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FULL-WAVE FDTD ANALYSIS OF RECTANGULAR MICROSTRIP ANTENNA ON GRADED COMPOSITE SUBSTRATE

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ABSTRACT. The Finite Difference Time Domain (FDTD) full wave analysis technique is applied to microstrip antenna designed on LDPE/titania graded dielectric substrates. The FDTD simulation generates data which helps in visualizing the time progression of vector fields throughout the three-dimensional solution space. It gives a physical insight of complex field interactions at different stages of field propagation. The radiation response of the microstrip antenna is analysed by finding the scattering parameters by taking Fourier transformation of the transient E field component. The S_{11} obtained using this method for the graded substrate antenna is compared with the measured and simulated (using CST Microwave Studio) results which shows proximity.

1. INTRODUCTION

Solutions to Maxwell's equations play a fundamental role in solving electromagnetic problems. Finite Difference Time Domain (FDTD) technique is an efficient tool that can be used to analyse electromagnetic problems by solving the Maxwell's equations on any scale with almost all kinds of environments [1–11]. The technique can be effectively applied to analyse the electric field distribution inside the antenna structure as well as in the surrounding area of interest [1].

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The FDTD method discretizes the time dependent Maxwell's equation for vector components using central difference approximations for space and partial derivatives for time [1,2]. The EM wave solution in FDTD is fully worked out in space grid and time-stepping algorithm within the computation domain, where, at any point in space the updated value of the E-field in time is dependent on the stored value of the E-field and the numerical curl of the local distribution of the H-field in space. Similarly, the updated value of the H-field in time is dependent on the stored value of the H-field and the numerical curl of the local distribution of the E-field in space (leap frog arrangement) [1–4].

2. Methodology

The 3D FDTD formulation developed here is for rectangular microstrip antenna on graded composite substrates fed at 50Ω impedance matching points within the patch. A Gaussian discrete pulse is used to excite the radiating patch at the feed point. The substrate is dielectric and the permittivity is taken as isotropic [12,13]. The electric field and magnetic field gets updated, both at every space grid coordinates and time stepping. An in-house program is developed to analyze the field distribution of the antenna.

The FDTD method provides a direct time domain solutions of Maxwell's equations in differential form by discretizing both the physical region and time interval using a uniform grid, known as Yee cells (figure 1(a)). An electromagnetic wave interaction structure is mapped into the three dimensional space lattice by assigning appropriate values of permittivity to each electric field component, and permeability to each magnetic field component as shown in figure 1(b).

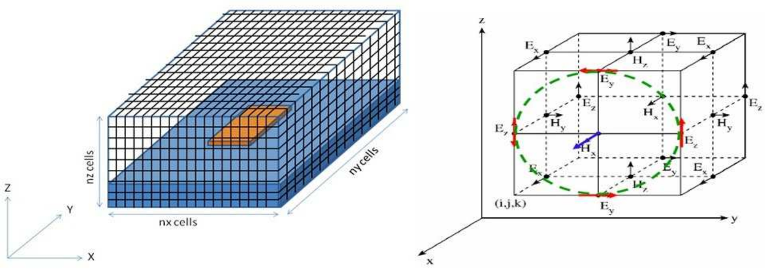


Fig. 1(a) Fig 1 (b)

The 3D FDTD scheme for microstrip antenna on dielectric substrates is realized in two modules:

a) Maxwell's curl equations are expressed in partial differential form.

b) These scalar equations are expressed in finite differential form in spatial and temporal coordinates.

The electric field and magnetic field gets updated, both at every space grid coordinates and time stepping.

$$\frac{\partial D_x}{\partial t} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} \right), \quad \frac{\partial D_y}{\partial t} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} \right)$$

$$\frac{\partial D_z}{\partial t} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \right), \quad \frac{\partial H_x}{\partial t} = \frac{-1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} \right)$$

$$\frac{\partial H_y}{\partial t} = \frac{-1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} \right), \quad \frac{\partial H_z}{\partial t} = \frac{-1}{\sqrt{\epsilon_0 \mu_0}} \left(\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \right).$$

Finite difference approximation solution of these Maxwell's partial differential equations are found by discretizing the problem space over a finite three dimensional computational domain in spatial and temporal coordinates in accordance to the Yee's mesh as shown in figure 2.

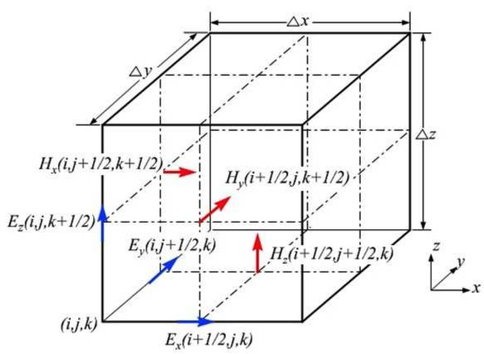


Fig. 2

The modified equations for all the $\underline{E}$ and $\underline{H}$ components are,

$$\begin{aligned} D_x^{n+\frac{1}{2}}\left(i+\frac{1}{2}, j, k\right) = D_x^{n-\frac{1}{2}}\left(i+\frac{1}{2}, j, k\right) \\ + \frac{\Delta t}{\Delta y \cdot \sqrt{\epsilon_0 \mu_0}} \left[H_z^n\left(i+\frac{1}{2}, j+\frac{1}{2}, k\right) - H_z^n\left(i+\frac{1}{2}, j-\frac{1}{2}, k\right) \right] \\ - \frac{\Delta t}{\Delta z \cdot \sqrt{\epsilon_0 \mu_0}} \left[H_y^n\left(i+\frac{1}{2}, j, k+\frac{1}{2}\right) - H_y^n\left(i+\frac{1}{2}, j, k-\frac{1}{2}\right) \right] \end{aligned}$$

$$
\begin{aligned}
D_y^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k\right) = D_y^{n-\frac{1}{2}}\left(i,j+\frac{1}{2},k\right) &+ \frac{\Delta t}{\Delta z\cdot\sqrt{\epsilon_0\mu_0}} \\
&\left[H_x^n\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) - H_x^n\left(i,j-\frac{1}{2},k-\frac{1}{2}\right)\right] \\
&- \frac{\Delta t}{\Delta x\cdot\sqrt{\epsilon_0\mu_0}}\left[H_z^n\left(i+\frac{1}{2},j+\frac{1}{2},k\right) - H_z^n\left(i-\frac{1}{2},j+\frac{1}{2},k\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
D_z^{n+\frac{1}{2}}\left(i,j,k+\frac{1}{2}\right) = D_2^{n-\frac{1}{2}}\left(i,j,k+\frac{1}{2}\right) &+ \frac{\Delta t}{\Delta x\cdot\sqrt{\epsilon_0\mu_0}} \\
&\left[H_y^n\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) - H_y^n\left(i-\frac{1}{2},j,k+\frac{1}{2}\right)\right] \\
&- \frac{\Delta t}{\Delta y\cdot\sqrt{\epsilon_0\mu_0}}\left[H_x^n\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) - H_x^n\left(i,j-\frac{1}{2},k+\frac{1}{2}\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
H_x^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) &= H_x^{n-\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) \\
&- \frac{\Delta t}{\Delta y\cdot\sqrt{\epsilon_0\mu_0}}\left[E_z^n\left(i,j+\frac{1}{2},k+\frac{1}{2}\right) - E_x^n\left(i+\frac{1}{2},j,k\right)\right] \\
&+ \frac{\Delta t}{\Delta x\cdot\sqrt{\epsilon_0\mu_0}}\left[E_z^n\left(i+1,j,k+\frac{1}{2}\right) - E_z^n\left(i,j,k+\frac{1}{2}\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
H_y^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) = H_y^{n-\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right) &- \frac{\Delta t}{\Delta z\cdot\sqrt{\epsilon_0\mu_0}} \\
&\left[E_x^n\left(i+\frac{1}{2},j,k+1\right) - E_x^n\left(i,j,k+\frac{1}{2}\right)\right] \\
&+ \frac{\Delta t}{\Delta z\cdot\sqrt{\epsilon_0\mu_0}}\left[E_y^n\left(i,j+\frac{1}{2},k+1\right) - E_y^n\left(i,j+\frac{1}{2},k\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) = H_2^{n-\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right) &- \frac{\Delta t}{\Delta x\cdot\sqrt{\epsilon_0\mu_0}} \\
&\left[E_y^n\left(i+1,j+\frac{1}{2},k\right) - E_y^n\left(i,j+\frac{1}{2},k\right)\right] \\
&+ \frac{\Delta t}{\Delta y\cdot\sqrt{\epsilon_0\mu_0}}\left[E_x^n\left(i+\frac{1}{2},j+1,k\right) - E_x^n\left(i+\frac{1}{2},j,k\right)\right]
\end{aligned}
$$

3. IMPLEMENTATION OF FDTD CODE

At first the computational domain is defined over which the FDTD will be implemented. The gridding of the 3D structure is carried out considering the stability conditions. The geometry of the concerned structure is expressed in terms of material properties and the PML (Perfectly Matched Layer) boundary conditions [14, 15], which are initialized to define the actual computational domain. A Gaussian pulse is applied as the input stimulus at the feed point and at discreet time steps, the E and the H field components are updated in leap frog manner. The spatial field distribution can be visualized from the simulated E and H components in three dimensions. To extract the scattering parameters, Fourier transformation of the transient response is taken.

In case of graded substrates five material layers are to be considered; free space, three composite material layers and the metal as shown in figure 3.

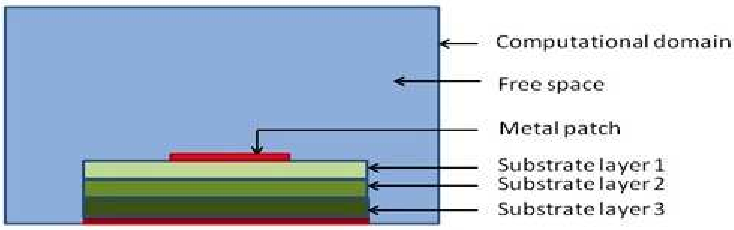


Fig. 3 FDTD computational domain showing different material zones

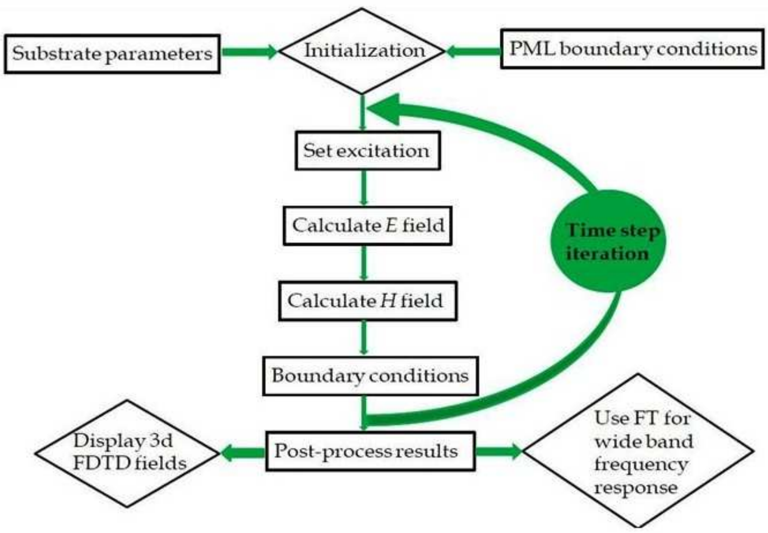


Fig. 4: Flowchart for FDTD algorithm

The complete flowchart for FDTD algorithm is shown in fig. 4, highlighting the electric field and magnetic field updating modules. A program in MATLAB is developed to implement this algorithm for study of microstrip antenna and E and H updating code modules.

4. Results

The FDTD technique is implemented for analysis of microstrip antenna structure on graded substrate, having isotropic permittivity over the layer. This technique successfully analyses the full-wave electric field distribution and return loss of microstrip antenna, fabricated on LDPE/titania graded composite substrate. The electric field distribution at 500^{th} time step is shown in the figure below.

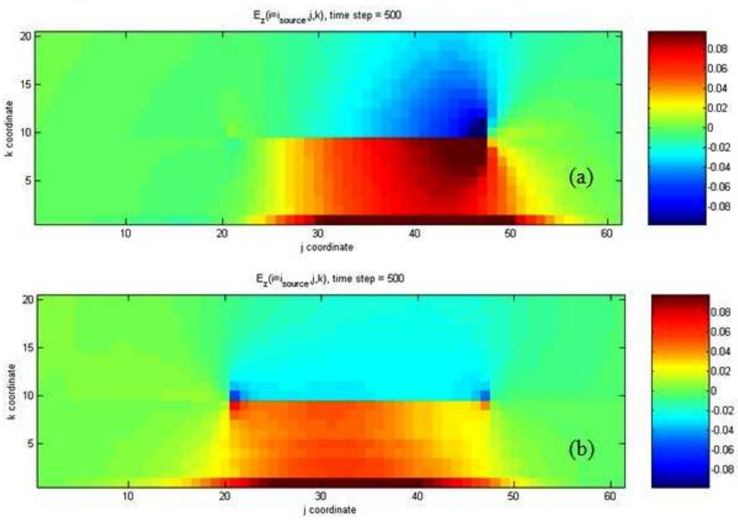
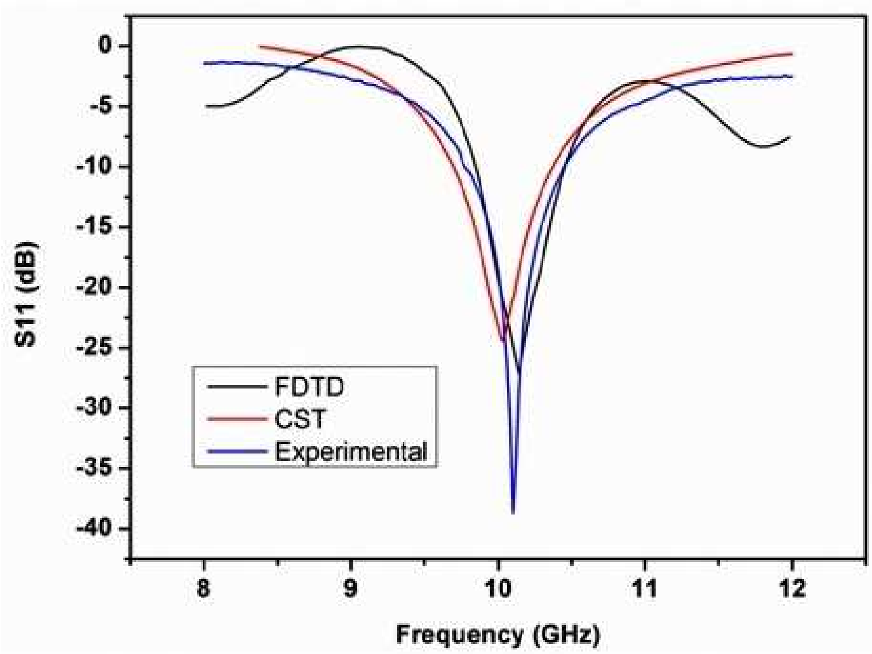


Figure 4 The FDTD simulated electric field components within the substrate of microstrip antenna at 500 time steps (a) Single layer substrate (b) Graded substrate

The S_{11} results shows that the -10 dB bandwidth is around 10 percentage and the S_{11} at the resonating frequency is -27dB which are in close proximity with experimental and CST simulated results.

5. Conclusion

From the electric field pattern studies, it is observed that due to change in permittivity at different sections of the graded substrate, the field distribution changes in comparison to the single layer counter part. This could be due to suppression of surface waves within the graded substrate leading to enhancement of the radiation phenomena and S_{11} parameter [12, 13].



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