CYLINDRICAL COORDINATES FD-TD ANALYSIS OF CIRCULAR POLARIZATION CYLINDRICAL MICROSTRIP ANTENNAS WITH HIGH PERMITTIVITY SUBSTRATE

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1. Introduction

When the conventional FD-TD (Finite-Difference Time-Domain) method based on the Cartesian coordinate system is attempted to apply straightforwardly to the geometry having curved conductor surfaces, it often requires an extremely large number of space division meshes if sufficient accuracy needs to be maintained. The reason is that a collection of perpendicularly directed planar conductor segments cannot make a good approximation to the curved conductor surfaces. Desirable measures for getting over this difficulty would be to try to use curved meshes as conformable to the curved surfaces as possible. Thus, if the geometry of problems has circular or cylindrical conductor surfaces, meshes based on cylindrical coordinates would be natural to be used.

There are not a few microstrip-type antennas whose structure mainly consists of circular or cylindrical shapes. If the FD-TD method is used to analyze such cylindrically shaped antennas, its algorithm should be based on the cylindrical coordinates. However, there is almost no literature published on the application of the genaral cylindrical coordinates FD-TD method to the actual electromagnetic problems. This paper reports the development of a series of cylindrical coordinates FD-TD algolithms appropriate particularly to the analysis of radiation properties of cylindrically shaped microstrip antennas. As the absorption boundary, that of Berenger's PML(Perfectly Matched Layers)[1] adapted to the cylindrical coordinates is employed.

The present cylindrical coordinates FD-TD algorithm is verified by applying it to the analysis of radiation properties of circular polarization cylindrical microstrip antennas with high permittivity substrate, antenna for mobile satellite communication.

2. FD-TD algorithm in cylindrical coordinates

The basic algorithm for cylindrical coordinates is the same as that for rectangular coordinates. The basic cylindrical coordinates FD-TD equations for calculating fields at a time step n are described, for example, in Ref.[2]. Let the cylindrical coordinates be (ρ, ϕ, z), and space and time increments be ($\Delta\rho$, $\Delta\phi$, Δz) and Δt, respectively. Then, following the Yee's notation[3], the equation calculating E_z at time $t = n\Delta t$, for instance, is written as

$$\begin{aligned} E_z^n(i,j,k) &= E_z^{n-1}(i,j,k) \\ &+\frac{\Delta t}{\varepsilon\rho_i\Delta\rho}\left[\rho_{i+\frac{1}{2}}H_\phi^{n-\frac{1}{2}}(i+\frac{1}{2},j,k)-\rho_{i-\frac{1}{2}}H_\phi^{n-\frac{1}{2}}(i-\frac{1}{2},j,k)\right] \\ &-\frac{\Delta t}{\varepsilon\rho_i\Delta\phi}\left[H_\rho^{n-\frac{1}{2}}(i,j+\frac{1}{2},k)-H_\rho^{n-\frac{1}{2}}(i,j-\frac{1}{2},k)\right] \end{aligned} \tag{1}$$

where ε is the permittivity, and i, j, and k are the integer numbers corresponding to the space location of field components in the ρ, ϕ, and z directions, respectively. On the central axis (ρ = 0), only the E_z component is allocated[4], which is calculated using the equation derived from Ampere-Maxwell's integral law.

The equations in the PML regions are easily deduced referring to those for the three dimensional rectangular coordinates[5]. The E_ρ component, for example, is separated into $E_{\rho\phi}$ and $E_{\rho z}$ subcomponents, which are related to H_z and H_ϕ components, respectively, as the following:

$$\varepsilon_0 \frac{\partial E_{\rho\phi}}{\partial t} + \sigma_\phi E_{\rho\phi} = \frac{1}{\rho} \frac{\partial (H_{z\rho} + H_{z\phi})}{\partial \phi} \tag{2}$$

$$\varepsilon_0 \frac{\partial E_{\rho z}}{\partial t} + \sigma_z E_{\rho z} = - \frac{\partial (H_{\phi\rho} + H_{\phi z})}{\partial z} \tag{3}$$

Similar relations hold for other components. It should be noted here that the conductivity in the ϕ direction, σ_ϕ, and its magnetic counterpart σ_ϕ^* are always equal to zero because the ϕ direction is always perpendicular to the thickness direction of the PML, everywhere.

3. Antenna for numerical example: Cylindrical microstrip antenna

The configulation of the microstrip antenna used for a numerical example is shown in Fig.1[6]. Circular patch of radius a is placed on the top of a cylindrical dielectric substrate of thickness h_1 and specific permittivity ε_r, and the patch has two small notches of dimensions $g_1 \times g_2$ to generate circularly polarized waves. The radius of the ground conductor b is the same as that of dielectric substrate. To produce broad hemispherical radiation patterns, the cylindrical skirt conductor strip of hight h_2 is attached to the edge of the ground conductor. Feeding coaxial line of inner and outer conductor radii r_a and r_b is positioned at $\rho = c$ and $\phi = 135$ degrees.

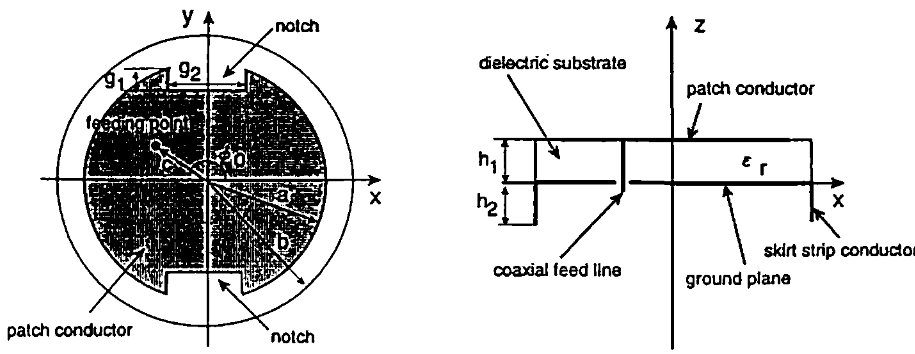
4. Numerical investigation

Actually manufactured antenna used for a model for FD-TD analysis has the following parameter values:

$$a = 17mm,\ b = 21mm,\ h_1 = h_2 = 10mm,\ c = 8mm,\ g_1 = 3.5mm,\ g_2 = 5mm$$
$$r_a = 0.455mm,\ r_b = 1.5mm,\ \varepsilon_r = 8.84$$

The FD-TD computation was performed for frequency being around $1.58GHz$, the layer number of PML being 8 with reflection coefficient 10^{-4}, mesh numbers taken in the computation range being, for example, 25, 40 and 120 in the ρ, ϕ, and z directions, respectively. Radiated fields were calculated from steady state field distribution of sinusoidal wave excitation, while frequency characteristics of input impedance were obtained from the response fields of Gaussian pulse modulated wave excitation. Two numerical excitation models were tested: one is delta gap excitation and the other is the excitation from the inside of coaxial line.

The cylindrical coordinates PML algorithm developed in the present work showed very



(a) Top view (b) Side view

Fig.1. Geometry of the antenna.

good absorption property. It was found that considerably larger number of time steps seems to be needed to attain steady state probably because very high permittivity substrate is used in the present antenna. Figure 2 shows radiation patterns of right-handed circularly polarized wave obtained from numerical computation together with those from measurements; frequency is $1.575GHz$. The dimensions employed for this calculation are chosen very close to those of the antenna used for measurements, but it is impossible to perfectly match each dimension; the chosen values are

$$a = 17.3mm, \ b = 21mm, \ c = 8.4mm$$
$$g_1 = 3.15mm, \ g_2 = 5.57mm \ (notch \ of \ type \ 1)$$

Numerically obtained patterns for this shape do not seem to agree sufficiently with the measured ones. However, better agreement with the measured data can be attained if the size of notches is chosen to be $g_1 = 4.2mm$ and $g_2 = 7.22mm$ (notch of type 2) as shown in Fig.3.

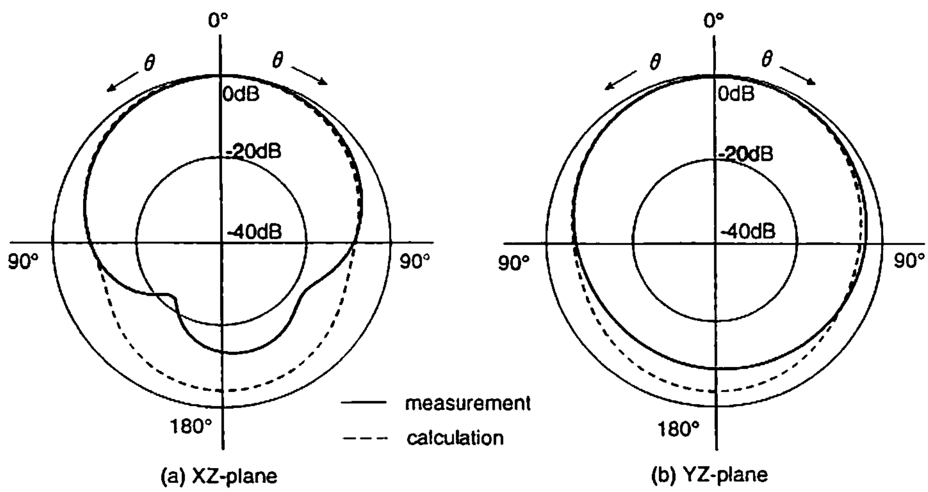


Fig.2. Right-handed circular polarization patterns(type 1).

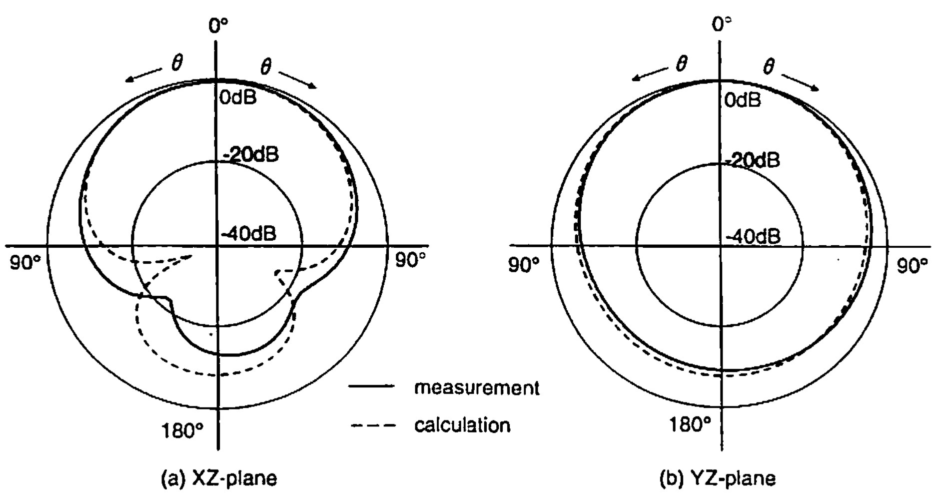


Fig.3. Right-handed circular polarization patterns(type 2).

This size is considerably larger than that of the real antenna. A plausible reason of this discrepancy is that the contours of the notches used in the numerical model are composed of curved lines and radial lines, while those of the real antenna, only straight lines.

Frequency characteristics of input impedance was calculated to become Fig.4. These results were obtained for the antenna with the same dimensions as those of Fig.2. Other properties such as axial ratio and gain patterns can readily be obtained since the radiated field component patterns are calculated first.

As for the two models of numerical excitation, numerical examination reveals that delta gap excitation tends to need larger number of time steps to reach steady state than the coaxial line excitation, but that both excitation models give similar results.

5. Conclusion

FD-TD algorithm in cylindrical coordinates has been developed and applied to the analysis of a circular polarization cylindrical antenna for satellite communication. This algorithm assures sufficient accuracy even with moderate number of space mesh division as long as the problem configulation concerned mainly consists of cylindrical shapes.

References

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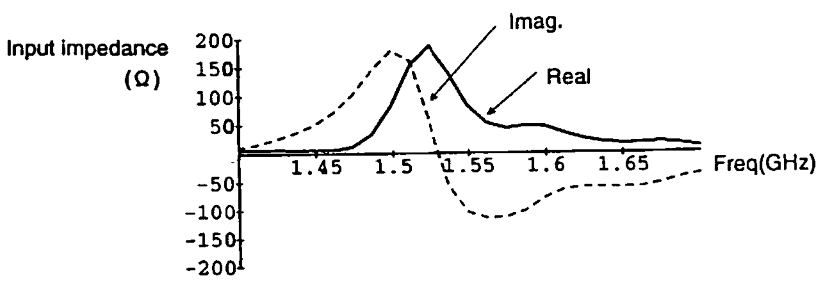

Fig.4. Input impedance.