easier since the position of electric field and magnetic field can be easily recognized on the Yee Cell. Electric field is on the edge of the Yee Cell and magnetic field is at the middle of the Yee Cell. The Yee Cell concept is the best to be use together with FDTD method.

Then the modeling is for Radar Absorbing Material (RAM), not for antenna or other application. Frequency Selective Surface is implemented together with the Radar Absorbing Material. Good understanding about these two structure is needed so that the theoretical knowledge will be easily applied into the coding to build the program. In modeling the Radar Absorbing Material, Fortran language in used instead of Matlab, C++ or C language. This is because Fortran language will produce execution file which is not available on other language. Besides, Fortran language is easier to be understand.

For the structure, the metal patch is made up only using the Perfect Electrical Conductor (PEC) metal. The other type of metal is not used in this project. Besides that, the type of dielectric used is perfect dielectric. The perfect dielectric only has dielectric constant value which need to be taken into consideration in carry out the computational. This value will be the main parameter that will effect the result obtained form the simulation. The conductivity of the dielectric is not covered in this project.

The other concept that is used in this project is the absorbing boundary condition. The type of boundary used is Convolution Perfect Matched Layer (CPML) instead of Perfect Matched Layer (PML). CPML has simpler equation and easier to use. Although the equation of CPML is based on PML, but this project only focusing on the CPML equation and does not cover any PML equation. Only the concept of PML is taken since it is same for CPML and the function also same, to absorb electromagnetic waves until it fully attenuate.

1.5 Project structure

The project is build up from many components. It can be illustrates as in the Figure 1.1 below

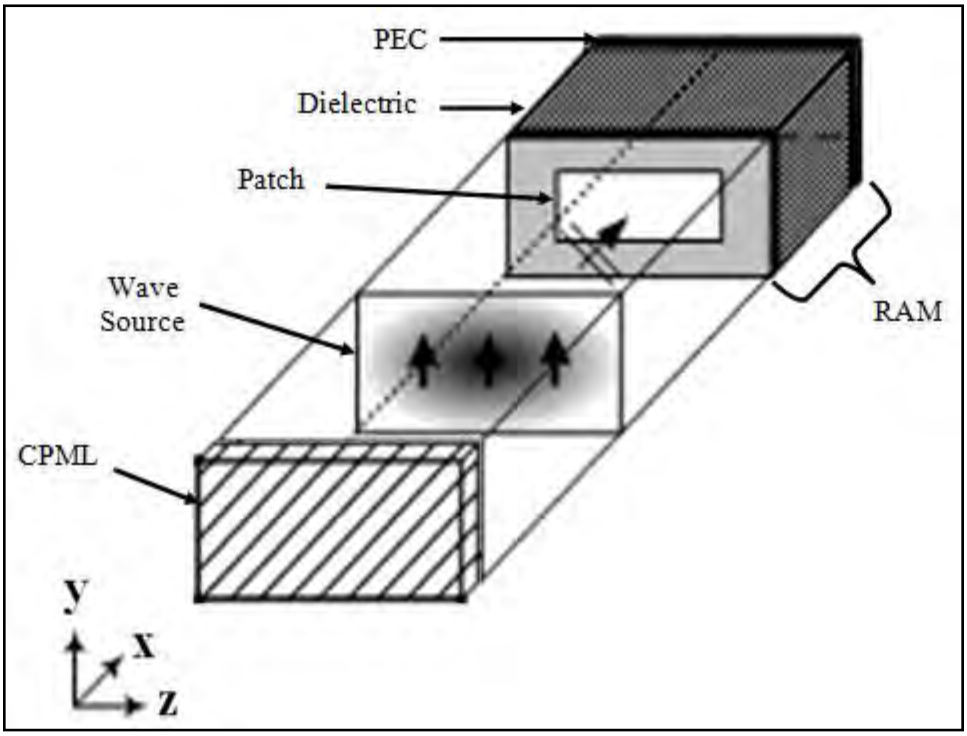

Figure 1.1: Project structure

The project is built up from many components. The main component is the RAM structure that wanted to be analyzed. The RAM structure is made up of patch, dielectric and PEC metal. Then, the wave source is used to supply electromagnetic wave to the structure. The wave source is Gaussian plane wave source. Then, convolution perfectly match layer (CPML) is placed at the end of the structure arrangement. All of these components has their own functions that will be explained later in the literature review chapter.

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, which called as discretization 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].

2.1.1 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]-[5].

Ampere Maxwell's Law

$$\frac{\partial \vec{D}}{\partial t} = \nabla \times \vec{H} - \vec{J} \qquad 2.1.1\text{ (a)}$$

Faraday Maxwell's Law

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \vec{E} - \vec{M} \qquad 2.1.1\text{ (b)}$$

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)

2.1.2 Yee Cell's Concept

In FDTD method, 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 [1]-[5].

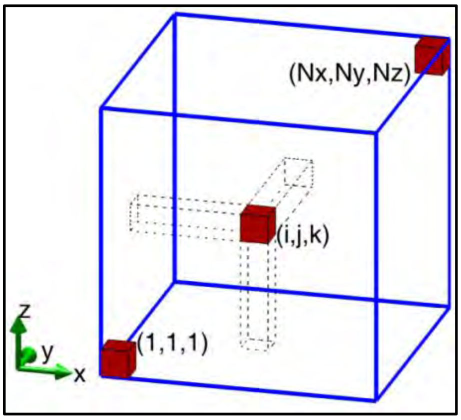

Figure 2.1: 3D FDTD Computational Space Composed of Yee's Cell

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.

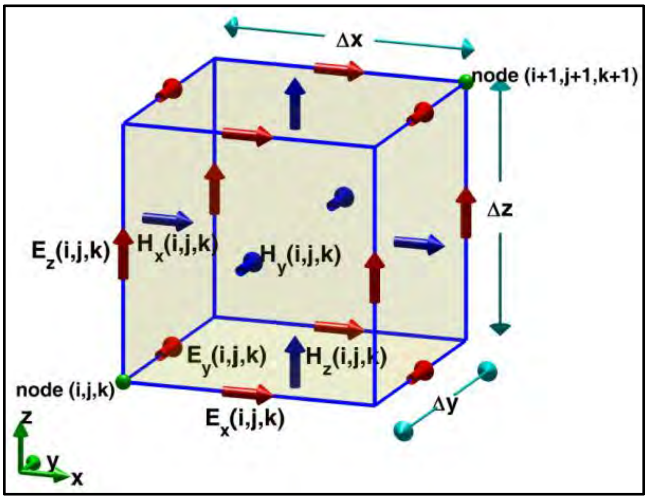

Figure 2.2: Arrangement of Field Component on Yee's Cell

In the Yee cell scheme, the electric fields are located along the edges of the Yee Cell cube while the magnetic fields are located at the center of the cube. The electrical elements are oriented normal to these surfaces that are consistent with the duality property of the electric and magnetic fields of Maxwell's equation. Each of the cube has three electric components and three magnetic component since it is seen in the three dimensional perspective.