FDTD Analysis of a Compact Microstrip Patch Antenna Using CPML Boundary Condition

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Abstract—*A compact microstrip line fed printed rectangular patch antenna analysed using efficient Finite Difference Time Domain (FDTD) Method with Convolutional Perfectly Matched Layer (CPML) Absorbing Boundary Condition (ABC) is presented in this paper. The proposed antenna is simulated using Ansoft High Frequency Structure Simulator (HFSS) software and the results are in good agreement with theoretical FDTD analysis. The antenna has the dimensions of (19x21x1.6) mm^3 and is resonated at (3.92-7.9) GHz which cover the C- communication frequency band. The proposed antenna exhibits omnidirectional radiation pattern and good peak gains across the operation bands.*

1. INTRODUCTION

Recent advances in wireless communication have led to the improvement in the performance of wide band and compact antennas, a priority among researchers. . The design of compact antennas with wide band characteristics [1-2] is significant in wireless local area network (WLAN), wireless interoperability microwave access (WiMAX), Satellite links and radio frequency identification systems. Microstrip patch antennas are widely used because of thin profile, light weight, low cost, conformability to shaped surface and compatibility with integrated circuits. But the major drawbacks of these antennas are narrow bandwidth in its basic form. In order to increase the strengths of these kinds of antennas, a number of analysis techniques like finite difference time domain technique (FDTD) are used. The FDTD method transforms the time domain Maxwell's curl equations to finite differential equations. A scattering effect of an electromagnetic pulse and the time domain response of perfectly conducting cylinder is studied in [3]. In 1990 David Sheen etal used the FDTD method to perform time domain simulations of pulse propagation in several printed microstrip circuits [4]. In addition to this, the frequency dependent scattering parameters and the input impedance of rectangular microstrip patch antenna are also calculated and measured. FDTD method is widely used in the field of electromagnetic due to the direct time domain calculation method, saving storage space and calculation time, simple and easy to understand and can be used to analyze the complex structure.

To perform the electromagnetic simulations in space regions the absorbing boundary condition (ABC) is a key problem with the FDTD technique. One of the most efficient and flexible absorbing boundary conditions is perfectly matched layer (PML) first proposed by Berenger [5]**.** A PML is an artificial absorbing medium that is used to truncate the computational grids for stimulating Maxwell's wave equations and is designed to have the property that the interfaces between the PML and the adjacent media are reflection less in the exact wave equation. Now a days the mostly used PML formulation s Convolutional PML (CPML). CPML constructs the PML from an anisotropic, dispersive material. CPML does not require the field to be split and can be implemented in a relatively straightforward manner.

In this paper the FDTD analysis method with CPML absorbing boundary condition is applied in designing a rectangular patch antenna. The result of this modelling is compared with HFSS simulated results to show effectiveness of this approach. The proposed antenna covers the frequency range of C communication band (3.92-8 GHz).

2. FORMULATION OF FDTD METHOD

The FDTD method is based on the numerical solutions of Maxwell's equations. The electromagnetic fields can be described in a linear medium by the Maxwell's equations in differential form.

$$\nabla \times \vec{H} = \mathrm{J} + \frac{\partial \mathrm{D}}{\partial \mathrm{t}} ------(\mathrm{i})$$

$$\nabla \times \vec{E} = -\frac{\partial B}{\partial t} ------(ii)$$

where E and H are the electric and magnetic field vectors in three dimensions.

Solving equations (i) and (ii) a set of six equations is produced.

$$\frac{\partial H_x}{\partial t} = -\frac{1}{\mu}\left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}\right)$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_z}{\partial z}\right)$$

$$\frac{\partial H_z}{\partial t} = -\frac{1}{\mu}\left(\frac{\partial E_y}{\partial y} - \frac{\partial E_x}{\partial z}\right)$$

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z}\right) - \frac{\sigma}{\varepsilon}E_x$$

$$\frac{\partial E_y}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial y} - \frac{\partial H_z}{\partial z}\right) - \frac{\sigma}{\varepsilon}E_y$$

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial y} - \frac{\partial H_x}{\partial z}\right) - \frac{\sigma}{\varepsilon}E_z$$

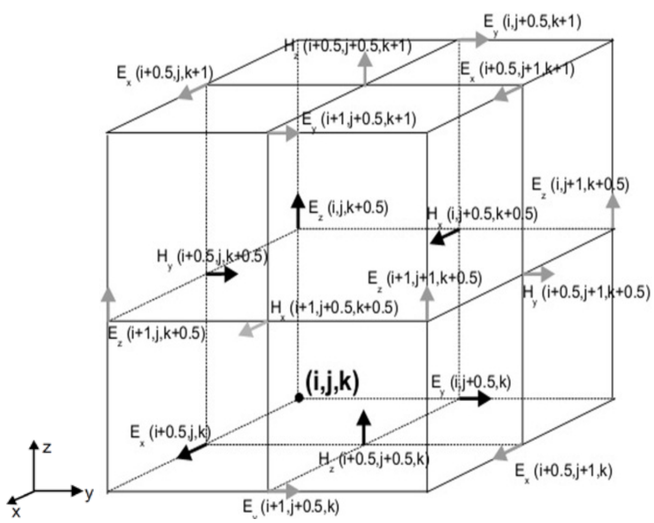


Fig. 1: The position of electric and magnetic field component in an FDTD or Yee Cell

The FDTD method is concerned with the numerical solutions of the above equations. To implement the finite difference scheme, the problem space is divided into a number of Cartesian cells developed by Yee [3,6] as shown in Fig. 1. The significant of this cell is that the position of different components of E and H satisfy the differential form of Maxwell's equations. The electric field components are placed in the middle of the edges and the magnetic field components are reside in the centre of the faces of this cell. The computation of E and H field components follows leap frog algorithm with the components of E being calculated at nΔt and components of H being calculated at (n+1/2)Δt, where Δt is the discretization step in time.

$$\boldsymbol{E_x^{n+1}\left(i+\frac{1}{2},j,k\right) = \frac{1-\frac{\sigma.\Delta t}{2\varepsilon}}{1+\frac{\sigma.\Delta t}{2\varepsilon}}\,E_x^{n}\left(i+\frac{1}{2},j,k\right) + \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta y}\left[H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) - H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j-\frac{1}{2},k\right)\right] - \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta z}\left[H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) - H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k-\frac{1}{2}\right)\right]}$$

$$E_y^{n+1}\left(i,j+\frac{1}{2},k\right) = \frac{1-\frac{\sigma.\Delta t}{2\varepsilon}}{1+\frac{\sigma.\Delta t}{2\varepsilon}}\,E_y^{n}\left(i,j+\frac{1}{2},k\right) + \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta z}\left[H_x^{n+\frac{1}{2}}\left(i,j,k+\frac{1}{2}\right) - H_x^{n+\frac{1}{2}}\left(i,j,k-\frac{1}{2}\right)\right] - \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta x}\left[H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k\right) - H_z^{n+\frac{1}{2}}\left(i-\frac{1}{2},j,k\right)\right]$$

$$E_z^{n+1}\left(i,j,k+\frac{1}{2}\right) = \frac{1-\frac{\sigma.\Delta t}{2\varepsilon}}{1+\frac{\sigma.\Delta t}{2\varepsilon}}\,E_z^{n}\left(i,j,k+\frac{1}{2}\right) + \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta x}\left[H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k\right) - H_z^{n+\frac{1}{2}}\left(i-\frac{1}{2},j,k\right)\right] - \frac{\Delta t}{\varepsilon\left(1+\frac{\sigma.\Delta t}{2\varepsilon}\right)\Delta y}\left[H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k\right) - H_x^{n+\frac{1}{2}}\left(i,j-\frac{1}{2},k\right)\right]$$

$$H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) = H_x^{n-\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) + \frac{\Delta t}{\mu\Delta z}\left[E_y^{n}\left(i,j+\frac{1}{2},k+1\right) - E_y^{n}\left(i,j+\frac{1}{2},k\right)\right] - \frac{\Delta t}{\mu\Delta y}\left[E_z^{n}\left(i,j+1,k+\frac{1}{2}\right) - E_z^{n}\left(i,j,k+\frac{1}{2}\right)\right]$$

$$H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) = H_y^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) + \frac{\Delta t}{\mu\Delta x}\left[E_z^n\left(i+1,j,k+\frac{1}{2}\right) - E_z^n\left(i,j,k+\frac{1}{2}\right)\right] - \frac{\Delta t}{\mu\Delta z}\left[E_z^n\left(i+\frac{1}{2},j,k+1\right) - E_z^n\left(i+\frac{1}{2},j,k\right)\right]$$

$$H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) = H_z^{n-\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) + \frac{\Delta t}{\mu\Delta y}\left[E_x^n\left(i+\frac{1}{2},j+1,k\right) - E_x^n\left(i+\frac{1}{2},j,k\right)\right] - \frac{\Delta t}{\mu\Delta x}\left[E_y^n\left(i+1,j+\frac{1}{2},k\right) - E_y^n\left(i,j+\frac{1}{2},k\right)\right]$$

Introducing the CPML boundary condition into the complex frequency domain transform, makes the discrete equations independent of the type of simulation material [7]. The different material properties of the medium make no change in this calculation.

3. ANTENNA CONFIGURATION AND FORMULATIONS

The geometry of the proposed rectangular patch antenna is shown in Fig. 2. The antenna is designed on FR4 substrate with dielectric constant 4.4. To analyse the antenna correctly space steps Δx, Δy, Δz are used as integral number of nodes to represent antenna parameters exactly. The size of the space cells are Δx=.2375mm, Δy=0.175mm and Δz=0.100mm.The total mesh dimensions are 80x120x30 in x, y and z directions. The rectangular patch size is 69Δx ×57Δy and the length of the microstrip line is 45.7Δy.

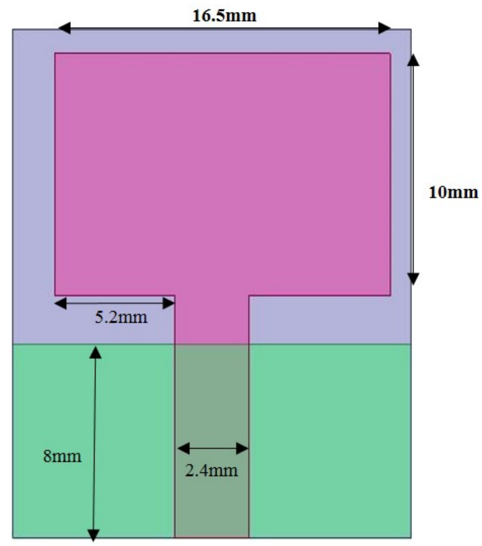


Fig. 2: Proposed geometry of the antenna

The stability condition for the FDTD method is given by

$$\Delta \le (\lambda_{min}/10) \text{ and } \Delta t \le \Delta/c\sqrt{(n)}$$

where, $\lambda_{min}=c/f_{max}$, is the minimum value wavelength supported by the structure being studied and n varies depending on dimension. Here c is the velocity of light in vacuum.

For the excitation source in the source plane of the conduction band, Gaussian pulse is used and it is expressed as

$$E_z(t) = e^{-(t-t_0)^2/T^2}$$

The Gaussian half width T=15 ps and the time delay t_0=3T. The simulation is performed for 3000 time steps.

The result of this modelling is the reflection coefficient. The return loss of this rectangular microstrip antenna is represented by,

$$S_{11}(f)_{dB} = 20.\,log_{10}\frac{E_{out}(f)}{E_{in}(f)}$$

Where E_{in}(f) is the incident wave and E_{out}(f) is the reflected wave.

The return loss value S_{11}(f) is obtained with the help of MATLAB Fast Fourier Transform (FFT) function. Fig. 3 shows the variation of S_{11}(dB) with respect to frequency value is potted in a graph. The proposed design is again simulated in HFSS and return loss values are compared with FDTD. From the simulation results, the obtained impedance bandwidth (determined from -10dB reflection coefficient) of the proposed antenna can operate from 3.92 to 7.95 GHz covering the C-communication frequency bands. The antenna also exhibits good radiation pattern over E-plane and H-plane at its two resonating frequency 5 GHz and 6.45 GHz shown in Fig. 4.

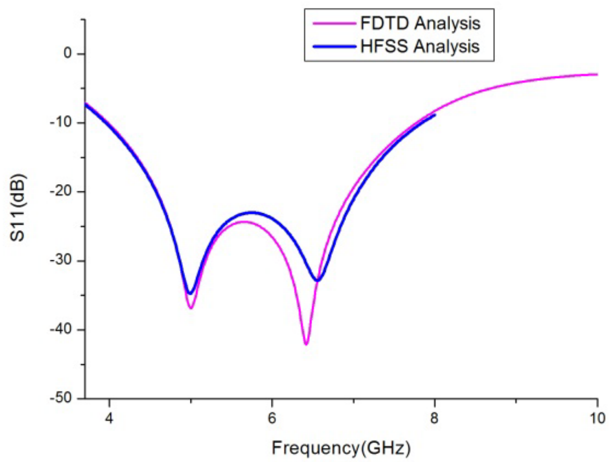
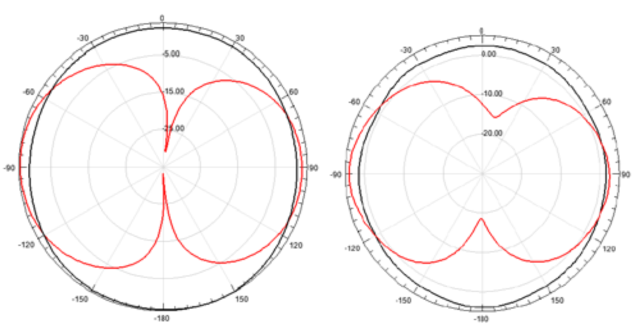


Fig. 3: Return loss value of rectangular microstrip patch antenna



(a) **(b)**

Fig. 4: E and H plane radiation pattern of the proposed antenna at (a) 5 GHz and (b) 6.45GHz

4. CONCLUSION

In this work the FDTD method with CPML boundary condition is used in analysis of a compact rectangular microstrip patch antenna is presented. The proposed antenna again simulated on Ansoft HFSS software and a good agreement is observed. The antenna has nearly omnidirectional radiation pattern, peak gain varies from 1.78-4 dB and suitable to operate in C-communication frequency bands.

REFERENCES

[1] Ray, K.P., Kumar,Girish , Broad band Microstrip antennas, *Artech house,2003*.

[2] Bora, H. K., Neog, Kr. Dipak, "A novel quad band antenna for wireless applications", *Proceeding of IEEE-AEMC,* Odissa, Dec 2013.

[3] Yee, K. S., "Numerical solution of initial boundary value problems involving boundary value problems using Maxwell's equation in isotropic media", *IEEE Transac. Antenna Propag.*, vol.14, no.2, pp.302-307, May1996.

[4] Sheen, M. David, Ali, S.M., Abouzahra, M.D., Kong, J.A.,"Application of three dimensional finite difference time domain method to the analysis planar microstrip antenna circuits", *IEEE Trans on Microwave Theory and Tech*, vol.38, no.7,1990.

[5] Berenger J.P., "A perfectly matched layer for the absorption of electromagnetic wave", *Journal of Computational Physics*, vol.114, pp.195-200, 1994.

[6] Taflove A., Hangness S.C., *Computational electrodynamics: The finite difference time domain method, The Transformation*, MA:Artech House,2005.

[7] Roden, J, Gedney, S,"Convolutional PML (CPML) an efficient FDTD implementation of the CFS-PMLfor arbitrary media", *Microwave and Optical Technology Letter,* vol.27, no.5, pp.334-339,2000.