Frequency Domain Analysis of Microwave Structures Using Computational Based Simulation

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Abstract

The advent of fast digital computers has facilitated the use of numerical methods in many disciplines. One area in which computer based simulation is very useful is in electromagnetics theory, microwave, and antenna engineering. In this work, two different electromagnetic simulators are used for the simulation of the same patch antenna. The simulators are HP-Momentum, based in method of moments in the frequency domain and Remcom-XFDTD, which is based in the finite difference time domain for electromagnetics. The antenna is designed for GPS applications at 1.575 GHz. This paper presents results of the simulation and discusses strengths and weaknesses between the two approaches.

1. Introduction

Electromagnetic problems can be solved using either analytical or non-analytical methods. Analytical solutions are obtained in closed form that is an explicit algebraic equation where the values of the parameters can be substituted. These expressions give exact solutions, however they are available only for simple or ideal configurations [2].

When analytical solutions are impractical because of the complexities of the structures, then we can use numerical methods to get the solutions of each specific problem. These become very attractive with the existence and development of fast digital computers.

In our case, two of the numerical methods that are used to analyze microwave structures, such as antennas and other microwave passive structures, are the Finite Difference Time Domain Method (FDTD) using Remcom-XFDTD, and the Method of Moments (MoM) used by HP-Momentum. In this paper we will present and compare the results of simulating the same patch antenna, designed for the frequency of 1.575 GHz, with both simulators.

Computer based simulation allows the researcher in electromagnetics to get reliable solutions for the behavior of complex structures in the frequency or time domain. The graphic user interface of each software also allows the easy visualization of the electromagnetic fields intensity around the structure.

2. Finite Difference Time Domain Methtod

The Finite Difference Time Domain Method (FDTD) analyzes the propagation of electromagnetic waves in a structure by solving Maxwell's equations as a function of time at discrete locations. First, the device under study is modeled by defining the geometry itself using 3-D cells, being each cell properly characterized with its electrical conductivity, permittivity, and loss tangent [4]. Each cell is referred as a Yee cell, in honor of Kane S. Yee, who originally developed the FDTD method in 1966. By stacking several Yee cells, an FDTD volume can be created. The structure under study is fabricated inside this volume.

Important considerations in the design of the geometry include that the ratio of the sides of the cell cannot exceed two, and that the biggest cell dimension must be at least 1/20 of the highest frequency of interest. If this conditions are not met the results are not reliable. Arbitrary structures of complex composition, like anisotropic and inhomogeneous bodies, can be easily modeled using this technique [3,4].

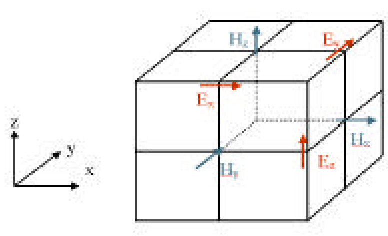

Figure 1. Yee Cell showing 3 electric field and 3 magnetic field components.

Once the computational domain or geometry is established, a source is specified. Usually it is set as a voltage source with an internal resistor of 50Ω. The transient waveform of the input signal can be defined by the user, being the Gaussian pulse one of the most widely used. Defining the excitation includes declaring the pulse width and also the number of time steps that the computational algorithm will be collecting data. By modifying the width of the pulse, the operational frequency range can be controlled.

Once the excitation is applied, the electrical and the magnetic field components are being calculated in each cell at every time step. This is possible applying Maxwell equations in differential form. The equations are first modified to a central-difference approximation for the spatial and time derivatives. The discretized equations are easily coded in software. It can be observed in Figure 1 that the normal magnetic field components are obtained at the cell's center, while the tangential electric field components are obtained at the cell's border. The equations are solved in a leap-frog manner; that is, the electric field is solved at a given instant in time, then the magnetic field are solved at the next instant in time, and the process is repeated for the specified number of time steps [3].

To obtain the frequency response of the structure an FFT is applied to the time domain data [4]. In the case of an antenna the voltage and current are collected for each time step at the input. This data is transformed using the FFT and the reflection coefficient is computed. The reflection coefficient will provide important information of the performance of the antenna at the desired frequency range.

In our current research, we intend to use the FDTD method to observe the input impedance characteristics for microstrip and coplanar waveguide antennas and their radiation pattern characteristics as well.

3. Method of Moments

HP-Momentum uses MoM to predict the performance of high-frequency circuit boards, antennas and ICs. The method of moments, which is a frequency domain technique, has been used for many years and is one of the most popular techniques used in the electromagnetic analysis of structures.

While the finite difference method is used in solving differential equations, the method of moments is commonly used in solving integral equations. The method consists of dividing the entire structure into wires or metal plates. Then each piece is subdivided to a number of segments that are small enough compared to the frequency's wavelength so that we can assume they have constant current. With the current then the electric and magnetic fields can be derived and important parameters such as impedance and reflections calculated.

The geometry of the structure can be input into Momentum either by entering a schematic with the components and its dimensions, and then a layout will be generated by the program, or by directly drawing the layout using polygons. The material is defined with parameters like substrate thickness and permittivity, metal conductance, and the operation frequency is specified. A mesh is defined for analysis and the cells should have a length of less than a twentieth of a wavelength ($\lambda/2$).

One of the strengths of this method is that it is very intuitive, because of its conceptual simplicity. Another advantage is that if only analyzing one frequency it provides the results very quickly. However, its counterpart weakness is that if a large range of frequencies is to be analyzed then the computations will take a long time. Another drawback is that if the chosen step size for the simulation is not small enough then important results, such as resonance, may be overlooked [3].

4. Comparison of Results

The patch antenna that was used for the purpose of comparing the two simulators is shown in Figure 2 with the following parameters:

$$W = 91.92mils$$
$$L_a = 3.444cm$$
$$W_a = 4.02cm$$
$$h = 100mils \quad (e_r 10.2)$$

The patch antenna was designed using the transmission line method [1], which can account for up to 20% error on the operating frequency.

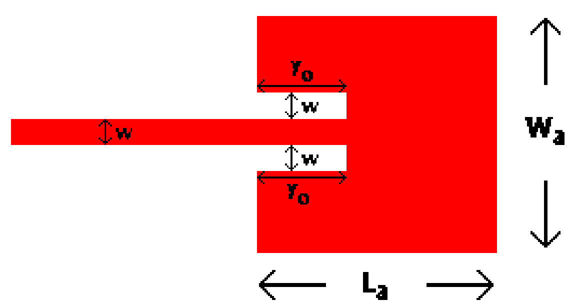

Figure 2. Layout of patch antenna.

Using HP-Momentum the layout of the antenna looks like Figure 3. Momentum is a 2½-dimension simulator, so we can work with layers that define the material, but do not see the figure's height.

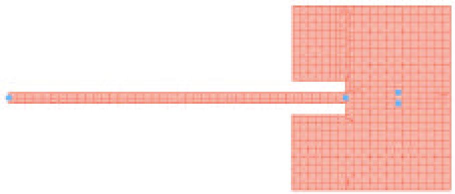

Figure 3. Layout generated using HP-Momentum

The results using HP-Momentum gave a resonance frequency of 1.36GHz, which accounts for 14.3% of error because of the use of the transmission line method. Momentum displays the results in rectangular form and Smith Chart for convenience.

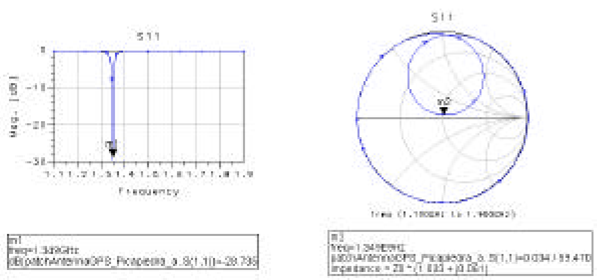

Figure 4. Frequency Response of patch antenna using Momentum

Remcom-XFDTD is a 3-D simulator and a view of the layout is shown in Figure 5. The frequency response is shown in Figure 6 and the resonant frequency is approximately 1.31 GHz.

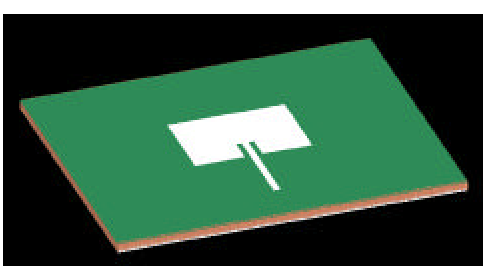

Figure 5. 3-D view of antenna geometry using Remcom-XFDTD

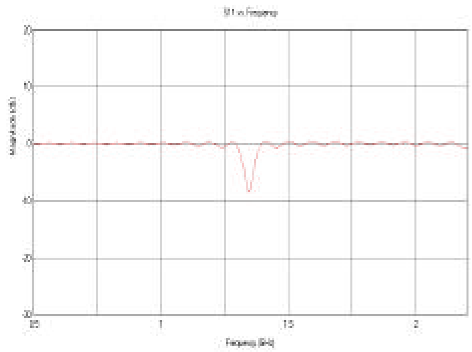

Figure 6. Frequency Response of patch antenna using XFDTD

During the simulation process with Momentum we found some difficulties for defining the exact dimensions of the antenna. Another weakness is the possibility of inaccurate results due to reduced number of frequency points. In the case of XFDTD, the signal reflections at the input because of the boundary layers can cause ringing in the frequency response. Other problems arose from the source excitation type, and the very time consuming simulations.

Besides of the difficulties in using Remcom-XFDTD and HP-Momentum, both software programs proved to be very powerful and valuable simulators for microwave antenna research and development.

References

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