Proceedings of the "2013 International Symposium on Electromagnetic Theory"

23PM3A-01

A Concentric Three-layer Half-split Cylindrical Dielectric Resonator Antenna for Wideband Applications

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***Abstract*—A Concentric 3-Layer half-split cylindrical dielectric resonator antenna (CDRA) for wideband application has been designed and developed. The effect of antenna parameters such as layer arrangement, geometrical parameters and probe length are investigated. The fabrication is performed with commercially available microwave laminates. The proposed antenna has measured impedance bandwidth of 84.72% ($S_{11} \leq$ -10 dB) at 5.50 GHz, which is from 4.51 GHz - 9.17 GHz. The proposed antenna has good radiation characteristics, with an average gain of 9.15 dB in the operating band, which is very suitable for wideband wireless system applications.**

I. Introduction

Dielectric resonator antennas (DRAs) are, as a potential alternative to the conventional printed and wire antennas like microstrip patch antenna, slot type antenna, loop antenna etc. With the appearance of DRAs in 1983 [1], the attention and the work on this type of antenna have grown rapidly due to its low loss, high radiation efficiency, wide bandwidth, small size and so on. At high frequencies, DRAs are reasonably useful because conductor losses become a serious problem for conventional printed antennas in high-frequency applications. For the single-mode operation, the bandwidth of DRA is near about 15% when the relative dielectric constant is in between 10 to 15 [2-4].

The initial research work on the wideband DRA was experimentally carried out in 1989 by Kishk *et al.* [5], who stacked two different permittivities of DRAs to obtain a dual-resonance property. After that other wideband staked DRAs have been reported [6, 7]. The idea of half-split cylindrical DRA with $TE_{01\delta}$ mode was first proposed by Mogia in 1989 for wide bandwidth applications [8]. In 1993, the slot coupling has been proposed to excite the $TE_{01\delta}$ mode in half-split cylindrical DRA by Mogia *et.al.* and about 10% bandwidth experimentally with broadside radiation pattern have been achieved [9].

The concept of stacked and embedded cylindrical DRAs introduced by Walsh *et al.*[10]. In this work, designing a staked, core-plug embedded, or embedded staked DRA is studied and shown 68.1% impedance bandwidth.

In this paper, we have proposed the concentric 3-Layer half-split CDRA for wideband application as shown in Fig. 1. The

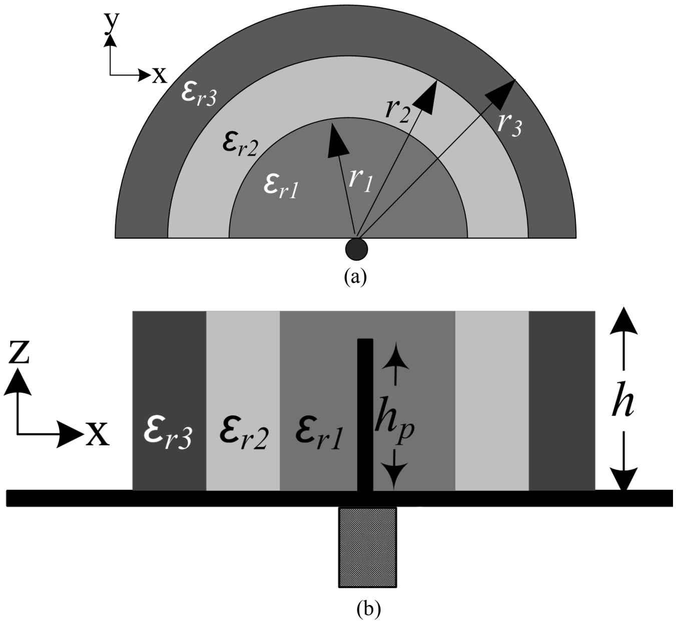


Fig. 1. The concentric 3-Layer half-split CDRA with permittivity variation in radial direction (a) Top view (b) Cross sectional view.

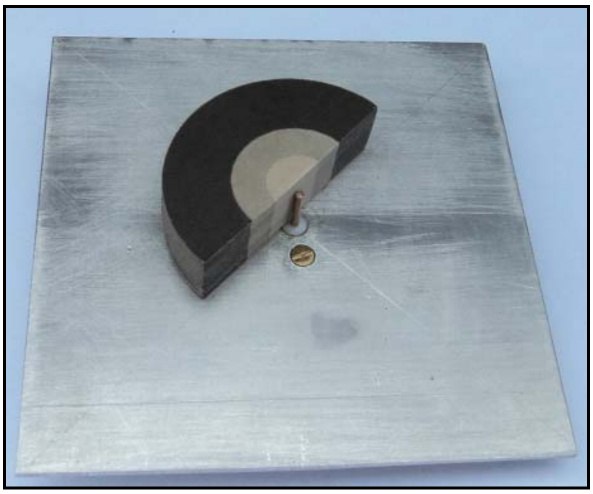


Fig. 2. 3D view of fabricated concentric 3-Layer half-split CDRA with permittivity variation in radial direction.

input reflection coefficient (S_{11}) and radiation patterns of proposed structure are simulated using the High Frequency Structure Simulator (HFSS).

II. Antenna Configuration And Parametric Study

The geometry of the 3-Layers half-split CDRA with varying permittivity in radial direction is shown in Fig. 1. The height (h) of each layer is kept same. The dielectric constant and radius of proposed antenna are ε_{r1}, ε_{r2}, ε_{r3}, r_1 r_2 and r_3 respectively as shown in Fig. 1. The antenna is placed on metallic ground plane and this arrangement is excited with $TM_{21\delta}$ mode by coaxial probe of height h_p and radius r_o. The 3D view of fabricated concentric 3-Layer half-split CDRA is shown in Fig. 2.

A. Dielectric Layer Arrangement with Varying Radius

The proposed antenna consists of concentric 3-layers half-split cylindrical DRs having different dielectric constant and radii. To achieve the wideband response, dielectric layers need to be arranged in some particular manner. The different arrangements of layers of proposed antenna have been simulated and it has been found that if outer annular-ring half-split DR having low dielectric constant, middle annular-ring half-split DR having moderate dielectric constant and inner half-split cylindrical DR having high dielectric constant then the bandwidth can be improved significantly. It is also well known that if high dielectric constant layer is kept near the probe then maximum energy will be confined inside high dielectric layer and that will propagate towards the lower dielectric layer and radiate afterward.

TABLE I
Layer arrangement of concentric 3-layers half-split CDRA
[r_1 = 6.67 mm, r_2 = 13.33 mm, r_3 = 20 mm, h = 11.4 mm]

ε_{r1}	ε_{r2}	ε_{r3}	h_p (mm)	f_r (GHz)	% Bandwidth
6.15	10.2	2.32	9.2	4.47	57.05
6.15	2.32	10.2	13.8	5.40	25.56
2.32	6.15	10.2	11.8	4.53	18.54
2.32	10.2	6.15	14.2	4.17	25.17
10.2	6.15	2.32	7.2	4.89	**82.01**
10.2	2.32	6.15	8.6	5.22	25.86

The layer arrangement for concentric 3-Layer half-split CDRA with equal layer thickness {$r_1 = (r_2 - r_1) = (r_3 - r_2)$} has been studied. It is clear from Table I that wide bandwidth can be achieved if the layers are arranged as ε_{r1} = 10.2, ε_{r2} = 6.15, ε_{r3} = 2.32. The maximum achieved bandwidth is 82.01% with probe height of 7.2 mm as shown in Table I.

After confirming the layer arrangements in concentric 3-Layers half-split CDRA, the parametric analysis is further performed for layer radii and dielectric constant. The optimal design parameters of the proposed antenna by the parametric analysis are: ε_{r1} = 10.0, ε_{r2} = 5, ε_{r3} = 2.5, r_1 = 2.0 mm, r_2 = 3.0 mm, r_3 = 20.0 mm, h = 11.4 mm, h_p = 6.6 mm. The proposed antenna shows impedance bandwidth of 104.78% (at 6.90 GHz) below -10 dB input reflection coefficient using above optimal design parameters.

However, it is very difficult to arrange these permittivities in practice therefore commercially available microwave laminates Polyflon Polyguide (ε_r = 2.32), Rogers RT/Duroid 6006 (ε_r = 6.15) and Roger RT/Duroid 6010 (ε_r = 10.2) are used for designing the antenna. To demonstrate the idea, concentric 3-Layer half-split CDRA is fabricated where the design parameters are ε_{r1} = 10.2, ε_{r2} = 6.15, ε_{r3} = 2.32, r_1 = 5.0 mm, r_2 = 10.0 mm, r_3 = 20.0 mm, h = 11.4 mm and h_p = 7.2. The simulated impedance bandwidth of 91.89% (at 5.55 GHz) has been achieved using above design parameters as shown in Fig. 3.

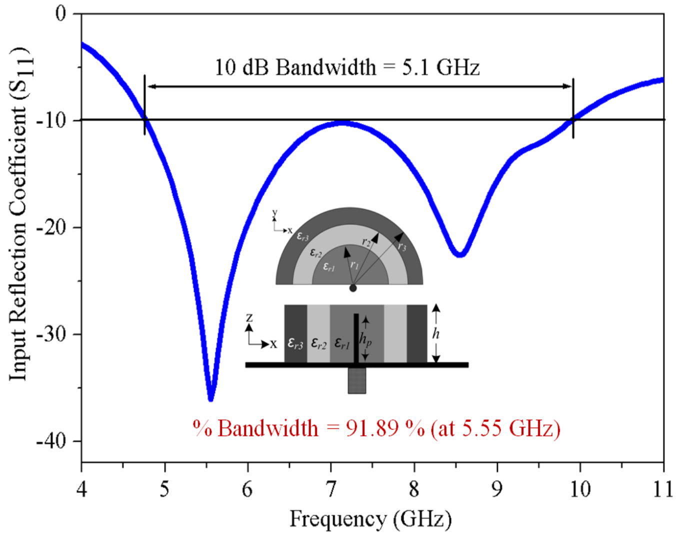


Fig. 3. Simulated input reflection coefficient of concentric 3-Layer half-split CDRA using commercially available microwave laminates. [ε_{r1} = 10.2, ε_{r2} = 6.15, ε_{r3} = 2.32, r_1 = 5 mm, r_2 = 10 mm, r_3 = 20 mm, h = 11.4 mm, h_p = 7.2]

Examples of earlier published half-split cylindrical DRAs with bandwidth enhancement techniques are listed in Table II for comparison with the proposed concentric 3-Layer half-split CDRA. It is clear from Table II that the proposed DRA demonstrates higher bandwidth relative to the other DRAs.

TABLE II Comparison of bandwidth for proposed concentric 3-layer half-split CDRA with earlier published work.

DR Geometry	Feeding	% BW (at f_r)
Half-split CDRA [8]	Probe	8.00
Half-split CDRA [9]	Slot	10.00
Half-split CDRA [11]	Microstrip	40.55
Half-split MLMP CDRA [12]	Probe	63.70
Proposed concentric 3-Layer Half-split CDRA	Probe	**91.89**

III. Experimental Results And Discussions

To validate the above design, a prototype of the proposed 3-Layer half-split CDRA is fabricated according to the optimized dimensions and measured by Agilent E5071C vector network analyzer. The 3D view of fabricated structure is shown in Fig. 2. The simulated and measured input reflection coefficients for the concentric 3-Layer half-split CDRA with permittivity variation in radial direction are shown in Fig. 4. An offset between simulated and measured input reflection coefficient is attributed to layer stacking and geometrical imperfection.

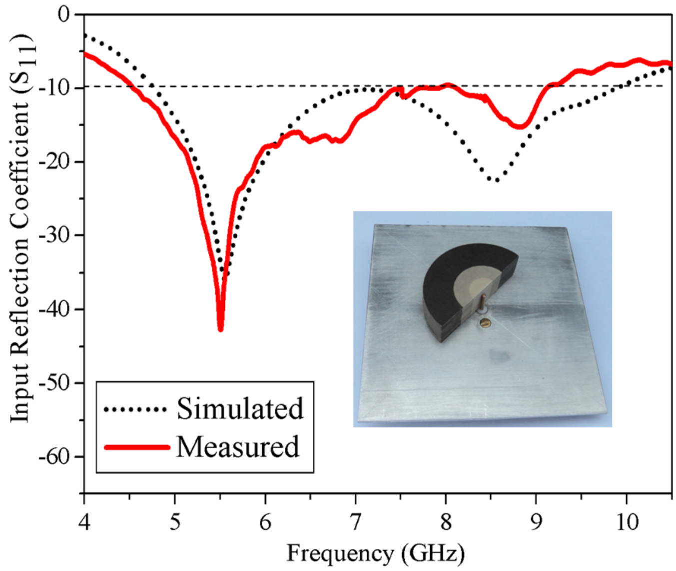


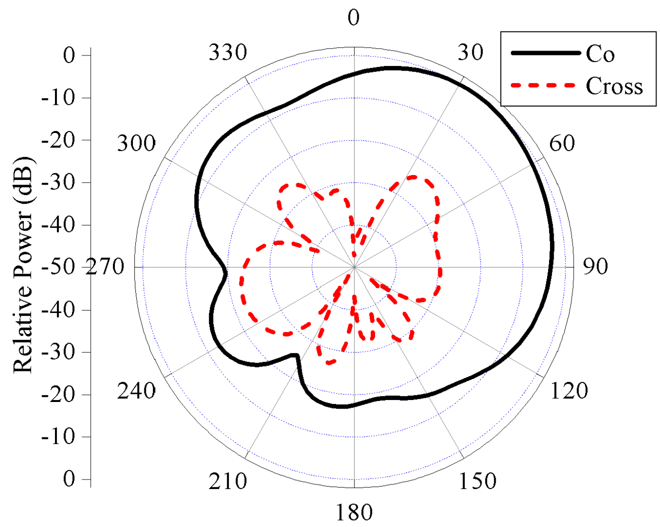
Fig. 4 Comparison of simulated and measured input reflection coefficient of proposed concentric 3-Layer half-split CDRA.

TABLE III COMPARISON BETWEEN SIMULATED AND MEASURED RESULTS

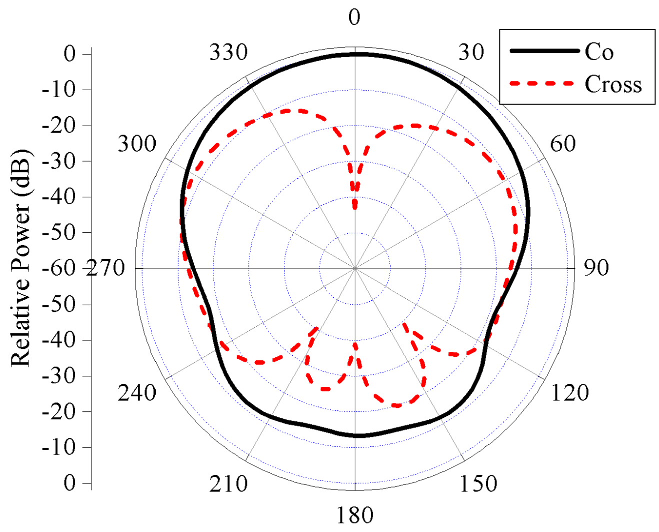
	Bandwidth	f_r (GHz)	%Bandwidth
Simulated	4.77 GHz - 9.87 GHz	5.55	91.89
Measured	4.51 GHz - 9.17 GHz	5.50	84.72

The comparison of simulated and measured bandwidth, resonant frequency (f_r) and percentage bandwidth of the proposed concentric 3-Layer half-split CDRA are shown in Table III.

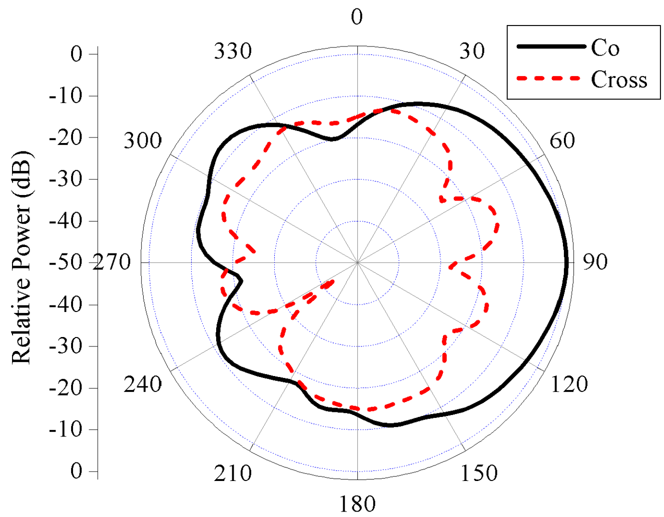
Fig. 5 and 6 show the simulated co- and cross-polarized radiation patterns in *xz*, *yz* and *xy*-plane at the frequencies of 5.55 GHz and 8.58 GHz respectively.



(a) *yz*-plane

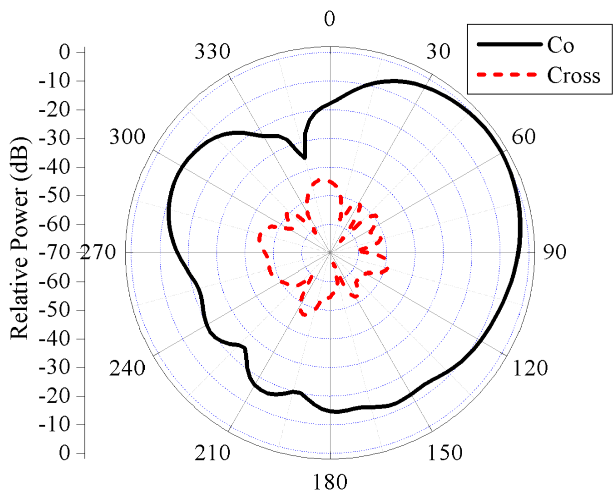


(b) *xz*-plane

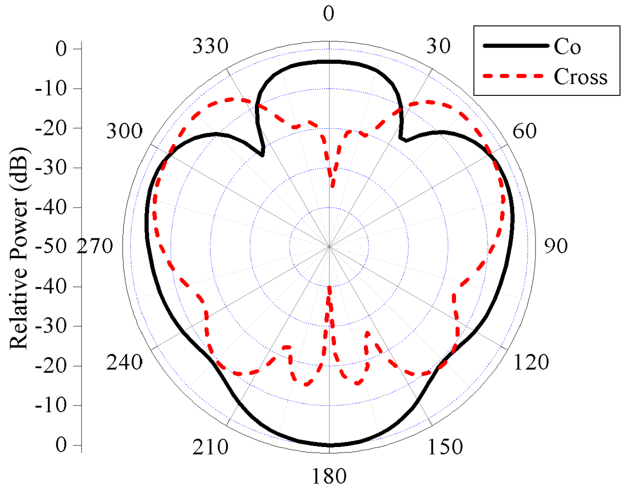


(c) *xy*-plane

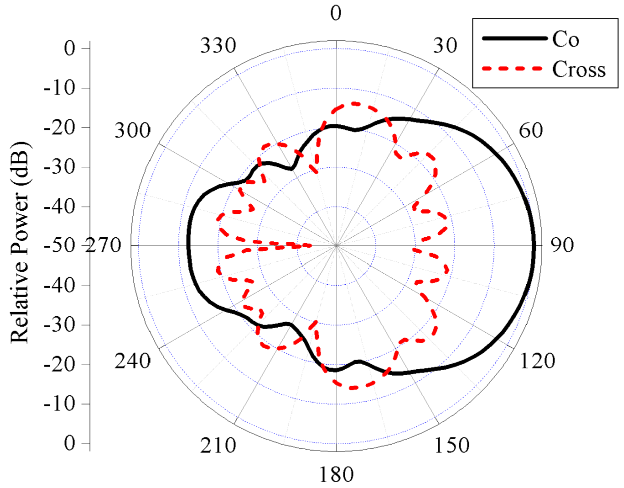
Fig. 5 Simulated radiation pattern of proposed concentric 3-Layer half-split CDRA at 5.55 GHz.



(a) *yz*-plane



(b) *xz*-plane



(c) *xy*-plane

Fig. 6 Simulated radiation pattern of proposed concentric 3-Layer half-split CDRA at 8.58 GHz.

Fig. 5 shows that the simulated normalized cross-polarization levels are around -22 dB, -23 dB and -26 dB at 5.55 GHz in *yz*, *xz*, and *xy*-planes respectively in the direction of maximum radiation. Whereas, the cross-polarization level is observed around -50 dB, -21 dB and -29 dB at 8.58 GHz in *yz*, *xz*, and *xy*-planes respectively in the direction of maximum radiation.

The 3D simulated gain patterns at 4.8 GHz, 6.4 GHz, 8.0 GHz and 9.6 GHz are shown in Fig. 7. The average gain is 9.15 dB in the frequency range of 4.77 GHz - 9.87 GHz.

IV. Conclusion

In this paper 3-Layer half-split CDRA with permittivity variation in radial direction is proposed for wideband applications. The measured results demonstrate that the proposed DRA achieves an impedance bandwidth of 84.72%, covering the frequency range from 4.51 GHz - 9.17 GHz with average simulated gain of 9.15 dB. The proposed antenna would be suitable for application in the field of wideband communications system.

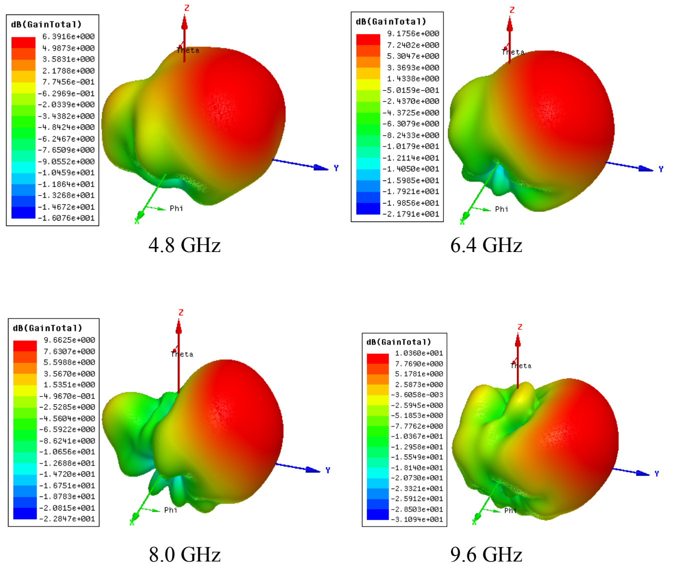


Fig. 7 Simulated 3D gain pattern.

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