3D-FDTD Analysis of Microstrip-Fed Rectangular Dielectric Resonator Antenna Using PML as Absorbing Boundary Conditions

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Abstract — In this paper, a rectangular dielectric resonator antenna (DRA) excited by microstripline is studied using the finite-difference time-domain (FDTD).The perfectly matched layer (PML) is used as absorbing boundary conditions (ABCs). Numerical results for the return loss S11and bandwidth of the DRA operating in TE111 mode are presented and compared with those obtained by experiments. The effects of various parameters on the characteristics of the DRA are studied.

Keywords;Dielectric resonator antennas (DRAs); FDTD method; microstrip line; PML.

I. INTRODUCTION

Since his first discovered by Long etal. [1] in 1983, the dielectric resonator antenna (DRA) has received increasing attention in the last two decades, many theoretical and experimental investigations have been reported on DRAs of various shapes such as cylindrical (or cylindrical ring) [1]-[2], rectangular [3], hemispherical [4], etc… Recent studies have demonstrated their potential for millimeter wave applications [5]-[7]due to their several advantages over microstrip patch antennas such as high radiation efficiency, absence of surface waves and lower (ohmic) losses, particularly at high frequencies. DRAs can be easily excited using coaxial probe [8], microstripline[9], and microstrip slot[10].

The rectangular DRA has some advantages over cylindrical and hemispherical DRAs. For example, by choosing proper dimensions of rectangular DRA, the mode degeneracy problem can be avoided and, in addition, the resonant frequency can be controlled [11]. The resonant modes of rectangular DRA can be the transverse electric (TE) to any of its three dimensions, the lowest order mode that is commonly used is the TE111 mode [12].

The FDTD method solves Maxwell's time-dependent curl equations directly in the time domain by converting them into finite-difference equations. These are than solved in a time matched sequence by alternately calculating the electric and magnetic field in an interlaced spatial grid [13].

The advantage of this approach is the ability to investigate basic structures as well as more elaborate DR antenna structures which are analyzed with difficulty by other previously proposed methods.In this work, the FDTD method is used to study rectangular DRA excited by microstripline, using perfectly matched layers (PML) as absorbing boundary conditions (ABCs). To verify calculations, the numerical results are compared with results reported by the reference [14].

The organization of the paper is as follow;the antenna's geometry and the FDTD model are described in the section II. In section III, the numerical results are presented and discussed. Finally, a conclusion is drawn in section IV.

II. ANTENNA ANALYSIS AND DESIGN

1. Antenna'sGeometry

Fig.1 illustrates the geometry of the antenna under consideration. The antenna comprise of a rectangular dielectric resonator with dimensions $a \times b \times d$ = 11.9mm×22.5mm×5.55mm, and dielectric constant εrd= 48. The DR is excited by a 50-Ω microstripline of width w = 3mm printed on a dielectric substrate of permittivityεd= 4.28 and thickness h = 1.6 mm. The size of the ground plane is 40×40 mm2.

2. FDTD Model

The DRA can be simulated using the FDTD method with uniform Cartesian grid.The space steps used in the FDTD simulation are Δx= 0.5 mm, Δy = 0.5 mm, Δz = 0.4 mm. The time step used is Δt = 0.719ps, which satisfies the courant stability condition [15].The total size of the computational domain is $110\Delta x \times 110\Delta y \times 33\Delta z$. The simulation is performed for 5000 time steps to allow the input response become approximately zero.

A simple source approximation is used to model the feed of the microstripline[16]. A baseband Gaussian pulse of half-width T = 20ps and time delay t0 = 6T is applied at the source plane. The width of the pulse and the time delay are chosen to suit the frequency bands of interest.

Berenger's perfectly matched layer (PML) absorbing boundary conditions (ABCs) were used toterminate the simulation space.The antenna under study is enclosed by four PML side walls in the transverse direction, and two PML side walls in the longitudinal direction, 6 layers are used for each wall.

The PML can absorb propagation effectively by using nonphysical lossy media adjacent to the outer-grid boundaries backed by perfectly conducting walls. Based on the splitting of each field component into two subcomponents the electric loss σ and magnetic loss σ* for a PML medium are specified by the impedance-matching condition [17].

$$\frac{\sigma}{\varepsilon} = \frac{\sigma^*}{\mu} \tag{1}$$

Whereε and μ are the permittivity and permeability of the PML, respectively. After introducing electric and magnetic losses, electromagnetic waves inside a PML medium will attenuate rapidly. Explicit exponentially differenced field updating equations are used to replace the conventionalFDTD algorithm.

Although the FDTD simulation is carried out in the time domain, the frequency dependent parameters of the DRA are of real interest. The return loss S_{11} of the antenna is defined as

$$S_{11}(dB) = 20\log\left(\frac{H_{ref}(f)}{H_{inc}(f)}\right) \tag{2}$$

Where H_{ref} and H_{inc} are, respectively, the reflected magnetic field and the incident magnetic field at the input port of the DRA, and are frequency domain quantities. The Fourier transformations must be employed for converting the time domain field, obtained from the FDTD simulation, to the frequency domain.

I. NUMERICAL RESULTS AND DISCUSSION

A. Validation of the Results

MATLAB was used to build the code, in order to solve the problem in which the FDTD numerical technique was applied to analyze the antenna configuration of Fig. 1. Fig.2 shows the total magnetic field at the terminate plane of this structure. To check the validity of the computer code, the return loss S11 (dB) was computed as a function of frequency, and plotted together with the computed return loss obtained from the FDTD analysis (using Mur's ABC) [14] and with the measured return loss [14] as illustrated in Fig. 3. The results in term of resonant frequency and bandwidth (|S11|< -10 dB) of these three return losses are compared in Table 1.

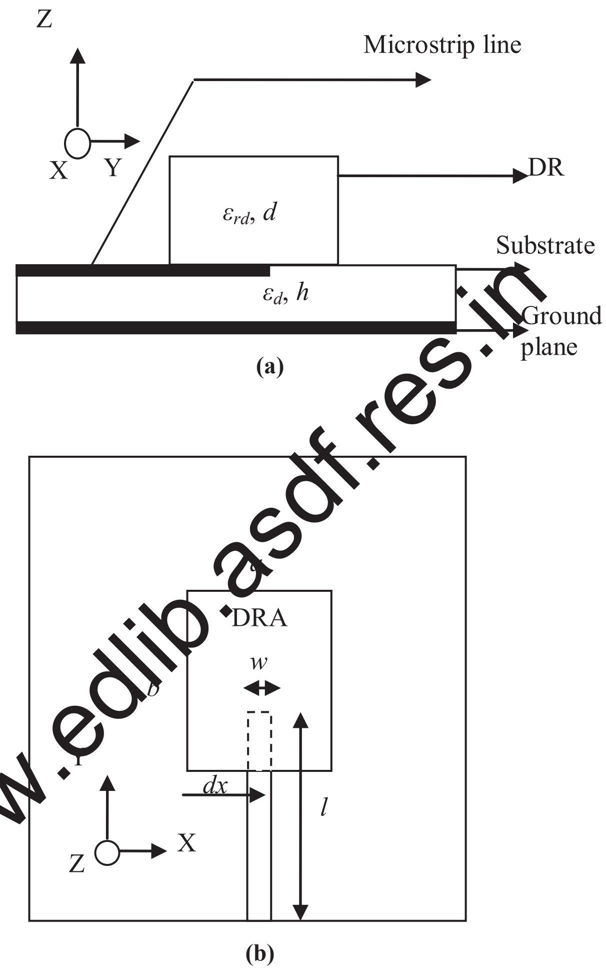

Figure1.Geometry of rectangular dielectric resonator antenna (a) Side view, (b) Top view.

As can be seen from the Table 1, the results of FDTD with PML adopted in this research and measured results of [14] are in very good agreement, and our results achieves lesserror, in term of resonant frequency and bandwidth, than the simulation results given by [14].

B. Effect of the DRA's permittivity

Fig. 4 presents the return losses of rectangular DRA for different values of DRA's permittivity (εrd = 48, 52, 56, 60). It is seen that increasing the dielectric constants of the DR lowers its resonant frequency (see Fig. 5).

The bandwidths are calculated and plotted against dielectric constant in Fig. 6. It is concluded that larger bandwidth can be attained if lower dielectric constant material is used for the DR.

TABLE1. Simulation and Experimental Resonant Frequencies and Bandwidths of Rectangular DRA.

	Experimental [14]	Simulation [14]	Error	Our simulation	Error
Resonant Frequency (GHz)	3.19	3.202	0.012	3.193	0.003
Bandwidth (%)	7.21	6.23	-0.98	6.89	-0.32

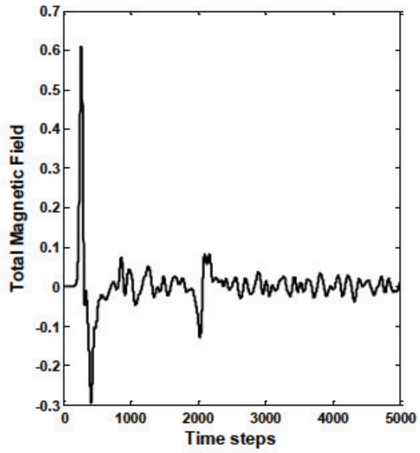

Figure 2. Total magnetic field at the terminate plan of the rectangular DRA with $a=11.9mm$, $b=22.5$ mm, $d=5.55mm$, $\varepsilon_{rd}= 48$, and $dx=3mm$.

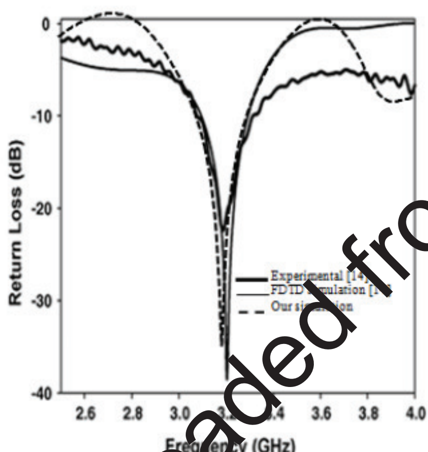

Figure3. Return loss vs. frequency of the rectangular DRA with $a=11.9mm$, $b=22.5$ mm, $d=5.55mm$, $\varepsilon_{rd}= 48$, and $dx=3mm$.

C. *Effect of the DRA's ratios*

The rectangular DRA offers practical advantages over the spherical and cylindrical shapes, due to the flexibility in choosing the aspect ratios. It has two independent shape parameters as degrees of freedom to achieve pre-specified resonant frequency for given value of the dielectricpermittivity. Fig.7 and Fig.8 show the resonant frequency as function of 'a/d' and 'b/d' respectively.

D. *Effect of the microstrip line's position*

The reference [14] optimizes the position of the excitation line, in the y direction, to obtain large bandwidth. In this work we make the same thing but in x direction by varying dx (distance between the leftextremity of the antenna and the center of the line in x direction) and calculating the bandwidth. Fig. 9 shows the return losses for different distance dx, the resonant frequency and the bandwidth are reported in the table 2.

TABLE2. Resonant Frequencies and Bandwidths for Different Positions of Excitation Line.

dx (mm)	1.5	3	4.5
Resonant Frequency (GHz)	3.188	3.198	3.193
Bandwidth (%)	7.81	7.19	6.89

From table 2, it can be seen that the bandwidth can be improved by shifting the excitation from the center of the DRA but in this case the reflections are increased.

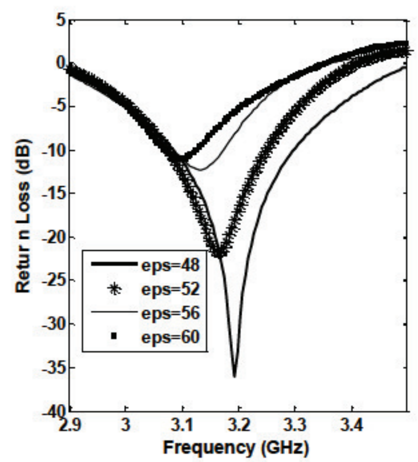

Figure 4.Returns losses vs. frequency of the rectangular DRAs for different values of ε_{rd}, with $a=11.9mm$, $b=22.5$ mm, $d=5.55mm$, and $dx=3mm$.

I. .CONCLUSION

A FDTD with PML's ABCs model for analyzing a rectangular DRA fed by a microstrip line has been presented in this paper. It has been demonstrated that the model is capable of generating very accurate numerical results. The effects of different parameters electrics and geometrics of the antenna on his characteristics are presented. Finally, the position of the excitation line is studied and optimized for large bandwidth

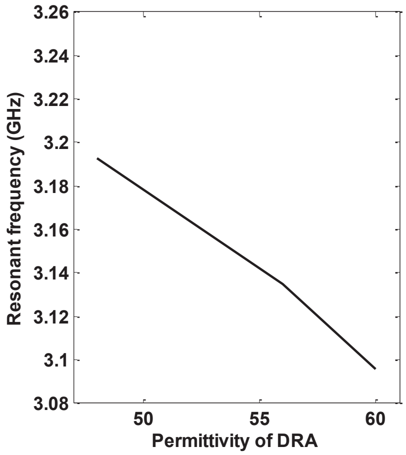

Figure 5. Resonant frequency vs. permittivity of DRA with *a=11.9mm*, *b=22.5 mm, d=5.55mm*, and *dx=3mm*

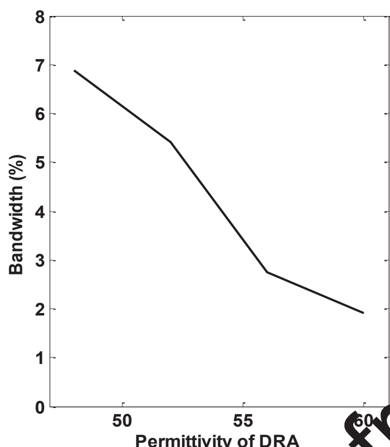

Figure 6. Bandwidth vs. permittivity of DRA with a=11.9mm, b=22.5 mm, d=5.55mm, and dx=3mm.

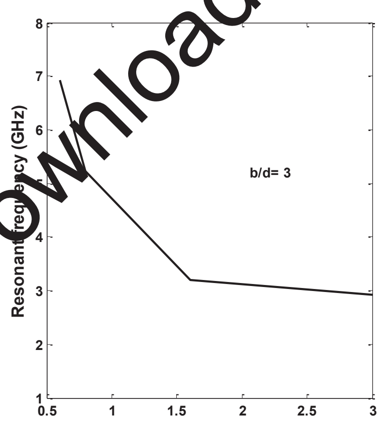

Figure7. Resonant frequency against ratio 'a/d' of DRA with b=22.5 mm, and 'b/d'=3.

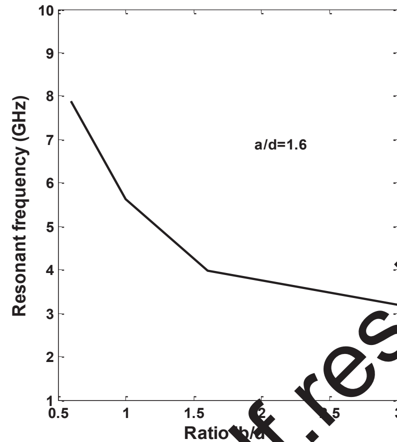

Figure 8. Resonant frequency against ratio 'b/d' of DRA with a=11.9 mm, and 'a/d'=1.6.

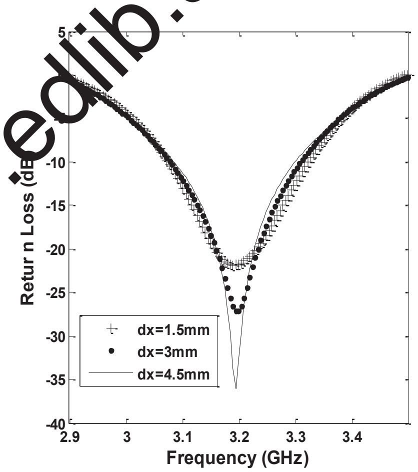

Figure 9. Returns losses vs. frequency of the rectangular DRA for different position (*dx*) of the microstrip line, with *a=11.9mm*, *b=22.5 mm, d=5.55mm*, and $\varepsilon_{rd} = 48$.

REFERENCES

[1] S. A. long, M. W. McAllister, and L. C. Shen, "The resonant cylindrical dielectric cavity antenna", IEEE Trans. Antennas Propagat., Vol. AP-31, pp. 406-412, May 1983.

[2] S. M. Shum, and K. M. Luk, "Staked annular ring resonator antenna excited by axi-symmetric coaxial probe", IEEE Trans. Antennas Propagat., Vol. AP-43, pp. 889-892, Aug. 1995.

[3] M. W. McAllister, S. A. Long, and G. L. Conway, "Rectangulardielectric resonator antenna," Electron. Lett.Vol. 19, pp. 218-219,Mar. 1983.

[4] M. W. McAllister and S. A. Long, "Resonant hemispherical dielectric antenna," Electron. Lett. Vol. 20, pp. 657-659, Aug. 1984.

[5] Q. Lai, G. Almpanis, C. Fumeaux,H. Benedickter, and R. Vahldieck, "Comparison of the Radiation Efficiency for the Dielectric Resonator Antenna and the Microstrip Antenna at Ka Band", IEEE Trans. Antennas Propagat., Vol. 56, pp. 3589-3592, November 2008.

[6] G. Almpanis, C. Fumeaux, and R. Vahldieck, , "The Trapezoidal Dielectric Resonator Antenna", IEEE Trans. Antennas Propagat., Vol. 59, pp. 2810-2816, September 2008.

[7] Wael M. Abdel Wahab, Dan Busuioc, andSafieddin Safavi-Naeini, “Low Cost Planar Waveguide Technology-Based Dielectric Resonator Antenna (DRA) for Millimeter-Wave Applications: Analysis,Design, and Fabrication”, IEEE Trans. Antennas Propagat. Vol. 58, pp. 2499-2507, August 2010.

[8] A. Kishk et al, “Numerical Analysis of Stacked Dielectric ResonatorAntennas Excited by a Coaxial Probe for WidebandApplications”,IEEE Trans. Antennas Propagat., Vol. 51, pp. 1996-2006, August 2003.

[9] D. Rotaru and K. Sykulski, “Design and Analysis of a Novel Compact High PermittivityDielectric Resonator Antenna”, IEEE Trans. on Magnetic, Vol. 45, pp. 1052-1055, March 2009.

[10] A. Buerkle,K. Sarabandi, andH. Mosallaei,“Compact Slot and Dielectric Resonator Antenna withDual-Resonance, Broadband Characteristics”, IEEE Trans. Antennas Propagat. Vol. 53, pp. 1020-1027, March 2005.

[11] K.-M. Luk and K.-W. Leung, “Dielectric Resonator Antennas”, Steven age, U.K.: Research Studies Press, Ltd., 2002.

[12] K. Mongia and A. Ittipiboon,“Theoretical and Experimental Investigationson Rectangular Dielectric Resonator Antennas”, IEEE Trans. Antennas Propagat. Vol. 45, pp. 1348-1356, September 1997.

[13] Yee, K. S., ‘‘Numerical solution of initial boundary value problems involving Maxwell’s equations in isotropic media.’’ IEEE Trans. Antennas Propagat. vol. 14, pp. 302- 307, 1966.

[14] P. Mohanan et al, ‘‘FDTD analysis of rectangular dielectric resonator antenna, ’’ Journal of the European Ceramic Society 27, pp 2753-2757, 2007

[15] Allen Tavlove, Susan C. Hagness, “Computational Electrodynamics: The Finite Difference Time Domain Method, Second Edition”, Artech House, London. 2000.

[16] Dennis M. Sollivan, “Electromagnetic simulation using the FDTD method,” IEEE press. Piscataway, NJ, 2000.

[17] J.-P. Berenger, “A Perfectly Matched Layer for the Absorption of Electromagnetic Waves,” Journal ofComputational Physics, vol. 114, pp. 185–200, 1994.

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