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Design of a Stacked Dielectric Resonator Antenna for X-band Applications

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***Abstract*— The dielectric resonator antenna (DRA) in a stacked configuration with a finite ground plane is presented in this paper. The proposed DRA is axisymmetric and is excited by coaxial probe feeding technique. Here broadside radiation pattern is obtained for exciting $HEM_{11\delta}$ mode of DRA by locating the coaxial feed at the off-axis position. This work mainly focuses on the improvement in the bandwidth of DRA. The analysis of the antenna with far-field radiation characteristics is performed. A $-10\ dB$ bandwidth of 44.88% is realized for the stacked DRA arrangement with suitable feed and selection of the dielectric resonator parameters. The proposed two-layer DR antenna can be appropriate for X-band applications.**

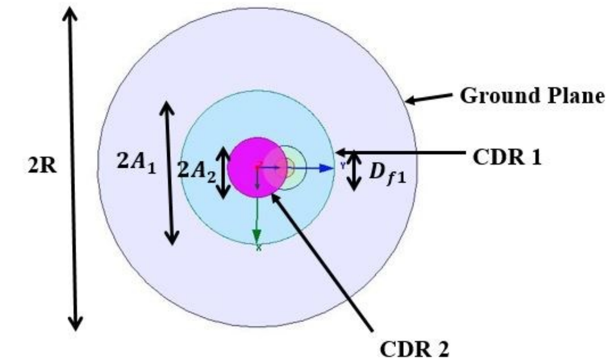
Keywords— Dielectric resonator antennas (DRA), stacked antennas, axisymmetric, coaxial probe.

I. Introduction

The need for dielectric resonator antenna (DRA) is continuously being enhanced because of the essential features such as reduced size, high radiation efficiency, and cost-effectiveness [1-2]. With the use of low or medium loss dielectric materials, DRA can achieve more than 90% radiation efficiency. The above is possible because of the absence of surface wave and conductor losses [3].

A variety of shapes such as hemispherical, cylindrical, triangular, spherical-cap, cylindrical-ring, and rectangular DRAs have been studied extensively for different applications. The above investigations were used mostly for enhancement of bandwidth [2-4]. However, there is much more space for research in DRAs having stacked configuration. Several feeding techniques such as coplanar waveguide (CPW) feed, microstrip line feed, coaxial probe feed, vertical strips feed and slotted couplings can be used to excite DRAs with various shapes and sizes [2-6].

In this article, a stacked DR configuration is proposed in order to enhance the bandwidth. The structure consists of two Cylindrical DRAs in a stacked manner. Here multilayer concept of dielectric is introduced to enhance the fractional bandwidth of the proposed DRA. With increasing value of dielectric constant, there is a trend of decrement in both resonant frequency and bandwidth and vice versa. Therefore, DR with low ϵ_r helps to improve the bandwidth and DR with high ϵ_r supports to lower the resonant frequency [6]. Lower DR probe coupling is used in order to excite the $HEM_{11\delta}$ mode. The optimization of the extent of coupling can be achieved by adjustment of the height of the coaxial probe as well as optimal ϵ_r used for the dielectric resonator (DR). The proposed design operates at two resonant



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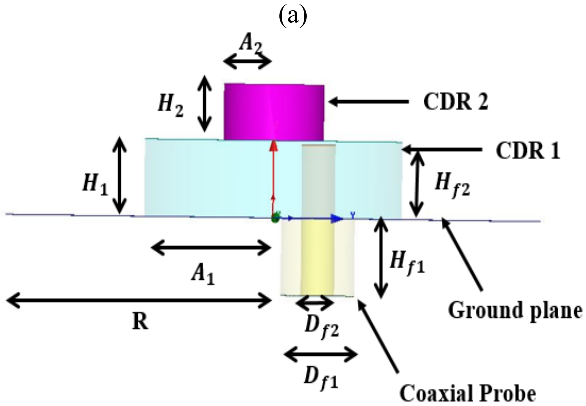

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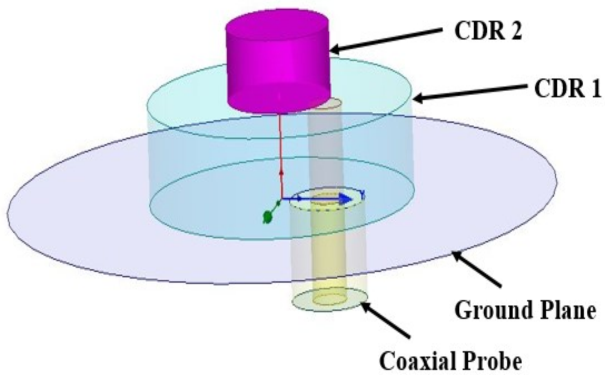


(c)

Fig.1. Antenna geometry (a) Top view, (b) Side view, (c) 3-D view.

frequencies i.e. 8.4 GHz and 11 GHz and can be suitable for X-band applications.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig.1. The antenna configuration having Cylindrical DR (CDR) view consists of two cylindrical DRAs in a stacked manner. The materials used for cylinder-1 (loaded by ground plane) and cylinder-2 (loaded by cylinder-1) are FR4 epoxy ($\varepsilon_r = 4.4, \tan\delta = 0.02$) and Arlon AD1000(tm)($\varepsilon_r = 10.2, \tan\delta = 0.0023$) respectively. This antenna has a circular finite ground plane with radius, $R = 16\ mm$ and is excited by coaxial probe feeding technique with 50 Ω port impedance value.

Resonant frequency (f_r) is one of the key features in designing DR Antenna. The following expressions describe the mathematical formulae for calculation of f_r operating in $HEM_{11\delta}$ mode in conventional cylindrical DRA [6].

For $HEM_{11\delta}$ Mode,

$$f_r = \frac{2.735 c \varepsilon_r^{-0.436}}{2\pi A}\left[0.543 + 0.589\left(\frac{A}{2H}\right) - 0.050\left(\frac{A}{2H}\right)^2\right] \quad (1)$$

and the expression of radiated Q-factor is given by:

$$Q_{rad} = 0.013\varepsilon_r^{1.202}\left[2.135\left(\frac{A}{2H}\right) + 228.043\left(\frac{A}{2H}\right)e^{-2.046\left(\frac{A}{2H}\right)+0.111\left(\frac{A}{2H}\right)^2}\right] \quad (2)$$

Where c, A, H, and ε_r are the velocity of light in free space, radius, height, and dielectric constant of the DR respectively.

The radiation Q-factor is one important parameter in estimation of impedance bandwidth of a DRA and it is given by the following expression [7-8]

$$\text{Impedance Bandwidth (BW)} = \frac{VSWR-1}{Q_{rad}\sqrt{VSWR}} = \frac{\Delta f}{f_r} \quad (3)$$

Where Δf represents the absolute bandwidth. As mentioned in eqn (3), large impedance bandwidth requires low Q-factor which mandates the use of low dielectric constant materials. This also depends upon the (A/H) ratio.

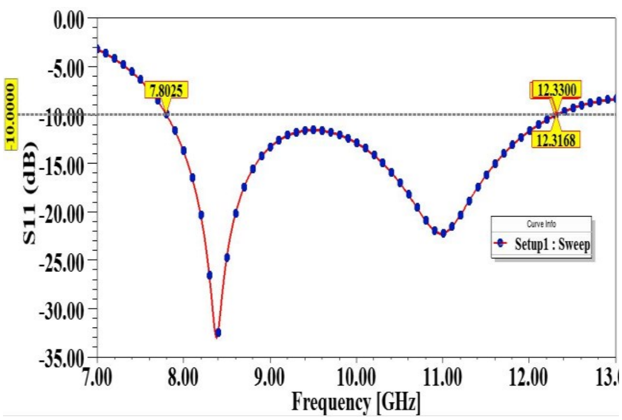


Fig. 2. Reflection coefficient variation for proposed antenna.

The enhancement of the bandwidth can be achieved by using of multilayer concept. Eqn (1) and (3) indicate the relationship between ϵ_r, f_r, and the bandwidth. With increment in ϵ_r, both resonant frequency and bandwidth decreases and vice versa. In the stacked configuration of the two-layer DRA, lower DR is responsible for enhancing the bandwidth whereas Upper DR assists in lowering the resonant frequency. For exciting the $HEM_{11\delta}$ mode, lower DR probe coupling is used. Adjustment of both probe height and the optimal dielectric constant of DR is made in order to achieve optimized coupling. After parametric analysis in the simulation environment, the optimized design dimensions of the antenna is calculated and is presented in Table-1.

Table 1: Details of Structural Geometry

Description	Parameter	Dimensions (mm)
Cylindrical Dielectric Resonator 1(CDR 1)	A_1	7.7
	H_1	4
Cylindrical Dielectric Resonator 2 (CDR 2)	A_2	3
	H_2	2.9
Radius of ground plane	R	16
Diameter of outer conductor of coaxial feed	D_{f1}	4.4
Diameter of inner conductor of coaxial feed	D_{f2}	2
Height of inner/outer conductor of coaxial feed below ground plane	H_{f1}	4
Height of inner conductor of coaxial feed above ground plane	H_{f2}	3.8

III. Results and Discussion

Proposed antenna has been simulated using ANSYS HFSS version 15 simulation tool. Fig. 2 presents the reflection coefficient variation of the structure.

It shows -10 dB bandwidth in the range of 7.81 GHz-12.33 GHz. The plot illustrates a fractional bandwidth of 44.88% for the center frequency at 10.05 GHz.

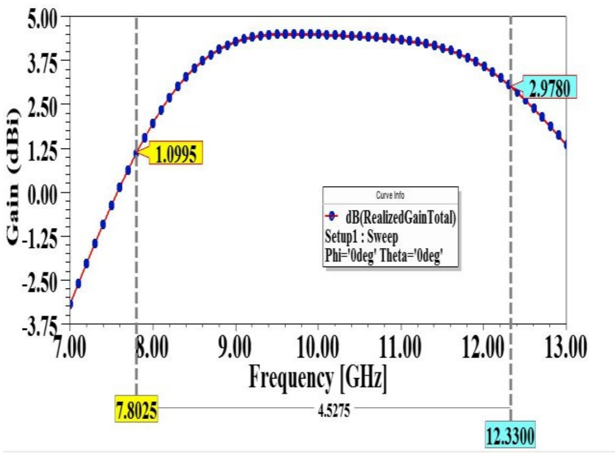
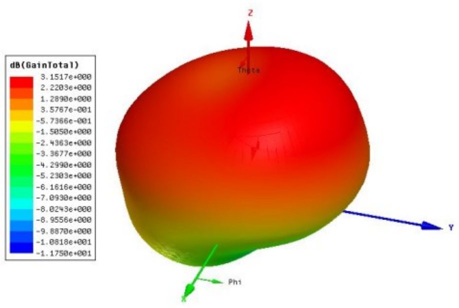


Fig. 3. Variation of gain for the proposed antenna.

The variation of gain for the proposed antenna is shown in Fig. 3. It clearly indicates the maximum gain of 4.48 dBi at 9.65 GHz.

The 3-D polar plot of the structure at four different frequencies i.e. at 7.81 GHz, 8.4 GHz, 11 GHz, and 12.33 GHz respectively is shown in Fig. 4. It shows the maximum gain of



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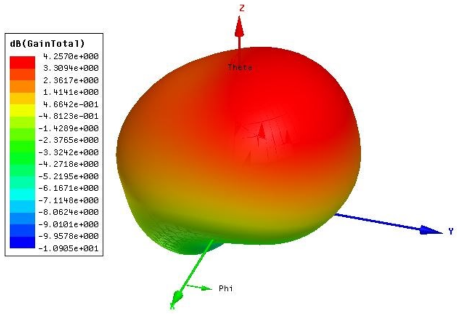

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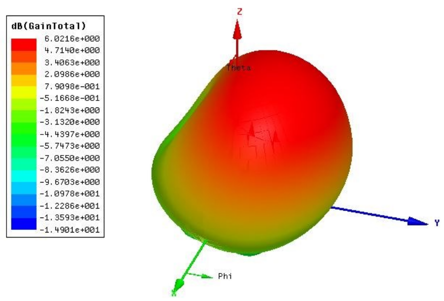

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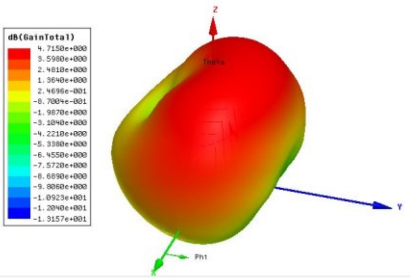
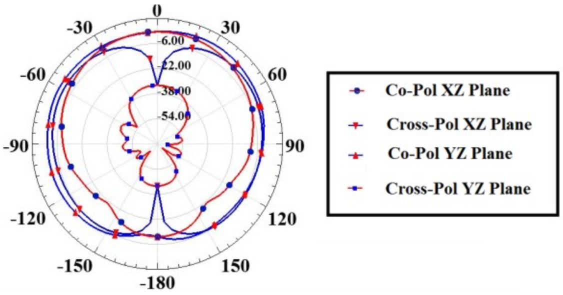


(d)

Fig. 4. 3-D polar plot at (a) 7.81 GHz, (b) 8.4 GHz, (c) 11 GHz, (d)12.33 GHz .

4.25 dB, 6.02 dB at the resonating frequencies 8.4 GHz and 11 GHz respectively.

Fig. 5. describes the radiation patterns obtained at four different frequencies i.e. 7.81 GHz, 8.4 GHz, 11 GHz, and 12.33



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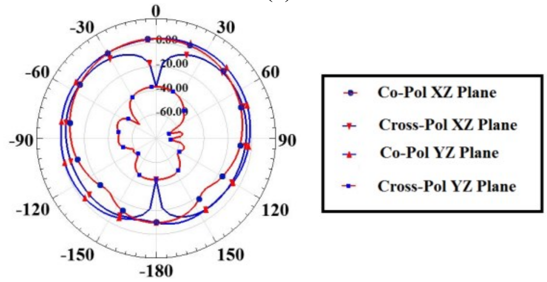

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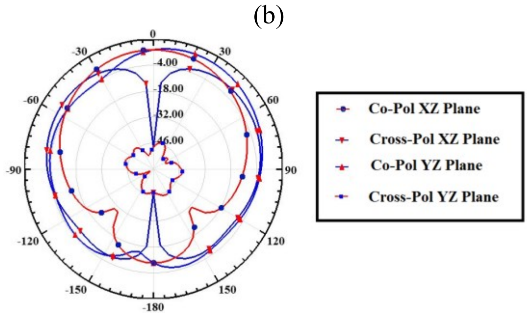

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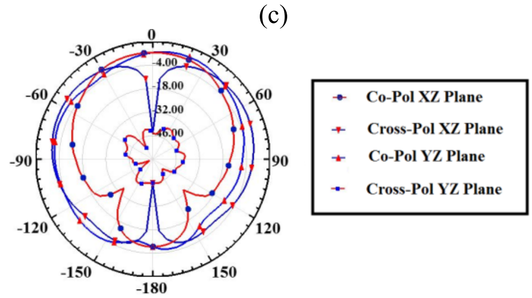

(d)

Fig. 5. Radiation pattern at (a) 7.81 GHz, (b) 8.4 GHz, (c) 11 GHz, (d) 12.33 GHz.

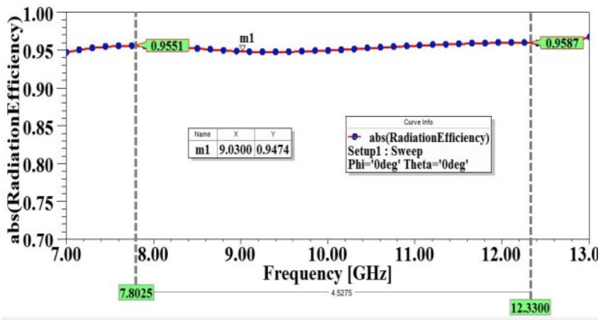

Fig. 6. Variation of radiation efficiency for the proposed antenna.

GHz. The results demonstrate that cross-polarization level is at nearly -18 dB and -40 dB low at 8.4 GHz in XZ-plane and YZ-plane respectively.

The radiation efficiency plot of the antenna is shown in Fig. 6. It is observed that efficiency is more than 94% throughout the band of 7.81 GHz-12.33 GHz.

IV. Conclusion

A stacked cylindrical DRA has been investigated. The antenna is designed using two dielectric materials of cylindrical shape. The proposed structure offers $-10\ dB$ bandwidth in the frequency range from 7.81 GHz-12.33 GHz. This provides an impedance bandwidth of 44.88% with a maximum gain of 4.48 dBi at 9.65 GHz and maximum efficiency of 96% at 12 GHz. The proposed X-band antenna is a suitable candidate that supports the application in the field of satellite communication, radar, terrestrial broadband, space communication.

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