

A HALF HOLLOW CYLINDRICAL ANTENNA (HHCA) ANALYSIS USING THE CFDTD ALGORITHM

D. Mohsen, N. Ghannay, and A. Samet

URCSE Group
Polytechnique School of Tunisia EPT
La Marsa 2070S, Tunisia

Abstract—In this paper, a direct three dimensional Finite-Difference Time-Domain (3D-FDTD) approach is implemented to investigate the electromagnetic behavior of a Half Hollow Cylindrical Antenna. The conformal shape of this antenna is studied using the Conformal Finite-Difference Time-Domain (CFDTD). We shall prove that a variation of the antenna shape generates an important shift of the values of the resonant frequency (about 0.467 GHz). Compared with the planar shape, the geometrical shape reduces the space occupied by the antenna of about 36.28%.

1. INTRODUCTION

One of the main advantages of microstrip structures [1] is that they can conform to arbitrarily curved surfaces, as shown in Fig. 1. Conformal microstrip structures, such as transmission lines, antennas and antenna arrays, have witnessed a huge amount of research work in recent years thanks to their interesting features for several applications, in particular, to meet the increasing demand for a smaller and more portable microwave, for aircraft-mounted and telecommunication equipments. This paper investigates the EM behavior of an interesting conformal passive microstrip structure, namely, Half Hollow Cylindrical Antenna using the CFDTD approach [2] which has not, to the best of our knowledge, been addressed in the literature so far and which is of great importance for several RF and microwave applications. The numerical approach implemented in this study is based on the CFDTD approach. This is a very powerful and versatile numerical tool which has been successfully used for the modeling and simulation of a very wide range of EM problems. The calculated

Corresponding author: D. Mohsen (ddmohsen@yahoo.fr).

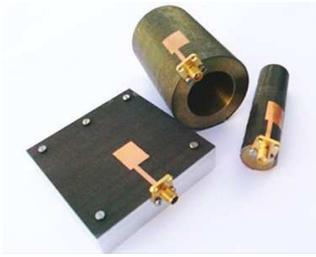


Figure 1. Planar and cylindrical patch antennas examples.

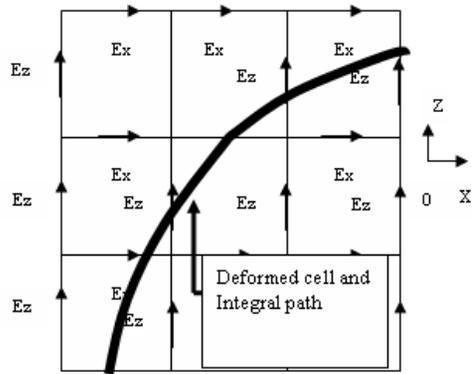


Figure 2. FDTD mesh for curved interface.

results are validated from the literature [3–7] where the antenna is planar and from commercial software where the antenna is conformal. Furthermore, these results offer an insight into the EM behavior of this structure.

2. FORMULATION

2.1. Curved Shape Modeling Technique

As one of the full-wave numerical methods, the Finite Difference Time Domain (FDTD) method has been widely used to simulate the electromagnetic scattering and radiation problems [8,9]. One of the most commonly used meshing techniques is to employ staircase in the Cartesian coordinates system, but this procedure not only introduces errors [4] due to the inaccurate modeling, but also can generate spurious results [5,6,10]. The locally conformal FDTD technique developed by Dey and Mittra [12–16] has been used to calculate the characteristics of a probe-fed cylindrically conformal microstrip patch antenna [13], which increases the accuracy and efficiency in the analysis significantly compared to the conventional one.

In this work, the CFDTD [14,15] technique has been used to describe curvilinear substrate surfaces. In this technique, the electric-fields updating algorithm remains unchanged compared to that conventionally used in Yee's scheme. The conformal FDTD technique has been used basically to deal with the perfectly conducting object including curved surfaces [16] and curved interfaces between dielectrics

[17]. Consider the zero patch thickness, the same approach mentioned in [18] and [19] is used, except that in the analysis the area of the regular cell is replaced by the approximation area of the distorted one, in order to make the simulation more accurate. With the CFDTD approach, we assume that both electric and magnetic fields inside the distorted cell are located at the same positions as those in the conventional FDTD scheme [20] and that Faraday’s law is applied to the entire FDTD cell [21, 22] as shown in Fig. 2, rather than only in the distorted part. This implies that the contour path follows the edges of the FDTD in its entirety [22].

2.2. Effective Dielectric Representation

Commonly with curved surfaces and edges, the conventional FDTD can also introduce significant staircase errors when dealing with curved interfaces between two dissimilar media.

The conformal FDTD technique has been generalized in [18] to improve the simulation accuracy for such geometries. This method also requires the mesh-truncation information of dielectric objects to calculate the effective dielectric constant along the deformed cell edge (Fig. 3).

The effective dielectric expression is given as following

$$\epsilon_z^{effective} = \frac{\Delta_{z1} * \epsilon_1 + \Delta_{z2} * \epsilon_2}{\Delta_{z1}} \tag{1}$$

3. HALF HOLLOW CYLINDRICAL ANTENNA

Figure 4 shows the shape of the structure considered in this analysis.

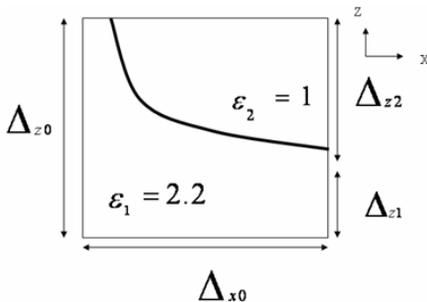


Figure 3. Effective dielectric representation.

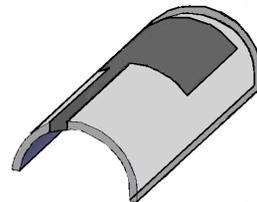


Figure 4. HHCA representation.

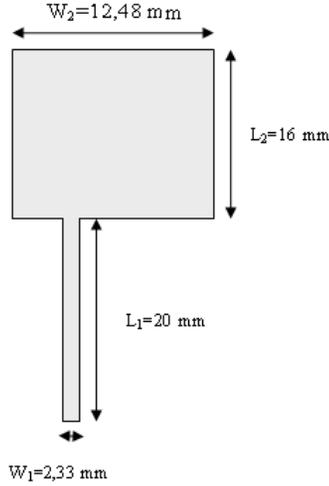


Figure 5. HHCA dimensions (top view).

The cross section of the conformal air-dielectric substrate interface is described in Cartesian coordinate system. The radius of the half cylinder is equal to 7.43 mm.

The dimensions of the studied antenna are presented in Fig. 5.

3.1. Source Considerations

In order to excite the microstrip line with a wide range of frequencies, a Gaussian pulse implemented as a soft source is used as the excitation source. This excitation is given by the following expression:

$$f(t) = \exp \left[-\frac{(t - t_0)^2}{T^2} \right] \quad (2)$$

where:

- $T = 15 \text{ ps}$, (Gaussian half width),
- $t_0 = 3T$, (Time delay)

This Gaussian distribution is assumed uniform across the width of the microstrip line [23].

3.2. Conductor Treatment

The boundary condition for a perfect electric conductor (PEC) requires the tangential electric field to be zero on this boundary.

3.3. Absorbing Boundary Conditions

In order to model open region problems, an Absorbing Boundary Condition (ABC) is often used to truncate the computational domain since the tangential components of the electric field along the outer boundary of the computational domain cannot be updated using the basic Yee algorithm. In the analysis, Mur's first order absorbing boundary conditions are used at the boundaries of the mesh. The buffer region between ABC and edges of the structure is long enough so that Mur's ABC can here efficiently absorb fields, especially evanescent fields and obliquely-incident fields.

4. NUMERICAL RESULTS

The simulation region was $38 \times 100 \times 50$ cells in the x , y , and z directions, respectively. The cell dimensions are $\Delta x = 0.3811$ mm, $\Delta y = 0.400$ mm and $\Delta z = 0.265$ mm, and the time step used is $\Delta t = 0.441$ ps. The dimensions of the conformal patch antenna analyzed here are $W_1 = 6$ cells, $W_2 = 29$ cells, $L_1 = 40$ cells and $L_2 = 50$ cells. The thickness of the antenna is 0.794 mm.

The excitation is launched through a 50 ohm microstrip feed line, which has the length of 20 mm and width of 2.33 mm.

The simulation of this circuit involves the straightforward application of the Finite-Difference equations, excitation source, absorbing boundary and stability conditions. The numerical results have been computed for 8000 iterations. With this iterations number, fields values are completely converged.

4.1. E_z -field Distribution

Figure 6 shows the E_z field component behavior for the cylindrical antenna. The obtained results prove the proper convergence of our algorithm.

4.2. S Parameters

The studied antenna's return loss results calculated with our algorithm, presented in Fig. 7, show good agreement with HFSS simulated data. The operating resonant frequencies at 7.96, 10.62 and 14.84 GHz are exactly shown by both our approach and HFSS. Because the highest resonant frequency are more sensitive to errors in the effective dimensions of the patch, the resonance frequencies 11.71 and 17.65 GHz calculated using the staircase technique are somewhat shifted.

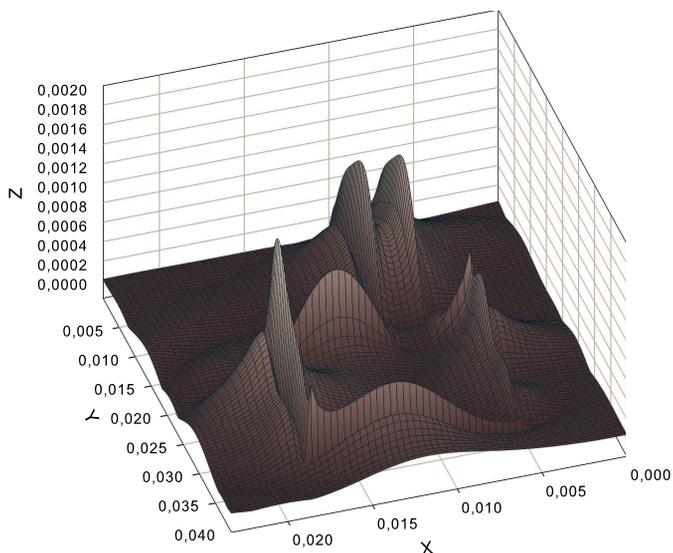


Figure 6. E_z field component behavior.

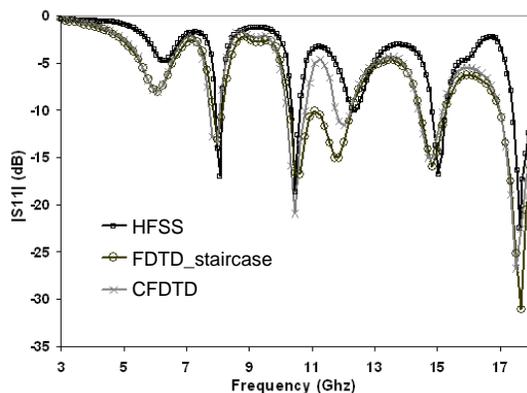


Figure 7. S_{11} parameter.

The return loss results, presented in Fig. 8, show the shift of the resonant frequencies between planar and cylindrical substrate structures. For the planar case, we consider the same antenna parameters given in [3]. We notice that a variation of antenna shape from the planar to the conformal substrate shape introduces an important shift of the values of the resonant frequency, such as about 0.467 GHz for the first resonant frequency.

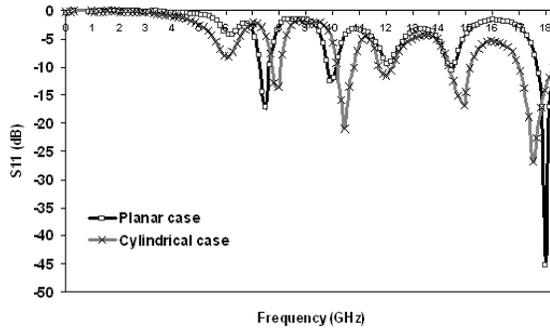


Figure 8. S_{11} comparison between planar and cylindrical case.

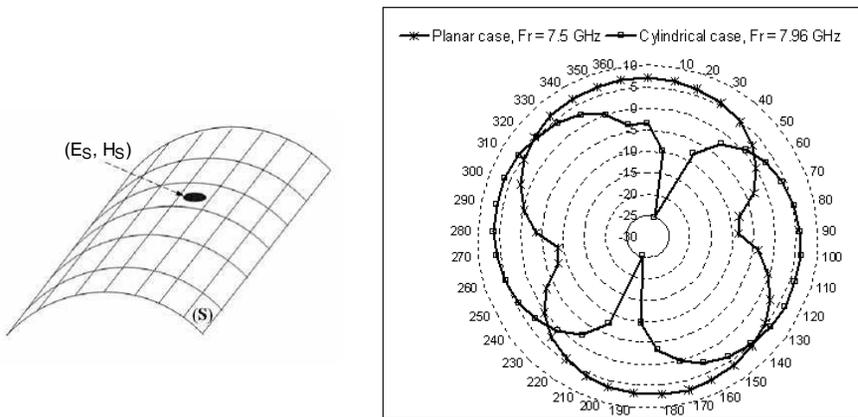


Figure 9. Cylindrical Huygens' surface. **Figure 10.** Gain total (dB).

4.3. Near-far-fields

We use the equivalence principle [24] to transform the time domain components of the near field to the frequency domain components of the far field [25].

For the planar antenna, Huygens' surface is also planar. For the HHCA, Huygens' surface is conformal (Fig. 9). We use the conformal shape to keep a vertical component of the E_z field.

The near field is computed by the CFDTD algorithm in Cartesian Coordinates System. Huygens' surface was placed above the patch and the equivalent surface currents are computed at the center of each cell on the surface. The FFT has been applied, and the field is expressed

in the frequency domain.

Figure 10 shows the difference of the Gain between planar and cylindrical case. Here the gain is calculated for the resonant frequency 7.51 and 7.96 GHz respectively for the planar and cylindrical shape. The overall gain decreases with the deformation of the substrate shape (7 dB for the planar substrate and 6.21 for the cylindrical).

5. CONCLUSION

The CFDTD technique has been implemented to investigate the frequency dependence of the relevant parameters characterizing a half hollow cylindrical antenna. It has been shown that the cylindrical shape of this microstrip structure can reduce the space occupied by the antenna. Conformal shape is another geometrical parameter considerably influencing these microstrip structure characteristics and thus can be considered as a possible parameter for monitoring them.

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