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Circularly polarized cross-slot-coupled stacked dielectric resonator antenna for wireless applications

Rushikesh Dinkarrao Maknikar*, **Veeresh Gangappa Kasabegoudar**

Post Graduate Department, Mahatma Basaveshwar Education Society's, College of Engineering, Ambajogai, India, 431 517

Email address:
maknikar_rushikesh@rediffmail.com (R. D. Maknikar), veereshgk2002@rediffmail.com (V. G. Kasabegoudar)

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Abstract: This paper presents a stacked cylindrical dielectric resonator antenna with wide circular polarization (CP) bandwidth (axial ratio < 3dB) of 16.0%. This wide CP bandwidth is achieved by stacking low permittivity dielectric (9.2) resonator on high permittivity dielectric (9.8) resonator to obtain improved impedance and axial ratio bandwidths as compared to conventional DRA. It is also shown that the asymmetrical structure used in the geometry results in a very high impedance bandwidth (more than 100%) in the frequency range of 2.1 GHz-12.0 GHz but at the expense of distorted CP operation on the off-broadside. This essentially covers the FCC band of operation (3.1GHz to10.6 GHz).

Keywords: Dielectric Resonator Antenna, Slot Coupling, Circular Polarization

1. Introduction

Dielectric resonator antennas (DRAs) were first discovered in 1983 by Long et. al., and since then they have been widely studied [1]. There have been several works reported in literature to improve various parameters (impedance bandwidth, axial ratio bandwidth, gain etc.) of DRAs [2-20]. Their inherent features of high radiation efficiency & ease of excitation, compactness, and ability to obtain radiation patterns using different excitation modes offer much to an antenna application [2]. Furthermore, the shape of a DRA can be custom, resulting in favorable operating modes or polarizations. Also, the DRAs supporting circular polarizations have been studied and can be found in the literature. Traditionally, circular polarization is achieved using quadrature couplers and elaborate feed systems which can also be done with DRAs as well [3, 4].

The design in [4] is unique in using a dual mode dielectric resonator (DR) excited by vertical strips fed in quadrature, while [3] uses an under-laid hybrid coupler. However, the bandwidth reported in [4] is only up to 8% whereas [3] offers an AR bandwidth of 33% but the geometry is not only complex but uses dual feed. Furthermore, four DRA arrays can be excited using sequential rotation to obtain wide axial ratio bandwidths [5]. In another effort [6], CP operation was accomplished by using two crossed slots of unequal lengths to couple energy from a microstrip line to a simple cylindrical DRA. Both slots were angled at 45° with respect to the feeding microstrip line and their centers were at the same position, cantered underneath the dielectric resonator (DR). Their lengths were unequal, so that two near-degenerate orthogonal modes of equal amplitude and 90^0 phase difference were excited at frequencies close to that of the fundamental mode of the DRA. The resulting CP bandwidth was 3.91%.

An optimization of this topology was presented in [1] where offsetting each slot from the end of the microstrip line (thereby having the slot's intersection off from DR center) allows for AR bandwidths up to 4.7% at broadside angle ($\theta = 0°$). This design excites the fundamental mode at 5.7GHz, where the lengths of slots and distance of slots to the end of microstrip line are tuned for the optimized performance. In [8] simulated results on a dual band single feed excited cylindrical DRA are discussed. However, this geometry offers dual band operations but they are linearly polarized.

Most of these techniques either involve laborious methods or they provide insufficient impedance and/ or axial ratio bandwidth values. Therefore, we demonstrate a geometry which offers an impedance and axial ratio bandwidth of more than 100% and 16% respectively. Although the configuration is a stacked one but uses equal radius dielectric resonators with different dielectric constant values. Hence, stacking alignment issue does not impose a problem. Also, antenna's impedance and axial ratio bandwidth values are significantly higher than the results presented in [1]. In other words, with the help of conventional stacking and suitable selection of dielectric substrate parameters, the axial ratio bandwidth of antenna reported in [1] can be increased from 4.7% to 16%, and impedance bandwidth from about 55% to more than 100% at the expense of increased height. However, this configuration is more useful where size is not the prime constraint.

Therefore, in this paper investigation results on wideband stacked DRA with wide AR and impedance bandwidth values are presented. The basic geometry of the DRA is presented in Section 2. Parametric studies and optimized geometry are explained in Section 3 followed by conclusions of this work are presented in Section 4.

2. DRA Geometry

The aperture coupled stacked DRA excited through cross-slots was designed and simulated using Ansoft's HFSS and is shown in Figure 1. Two slots are formed on the ground plane. Each of the slots forms an angle of 45° with respect to the microstrip line printed on backside. The slot lengths and permittivity of the substrate and dielectric resonator determine the frequency of slot resonance, while the DRA modes depend on the DR dimensions and permittivity. The ground plane having slots is sandwiched between the microstrip line and stacked dielectric resonators. The substrate used for etching the microstrip line is an FR4 with dielectric constant of 4.4, and height of 0.8mm. The two resonators having equal dimensions (discussed further in Section 3) with different dielectrics (9.2 and 9.8) are stacked and affixed on the ground plane (Figure 1). The resonant frequency of the stacked DRA structure is calculated by [7]:

$$f\,(\text{GHz}) = 30K_0a/(2\pi r(cm)) \quad (1)$$

Where,

$$K_0a = 0.8945(1 + 3.017X^{0.881} + e^{(0.962-1.6252X)})/\epsilon_{reff}{}^{0.45} \quad (2)$$

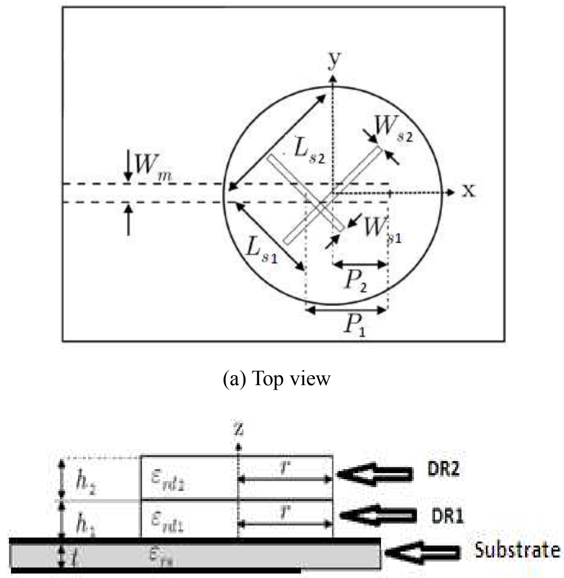
$$X = r/2h. \quad (3)$$

The effective permittivity is calculated using,

$$\epsilon_{reff} = \frac{h}{\epsilon_{r1}/h_1 + \epsilon_{r2}/h_2}. \quad (4)$$

Where

$$h = h_1 + h_2 \quad (5)$$



(a) Top view

(b) Cross sectional view

Figure 1: *Geometry of the proposed dielectric resonator antenna.*

3. Parametric Studies and Discussion

Extensive parametric studies were conducted on an early variant of the final design in order to understand how best to tune for wide axial ratio (AR) bandwidth, and impedance matching. The key design parameters used to optimize the antenna geometry are stubs length (P_1 and P_2), slots lengths (L_{s1} and L_{s2}) and their widths (W_{s1} and W_{s2}). All these parameters have been thoroughly investigated and their effects have been presented in the following subsections.

3.1. Effect of Variation of Stub Lengths

The DRA is excited from the microstrip line etched on the backside through the cross-slots, where their physical dimensions play a critical role in proper DRA excitation. The slots were modified one at a time to isolate each slot's effect on the antenna performance. At first P_1 was swept from 4.8mm to 5.2 mm in steps of 0.1mm and optimized value was found to be 5.0mm. Similarly, P_2 was optimized by varying it from 4.0 mm to 4.4 mm in 0.1 mm steps.

Table 1: *Effect of variation of stub length P_1 on axial ratio bandwidth*

Sr. No.	Stub Length P_1 (mm)	Stub Length P_2 (mm)	Axial Ratio Bandwidth (%)
1	4.8	4.2	4.7
2	4.9	4.2	14.8
3	5.0	4.2	16.0
4	5.1	4.2	10.2
5	5.2	4.2	7.4

Table 2: *Effect of variation of stub length P_2 on axial ratio bandwidth*

Sr. No.	Stub Length P_1 (mm)	Stub Length P_2 (mm)	Axial Ratio Bandwidth (%)
1	5.0	4.0	6.6
2	5.0	4.1	7.4
3	5.0	4.2	16.0
4	5.0	4.3	12.0
5	5.0	4.4	9.75

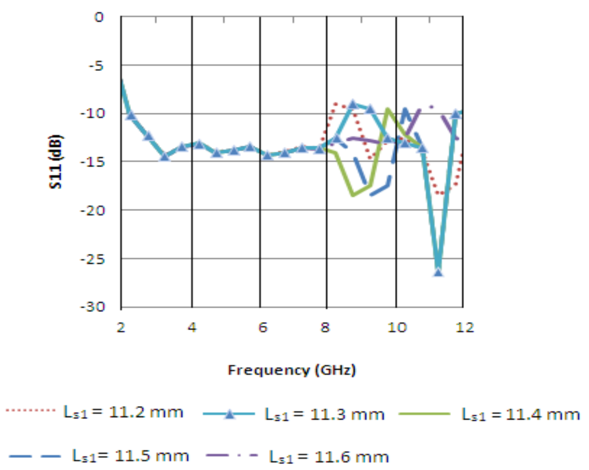
From the above investigation and Table 2 it can be noted that that maximum value of axial ratio bandwidth is achieved for stub lengths of 5.0 mm and 4.2 mm.

3.2. Effect of Variation of Slots Length

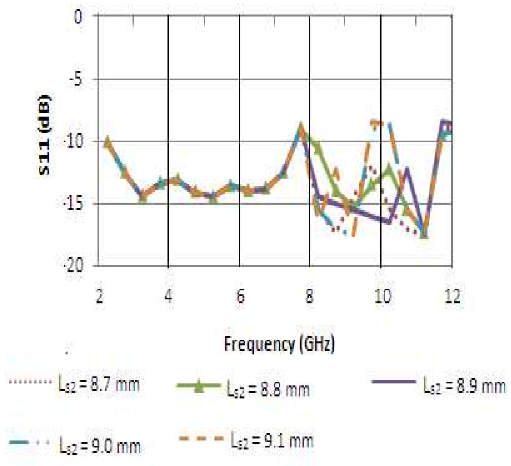
The energy excited from the microstrip line is coupled to dielectric resonators through these slots. Hence, slot lengths and widths play important role in optimizing the AR and impedance bandwidths. In the first attempt, effect of their lengths was investigated and in the next subsection their width values will be optimized.

The effect of variation of slot 1's length (L_{s1}) on return loss characteristics is shown in Figure 2 (a). Initially, L_{s1} is varied from 11.2 mm to 11.6 mm in steps of 0.1 mm with slot 2's length (L_{s2}) constant. It was observed the change in the value of L_{s1} shifts the frequency band i.e., increasing L_{s1} shifts the band on lower side and vice versa.

The length of slot 2 (L_{s2}) has a pronounced effect on both impedance bandwidth and axial ratio. As shown in Figure 2 (b), the length of *Ls2* was varied from 8.7 mm to 9.1 mm with L_{s1}= 11.4 mm constant. Due to its shorter length, L_{s2} dominates higher resonance frequency. In this investigation it was observed that the change in L_{s2} results in the shift of operating frequency band of the CP.



(a)



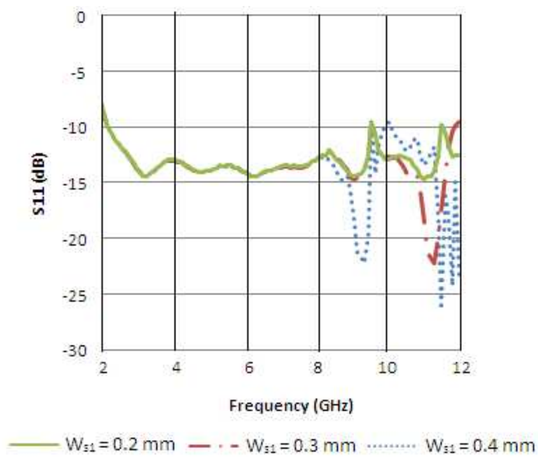
(b)

Figure 2: *(a) Reflection coefficient magnitude (s_{11}) vs. frequency for variation of length of slot 1, and (b) Reflection coefficient magnitude (s_{11}) vs. frequency for variation of length of slot 2.*

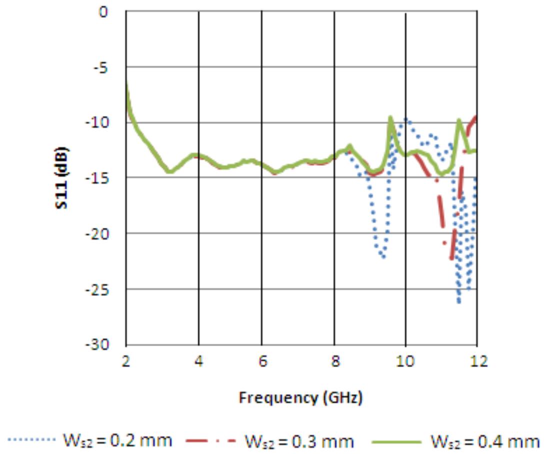
3.3. Effect of Variation of Slots Width

The effect of variation of slot width on return loss characteristics is shown in Figure 3 (a). Initially, W_{s1} was varied from 0.2 mm to 0.4 mm in steps of 0.1 mm with W_{s2} constant. It was observed that increase in value of W_{s1} shifts the band on upper side and vice versa.

In order to observe the effect of variation of width of slot 2 on return loss characteristics, W_{s2} was swept from 0.2 mm to 0.4 mm in steps of 0.1 mm while the width of slot 1 kept constant at 0.3 mm as shown in Figure 3 (b). It was observed that increase in value of W_{s2} shifts the operating band on lower side.



(a)



(b)

Figure 3: *(a) Reflection coefficient magnitude (s_{11}) vs. frequency for variation of width of slot 1, and (b) Reflection coefficient magnitude (s_{11}) vs. frequency for variation of width of slot 2.*

Based on the detailed parametric studies the optimum geometry was simulated and whose return loss characteristics are presented in Figure 4.

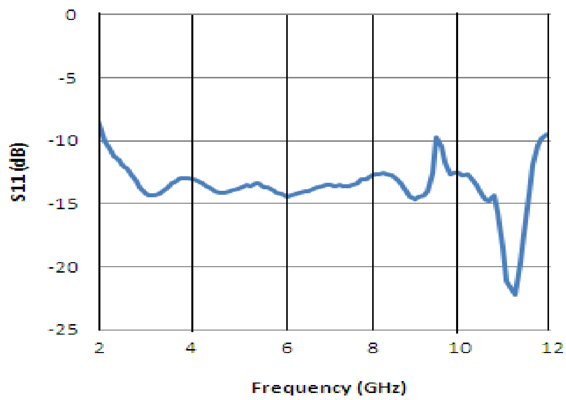


Figure 4: *Simulated return loss characteristics of optimized geometry shown in Figure 1.*

Also, these (optimum) dimensions are summarized in Table 3. The wide impedance bandwidth achieved here is due to the proper coupling between the slots & DRA resonances, and stacked arrangement of the DRAs. The presented antenna here achieves an impedance matching (S11< -10dB band) from 2GHz to 12GHz

Table 3: *Optimum values of dielectric resonator antenna geometry with ε_{rs}=4.4, ε_{r1}=9.8, and ε_{r2}=9.2*

Parameter	P_1	P_2	L_{s1}	L_{s2}	W_{s1}	W_{s2}	W_m	t	h_1	h_2	r
Value (mm)	5.0	4.2	11.4	8.9	0.3	0.3	2.4	0.8	5.1	5.1	15.2

The axial ratio characteristics of the antenna are depicted in Figure 5. From the Figure 5 it may be noted that the CP operation (AR≤ 3dB) is in between 10.0GHz to 11.4GHz which corresponds to an axial ratio bandwidth of 16.1%.

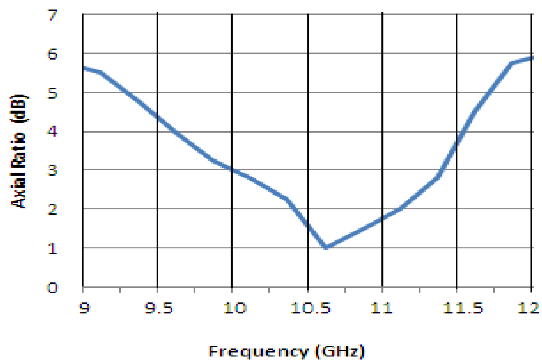
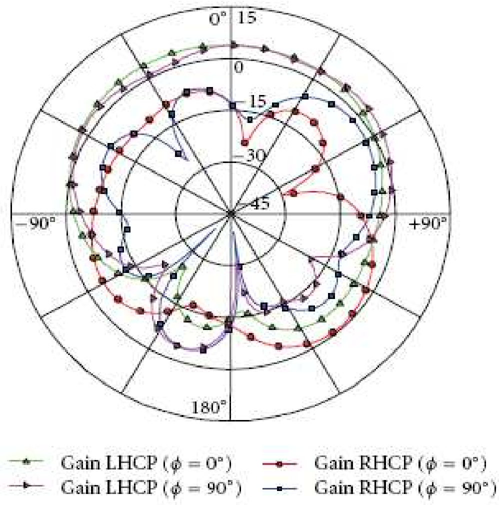
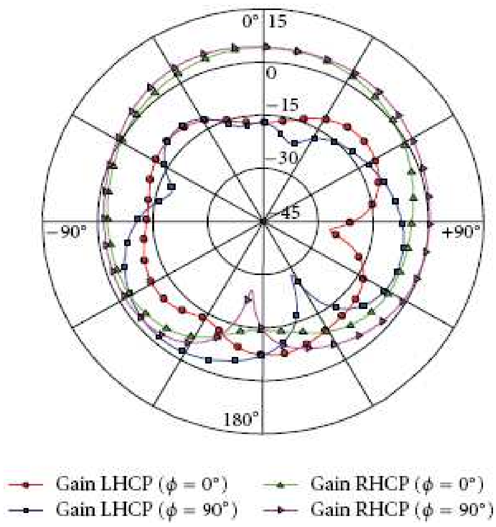


Figure 5: *Axial ratio vs. frequency plot.*



(a) LHCP pattern



(b) RHCP patterns

Figure 6: *Radiation patterns (LHCP and RHCP) of DRA at resonant frequency.*

Figure 6 shows radiation patterns of the proposed antenna at 10.5GHz at which it exhibits CP operation. The circular polarization obtained was left-handed when L_{s1}>L_{s2} (Figure 6 (a)). Similarly, RHCP operation was obtained by setting

$L_{s2} > L_{s1}$ and the same is depicted in Figure 6 (b). The gain vs. frequency plot in CP band is shown in Figure 7. From the Figure 7 it may be noted that the gain is positive throughout the band (LHCP) of operation and the maximum gain (about 5 dB) was observed at 10.6 GHz.

From the results presented here it may be noted that by stacking the dielectric resonators with equal diameter and height but with different dielectric constants the impedance and AR bandwidths may be significantly increased. The reason for using different dielectric constants is to make proper coupling between bottom and top resonators. This arrangement increases the axial ratio bandwidth from 4.7% [1] to 16.1% [our geometry] and impedance bandwidth from nearly 55% [1] to more than 100% in our case.

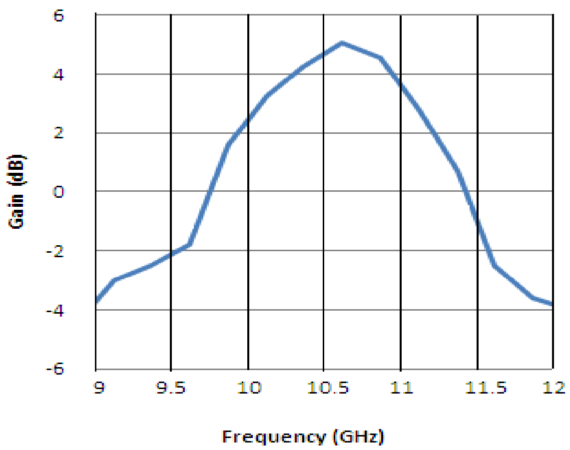


Figure 7: *Gain vs. frequency characteristics plot.*

4. Conclusions and Future Scope

The cross-slot coupled cylindrical DRA with wide impedance & AR bandwidth has been proposed. It was demonstrated that the bandwidth of cross-slot coupled DRA can be increased substantially by stacking two DRs vertically. The dielectric resonators are made up of same materials with different dielectric constants to achieve the benefit of compact size and wide bandwidth. Due to the absence of conductor loss, the proposed antenna has high gain and radiation efficiency. The future study of this work includes the fabrication and testing of the geometry proposed here. Also, all the modes and working of the geometry need to be verified analytically.

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