Analysis of Cylindrical Dielectric Resonator Antenna with Modified Micro-Strip

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Abstract— **This paper provides a comparative analysis of cylindrical dielectric resonator antenna with simple micro-strip feed to that of a modified micro-strip feed. The fundamental radiator is having a radius of 5.96 mm and height of 9.82 mm with relative permittivity ε_r of 10. It is placed over a substrate having dimension 40×40×0.785 mm3 with ε_r equal to 2.5. The substrate is embedded with an infinite ground plane to reduce the physical height of the antenna according to image theory. Two types of micro-strip feeding mechanisms are being experimented. The simplified micro-strip feed radiator resonates at 5.7 GHz with impedance bandwidth of 14.03%. The modified micro-strip feed with an added stub resonates at 10.65 GHz & 13.5 GHz with impedance bandwidth of 21.596% & 13.33% respectively. Matching profile, directive gain and efficiency can be enhanced by almost 10% by modifying simple micro-strip feed to micro-strip feed with stub structure of proposed antenna.**

Index Terms— *Cylindrical Dielectric Resonator Antenna, Micro strip feed, Finite Element Method*.

I. INTRODUCTION

Use of opened dielectric resonators as antenna was first approved by paper published on cylindrical dielectric resonator antenna by Professor S. A. Long [1]. After this, other shapes were also investigated like rectangular, hemispherical, triangular etc. DRA provides numerous advantages over metallic antennas like: high radiation efficiency (>95%) with absolute negligible loss due to presence of low loss tangent (tan δ)[2]. It is miniaturized in structure and possesses lower aspect ratio even at higher frequencies. It can be used in hybrid structures. Because of high directivity and high gain it is suitable for communication device used especially in tunnels and underground mines [3]. It has wide impedance bandwidth (of ~10% of dielectric permittivity) as dielectric radiates by using all the surface area [4]. There are different shapes of DRA available out of which cylindrical structure is chosen because they have high potentials to replace waveguide cavity resonators when fabricated from relatively high dielectric constant materials ($\varepsilon_r \geq$ 35%) for compactness [5]. Computational aspect of cylindrical DRA is simplest while comparing with other types of available structure. The aspect ratio of CDRA depends on both height and radius. Aspect ratio specially determines the resonant frequency of the cylindrical radiator. Both rectangular and cylindrical DRA supports lower order modes. But cylindrical DRA has more impedance BW than rectangular DRA while working

on the same mode configuration. Radiation pattern can also be electronically steered by turning on and off different combination of probes in cylindrical DRA. Here we are using micro strip feed by considering ease in manufacturing with minimum error and maximum stability. Here we are comparing two CDRAs based on their feed structure. The analysis software used is Ansys HFSS 14.0 which uses structural simulator method FEM (Finite Element Method) [6].

II. ANTENNA DESIGNS

A. Antenna with straight line feed on CDRA wall

Cylindrical shaped antenna is designed by using micro-strip feed line. The feed extends from the center of the substrate to the front cylindrical wall as shown in Fig (1a).
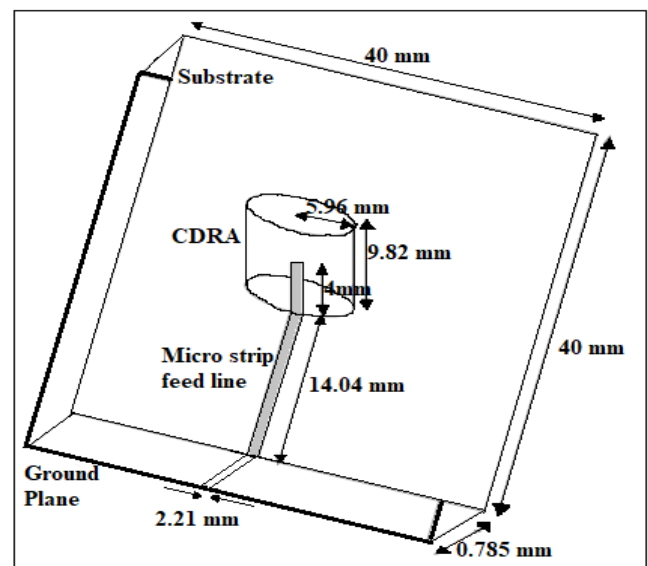

Fig. 1a. Geometry of the cylindrical DRA

As shown in the figure-1 the CDRA is placed over a substrate having dimension of 40×40×0.785 mm3 with relative permittivity of 2.5 and loss tangent (tan δ) of 0.002. An infinite ground plane with dimension of 40× 40 mm2 is placed at the bottom side of the CDRA. Micro-strip feed line is supplying energy from the source to the radiating CDRA. The length and width of the micro-strip transmission line is 14.04 mm and 2.21 mm respectively along the XY plane. Further transmission line is extended 4 mm up to the front

wall of the CDRA along the YZ plane. Cylindrical DRA has 9.82 mm in height and 5.96 mm in radius and is placed on the center of the substrate. It has relative permittivity 10 with loss tangent of 0.003. Figure (1 b) shows the design of the antenna fed by micro-strip line using Ansys HFSS software.
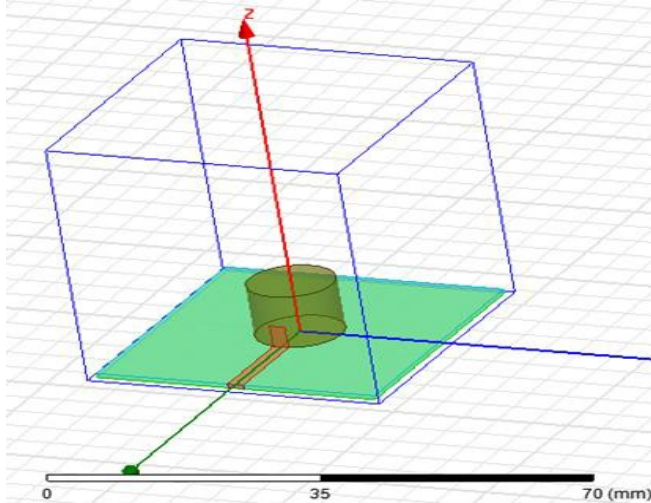

Fig.1b. Proposed cylindrical DRA

B. Antenna with cross feed structure slanting on CDRA wall

In this design only there is altercation in the feed structure while dimensions of the substrate, ground plane, CDRA, feeding techniques and height remain constant. The only difference lies in the cross structure of the feed as shown in figure 1c. The rectangular structure added on both sides of the feed of cylindrical wall of CDRA which has dimensions of 2×0.75 mm2 with a vertical distance of 2 mm from the substrate.
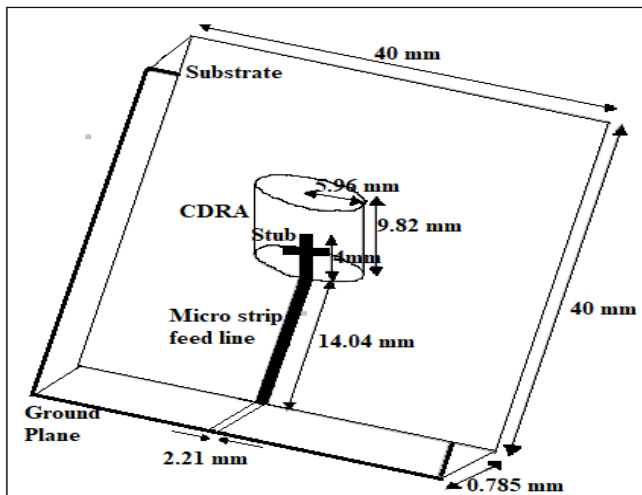

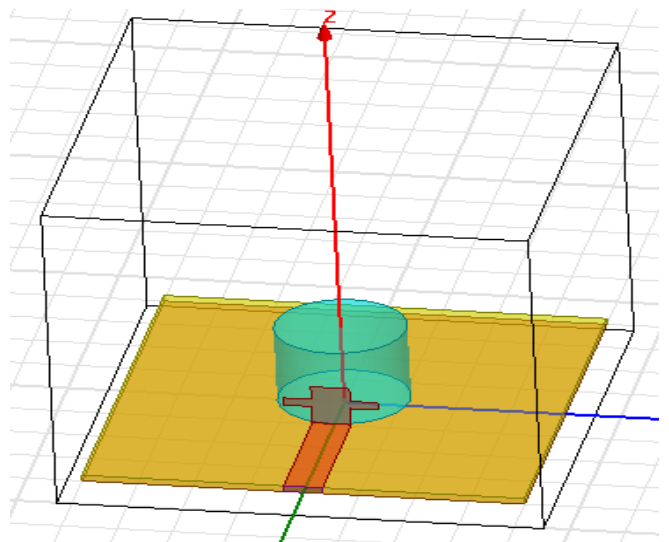**Fig. 1c.Geometry of the modified micro-strip feed in CDRA**

Fig.1d. Modified micro-strip feed in CDRA.

III. ANTENNA ANALYSIS

Resonant frequency of the Cylindrical DRA can be determined by solving the Helmholtz's equation and by considering source and boundary conditions in the CDRA. The characteristics equation of the CDRA is given as:

$$k_r^2 + k_z^2 = k^2 = \omega^2 \mu \varepsilon \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (1)$$

Where,

$$k_r = \frac{1}{a}\{X_{np}^{TE} X_{np}^{TM}\} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (2)$$

$$k_z = (2m+1)\pi/2d \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3)$$

Knowledge of these propagation constants lead to determination of both electric and magnetic field in the broadside z-direction and lowest order mode where optimum oscillation takes place within the radiating structure. Resonant frequency of the cylindrical DRA depends upon the aspect ratio and permittivity of the material [4]:

$$f_{npm} = \frac{c}{2\pi a \sqrt{\varepsilon_r}} \left[\left[\frac{X_{np}^{TE}}{X_{np}^{TE}} \right] + \left(\frac{(2m+1)\pi a}{2d} \right)^2 \right]^{0.5} \dots \dots \dots \dots \quad (4)$$

Where,
c= speed of light in vacuum
a= radius of cylindrical DRA
h= height of cylindrical DRA
ε_r = permittivity of dielectric material used
k_r & k_z= wave number inside the dielectric resonator in r & z directions respectively.
X= Function of Bessel function of respective mode and transverse characteristics.

IV. PARAMETRIC COMPARATIVE ANALYSISOF RESULTS

A. Reflection Coefficient Plots
    For the antenna shown in Figure 1b, reflection coefficient came out to be as in Figure 2a. Frequency range

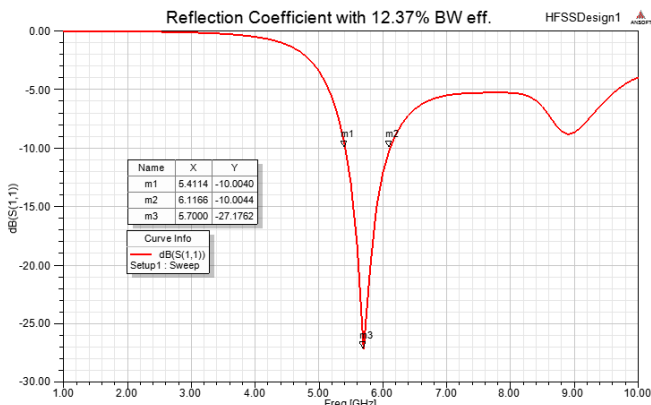is from 5.4 to 6.11 GHz resonating at 5.7 GHz with bandwidth efficiency of 14.03%.

Fig. 2a. Reflection coefficient versus frequency in GHz plot of the CDRA with simplified micro-strip feed

Figure 2b shows the reflection coefficient versus frequency in GHz plot of the designed CDRA with modified micro-strip feed as shown in Figure 1d. It shows dual impedance wideband i.e. Band-I: 8.7 GHz to 11 GHz resonating at 10.65 GHz with bandwidth efficiency of 21.59% and Band–II: 12.3 GHz to 14.1 GHz resonating at 13.5 GHz with bandwidth efficiency of 13.33%.
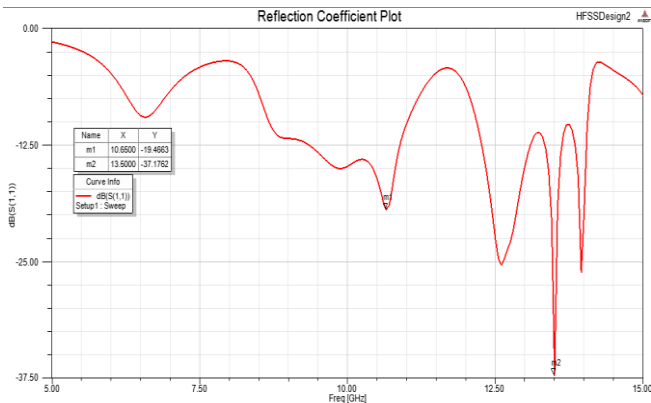

Fig. 2b. Reflection coefficient versus frequency in GHz plot of the CDRA with modified micro-strip feed

The variation in operational impedance band width is due to the presence of modified feeding technique which provides suitable matching profile to improve input and output characteristics of the desired antenna. From the above plot of figure 2b, it can be concluded that by changing feed structure on cylindrical wall along with increasing the interaction between CDRA and transmission line we can achieve wideband with greater bandwidth efficiency.

B. Three dimensional total gain plot

 Antenna corresponding to figure 1b results in 3-D gain plot as shown in figure 2c. It is observed that CDRA with simplified micro-strip feed radiates in the broad side direction where θ=0₀and front lobe contributes maximum in comparing to that of back lobe. Thus this design has high front to back ratio 30.067 dB with radiation efficiency of 90.41%. Similar plot can be obtained for the CDRA with modified micro-strip feed. We are again getting high front to back ratio of 37.96 dB with radiation efficiency of 100.03%.
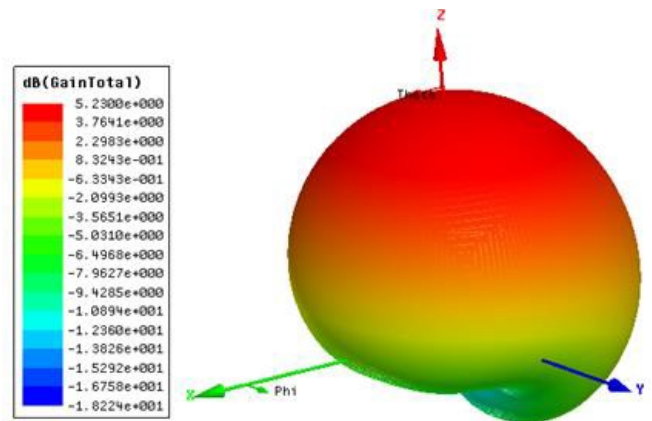

Fig. 2c. 3-Dimensional total gain plot

C. Analysis of total gain versus frequency plot

 According to the antenna design of figure 1b, gain total versus elevation angle results in maximum value of 5.8dB at 0 degree elevation angle in figure 2e.
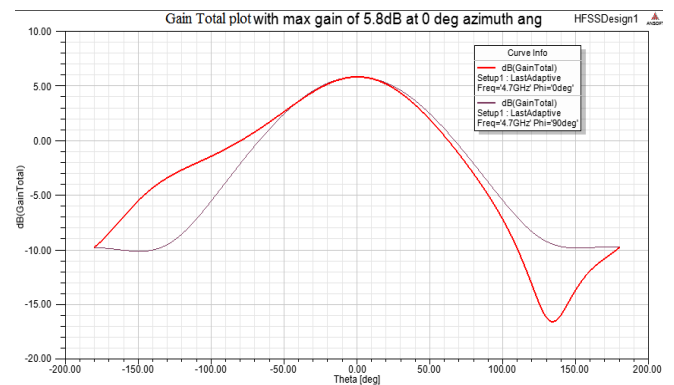

Fig.2d. Total gain versus azimuthal angle (θ) plot of the simplified micro-strip line

Figure 2d and 2e indicates the plot of total gain versus θ. From this 2-D plot it is obtained that both these antenna radiate in the broadside direction with θ=0°. There is linear response of the total gain whenever variation occurs in the elevation plane. CDRA with simplified and modified gain w.r.t θ is found to be 4.38 dB& 4.59 dB respectively.
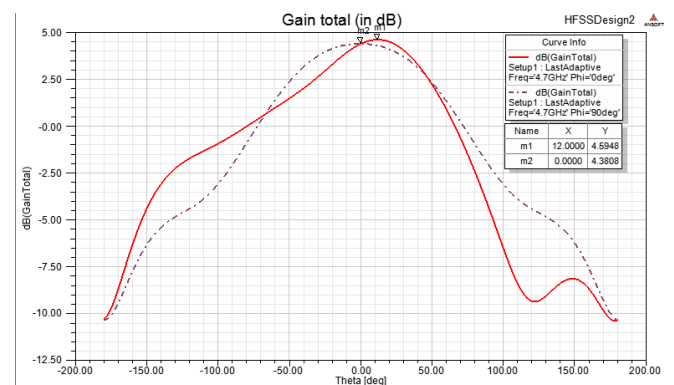

Fig.2e. Total gain versus azimuthal angle (θ) plot of the modified micro-strip line

From above both plots, we observed decrement in gain as per varying elevation angle and constant azimuth angle of 0 and 90 degrees respectively.

D. Gain in Phi Plane Analysis

As per figure 1b of CDRA design, gain in azimuth plane of 0 and 90 degrees shows good result of low cross polarization levels of lesser than -40 dB.
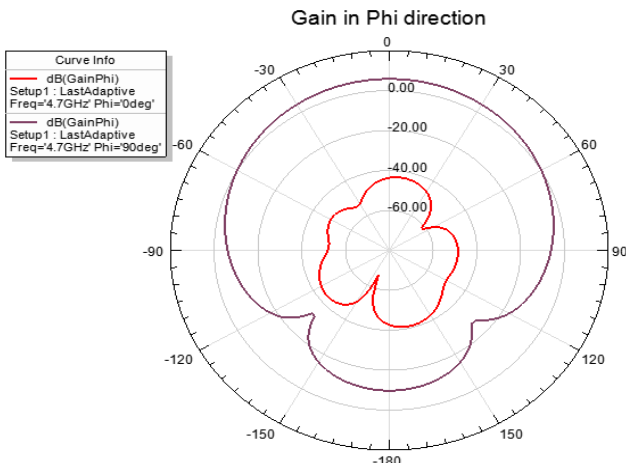

Fig.2f. radiation pattern of Gain in Azimuth angles of 0 and 90 degrees with all elevation angles.

Figure 2f shows co and cross polarization of the antenna at 4.7 GHz for the antenna with simplified feeding mechanism. It indicates that cross polarization levels to be lesser than 44 dB. Figure 2g shows the co and cross polarization of the antenna for the modified feed at 5.8 GHz.
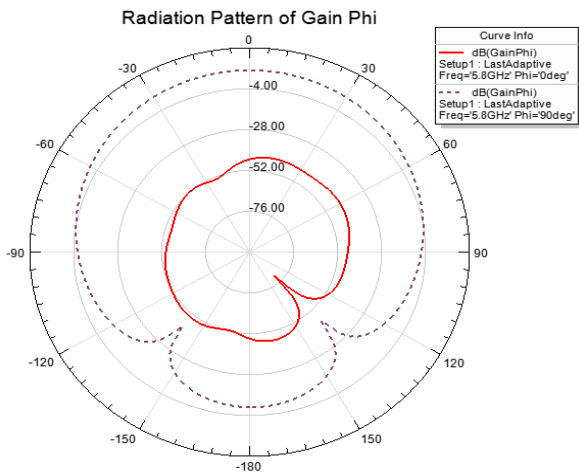

Fig.2g.Radiation Pattern of Gain in Azimuth angles of 0 and 90 degrees.

E. Surface current Density Plot Analysis

Figure 2h corresponds to antenna design of figure 1b and shows maximum of surface current density at micro strip feed near to the CDRA wall.
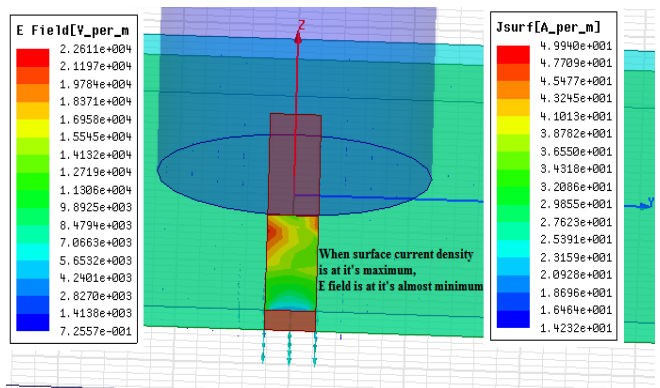

Fig.2h. Surface current density Jin Amp/m2

As per antenna design of figure 1d, surface current density plot in figure 2i depicts its maximum around the corners of feed line over the substrate just before and touching the cylindrical wall of DRA.
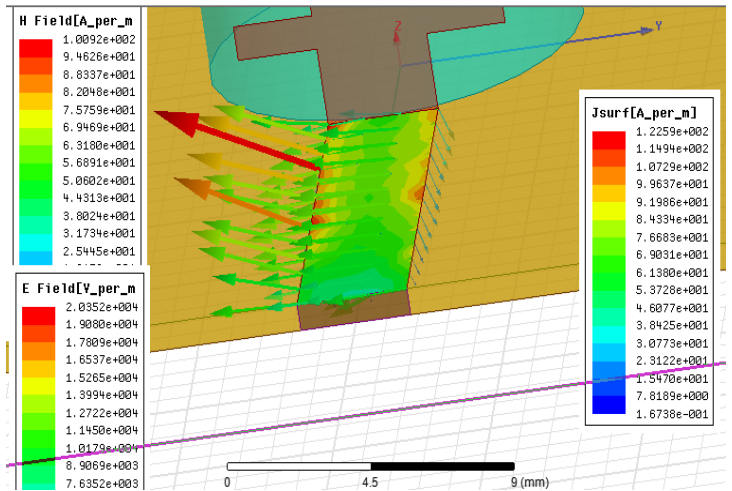

Fig.2j. Surface current density plot

S. No.	Antenna Parameters	Result corresponding to respective antenna design	
		Result of Fig. 1b.	*Result of Fig. 1d*
1.	Resonant Frequency	5.7GHz	10.65 GHz & 13.5 GHz
2.	Frequency Range	5.6 to 6.4 GHz	8.7 to 11 GHz & 12.3 to 14.1 GHz
3.	Bandwidth Efficiency	14.03%	21.596% & 13.33%
4.	Radiation Efficiency	90.41%	100.03%
5.	Peak Gain	3.8035 dB	4.7339
6.	Peak Directivity	3.8934 dB	4.7324 dB
7.	Front to Back Ratio	36.067 dB	37.966 dB

Table 1. Comparative analysis of input and output characteristics of both antenna designs

CONCLUSION

This paper provides a comparative analysis of CDRA with simplified and modified micro-strip feed. An impedance bandwidth of 12.3719% at 5.7GHz, 21.596% at 10.65 GHz and 13.33% at 13.5 GHz are obtained with peak gain of 3.8035 dB and 4.7339 dB respectively. Furthermore for both the designs linear polarization has been achieved with low cross polarization levels of lesser than 40 dB. This antenna can be useful in application such as Amateur radio and amateur satellite services, radio-locator, spectrum sensing communication link etc. This antenna can be fabricated from PCB integrated millimeter wave circuit design.

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