Tuning Microstrip Patch Antennas on Ferrite Substrate Using Simple Ground Plane Structures

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Abstract— An additional tuning strategy for microstrip patch antennas on magnetized ferrite substrates is presented. It is shown that by introducing simple ground plane structures, the response of the patch antenna can be improved considerably. The analysis method is based on a 3D FDTD algorithm. The FDTD model utilizes the auxiliary differential equation approach to represent the frequency dependent permeability tensor in the time domain equations. The resulting 3D full-wave numerical model is tested and verified against experimental data showing very good agreement.

1. INTRODUCTION

Microstrip patch antennas on ferrite substrates offer a number of advantages over normal dielectric material. Due to their fairly high dielectric constant, miniaturization is possible. Further, because of the property of frequency tuning by external biasing fields, the radar cross section of such antennas can be reduced [1–6]. Also, changing the beam width and direction is possible in ferrite-based antenna arrays [7]. However, the analysis of ferrite-based problems is often complex due to the inherent anisotropy and nonlinearity in the material. Analytical solutions are generally inaccurate because they are based on simplifying assumptions [8]. Therefore, the development of accurate numerical techniques is essential. Several numerical techniques have been used to study the response of ferrite-based microstrip patch antennas including the finite-element method (FEM) [9], the transmission line method (TLM) [10] and using Green's functions [11]. Schuster and Luebbers [12] reported the application of the FDTD method coupled with the recursive convolution method to model the frequency dependent response of ferrite materials. In their algorithm, four convolutions in the update equations required the storage of four complex numbers per cell. Because the FDTD method solves for the basic field quantities, it offers a great amount of information usually from one simulation run. This property makes the method very attractive and very popular in the computational electromagnetics society [13]. The FDTD algorithm presented in this paper is a straightforward full-wave algorithm based on the auxiliary differential equation (ADE) technique [14] to model the frequency dependent permeability tensor of ferrite materials. The resulting scheme retains the fully explicit nature of the original FDTD method and enjoys the same features of flexibility and simplicity. It is used in this paper to investigate the tuning capability of simple ground plane structures on the response of a microstrip patch antenna printed on a magnetized ferrite substrate. The simulation results are compared to published experimental data.

2. FORMULATIONS

For a ferrite material with magnetizing DC field in the z-direction, the frequency-dependent permeability tensor is given by

$$\mu = \begin{bmatrix} \mu_r & jk & 0 \\ -jk & \mu_r & 0 \\ 0 & 0 & \mu_o \end{bmatrix} \tag{1}$$

The non-zero elements in Equation (1) are given by

$$\mu_r = \mu_o \left[1 + \frac{\omega_m(\omega_o + j\alpha\omega)}{(\omega_o + j\alpha\omega)^2 - \omega^2}\right] = \mu_o + \frac{\mu_o\omega_m\omega_o + (j\omega)\alpha\mu_o\omega_m}{\omega_o^2 + (j\omega)2\alpha\omega_o + (j\omega)^2(1+\alpha^2)} \tag{2}$$

and

$$jk = \frac{j\mu_o\omega_m\omega}{(\omega_o + j\alpha\omega)^2 - \omega^2} = \frac{(j\omega)\mu_o\omega_m}{\omega_o^2 + (j\omega)2\alpha\omega_o + (j\omega)^2(1+\alpha)^2} \tag{3}$$

where, $\omega_m = 2\pi\gamma M_s$ is the magnetization frequency, $\omega_o = 2\pi\gamma(H_{DC} - N_z M_s)$ is the resonance frequency, γ is the gyromagnetic ratio, M_s is the saturation magnetization, H_{DC} is the applied

DC magnetic field, N_z is the demagnetization, α is the damping factor and μ_o is the free space permeability. The magnetic flux density, B, is given by

$$\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} = \begin{bmatrix} \mu_r & jk & 0 \\ -jk & \mu_r & 0 \\ 0 & 0 & \mu_o \end{bmatrix} \begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix} \tag{4}$$

Employing the ADE approach, the components of B in Equation (4) can be written in the time domain as

$$\begin{aligned} \omega_o^2 B_x + 2\alpha\omega_o \frac{\partial B_x}{\partial t} + (1+\alpha^2)\frac{\partial^2 B_x}{\partial t^2} &= \mu_o\omega_o(\omega_o+\omega_m)H_x + \mu_o\alpha(2\omega_o+\omega_m)\frac{\partial H_x}{\partial t} \\ &\quad + \mu_o(1+\alpha^2)\frac{\partial^2 H_x}{\partial t^2} + \mu_o\omega_m\frac{\partial H_y}{\partial t} \end{aligned} \tag{5}$$

$$\begin{aligned} \omega_o^2 B_y + 2\alpha\omega_o \frac{\partial B_y}{\partial t} + (1+\alpha^2)\frac{\partial^2 B_y}{\partial t^2} &= \mu_o\omega_o(\omega_o+\omega_m)H_y + \mu_o\alpha(2\omega_o+\omega_m)\frac{\partial H_y}{\partial t} \\ &\quad + \mu_o(1+\alpha^2)\frac{\partial^2 H_y}{\partial t^2} - \mu_o\omega_m\frac{\partial H_y}{\partial t} \end{aligned} \tag{6}$$

and,

$$B_z = \mu_o H_z \tag{7}$$

The resulting fully-explicit algorithm [14] starts by first finding all B^{n+1} components using the usual Yee's algorithm. Next, H_x^{n+1}, H_y^{n+1} and H_z^{n+1} are computed in the given order using Equations (5)–(7). Finally, the electric field components are computed using the standard Yee's algorithm.

3. SOLUTION METHOD AND NUMERICAL RESULTS

To test the application of the proposed numerical scheme to microstrip patch antennas, the response of a typical patch antenna is considered. The structure is shown in Figure 1 with the following dimensions: $x_1 = 9\,\text{mm}$, $x_2 = 5\,\text{mm}$, $x_3 = 2.5\,\text{mm}$, $y_1 = 3.1\,\text{mm}$, $y_2 = 0.7\,\text{mm}$, $y_3 = 0.3\,\text{mm}$ and $y_4 = 0.9\,\text{mm}$. The antenna is printed on a ferrite substrate with thickness of 1 mm, dielectric constant of 13.69, loss tangent of 0.0002 and saturation magnetization of 27.85 kA/m. The gyromagnetic ratio is taken as 35.173 kHz m/A. A DC biasing magnetic field of 234 kA/m is applied in the z-direction. Figure 2 shows the simulated return loss parameter (S_{11}) for the patch antenna under investigation. The simulation results are compared to published experimental data for the same antenna [10]. The simulated response shows three distinct resonances that can be identified at 6.6075 GHz, 7.1775 GHz and 8.1375 GHz. In general, the agreement between the measured and simulated responses is very good. To examine the effectiveness of device tuning using ground plane

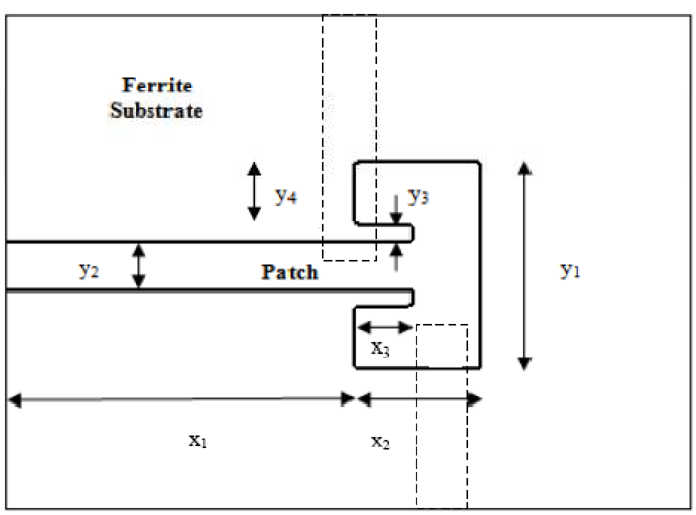

Figure 1: The ferrite-based patch antenna used in the analysis.

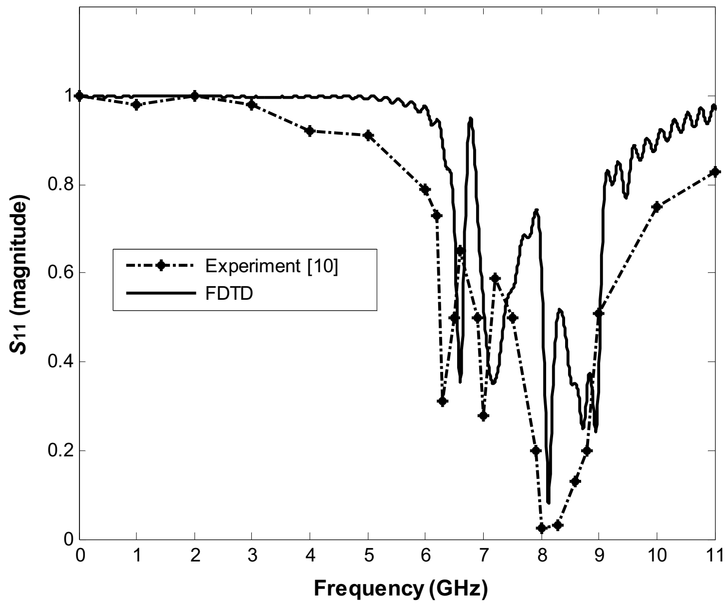

Figure 2: Return loss parameter S_{11} for the patch antenna as obtained using the FDTD calculations compared to experimental data [10].

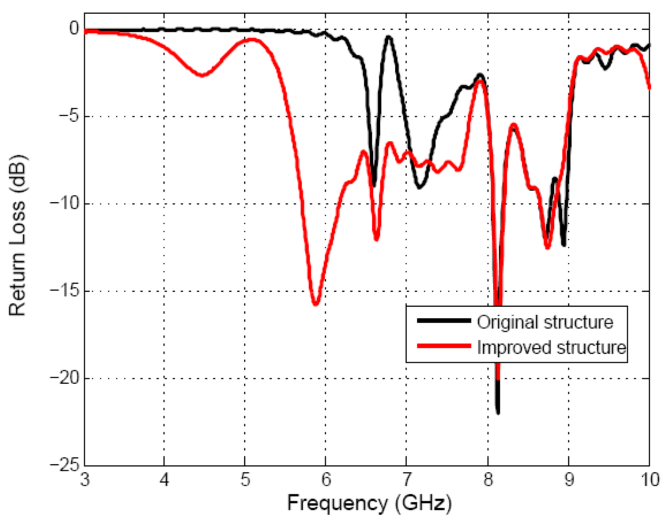

Figure 3: Return loss parameter for the patch antenna as obtained using the FDTD calculations with ground plane features of Figure 1 introduced.

structures, the features shown in Figure 1 (dashed lines) are introduced in the ground plane. Figure 3 shows the simulated return loss parameter for the original patch antenna under investigation with complete ground plane (black line) and the antenna response with ground plane features introduced (red line). The simulated response shows that the response is improved and can be tuned to the desired frequency and bandwidth. Future analysis will focus on the possibilities of tuning the device further by changing the dimensions and orientation of the ground plane features.

4. CONCLUSIONS

The response of microstrip patch antennas on magnetized ferrite substrates has been investigated using a 3D full-wave FDTD algorithm. To incorporate the frequency-dependent nature of the permeability tensor of the ferrite material in the time domain equations, the auxiliary differential equation approach has been utilized. Additionally, tuning of the device response using simple ground plane structures has been demonstrated. This method can introduce improvements to device bandwidth as well.

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