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Multi-Band Cylindrical Dielectric Resonator Antenna Using Permittivity Variation in Azimuth Direction

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Abstract—A novel multi-band cylindrical dielectric resonator antenna (CDRA) using microwave laminates with permittivity variation in azimuth direction fed by coaxial probe is proposed in this paper. The proposed structures are constructed using different materials having different permittivities in azimuth direction in cylindrical dielectric resonator (DR). In order to determine the performance of various design parameters on resonance frequency and bandwidth, parametric studies have been performed. The operating band can be scaled up or down by adjusting the design parameters. Dual-band and triple-band CDRAs have been fabricated using commercially available microwave laminates to validate the simulation results. For each case, the input reflection coefficient, radiation pattern and antenna gain are simulated and measured. Good agreement between simulated and measured results has been observed. The proposed antennas may be suitable for WLAN applications.

1. INTRODUCTION

Dielectric resonator antennas (DRAs) have received remarkable attention in modern wireless communication systems because of their great positive nature such as high radiation efficiency, great potential to work with different shapes and easy excitation technique [1–3]. With the progress of wireless communication systems, high frequency and dual/multi-band frequency antennas are extremely attractive. Recently, several studies have been reported on DRAs for multi-band frequency and wideband operations using various approaches, such as different coupling schemes [4, 5], hybrid structures [6], modified DR structures [7, 8], stacking two or more dielectric resonators (DRs) [9] and compact circular/annular sector [10]. Among many current applications of DRAs, dual/triple band frequency operation is highly desirable, and various approaches have been reported such as combining single DR with other kinds of planar radiator such as rectangular slot [4], microstrip line feed [11], loop slot [12] and split DRA [13]. A hybrid DRA with radiating slot for dual-band operation is proposed in [6], and the objective is to design a new low profile and compact size hybrid structure antenna which can operate at two different frequencies with stable radiation characteristics. Bit-Babik et al. [14] have reported a technique to enable multi-band operation by adding parasitically coupled conducting strips. The variation of permittivity in cylindrical DR along axial direction and radial direction has been studied by several researchers [9, 15–18]. It has been demonstrated that introduction of permittivity variation concept in cylindrical and half-split cylindrical DRA along the axial direction and radial direction improves impedance bandwidth significantly.

In this paper, multi-band cylindrical DRAs having permittivity variation in ϕ-direction fed by coaxial probe are analyzed, fabricated and measured. A dual-band response is obtained by the combination of two half-split cylindrical DRs of different permittivities whereas triple-band is also obtained by taking three equal sectors of split DRs. In these antenna configurations, the frequency bands can be controlled by using different permittivity materials of different sections of CDRA. Ansoft HFSS

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is used to simulate the input reflection coefficient and radiation pattern for the proposed configuration. Both the proposed configurations of antenna are fabricated using commercially available microwave laminates materials and measured.

2. ANTENNA CONFIGURATION

The proposed dual-band and triple-band with equal sectors cylindrical DRA with varying permittivity in φ-direction fed by coaxial probe are shown in Fig. 1. The dual-band CDRA consists of two different dielectric materials whereas triple-band with equal sectors consists of three different dielectric materials. The proposed antenna configurations are placed on finite ground plane of dimensions $120\,\text{mm} \times 120\,\text{mm}$ and fed by a $50\,\Omega$ coaxial probe. The DR materials used here are the FR4, Rogers RT/Duroid 6010 and 6006 with permittivities 4.4, 10.2 and 6.15, respectively.

2.1. Dual-Band Cylindrical DRA

In this section, dual-band cylindrical DRA using varying permittivity in φ-direction fed by coaxial probe is proposed and analyzed. Dual bands are obtained by the combination of two half-split DR arrangement with proper feeding position, in which most energy is coupled to the dielectric resonator (DR) over the desired bands. The initial study on this type of dual-band CDRA has been reported in [17].

The top view of the proposed dual-band CDRA structure is shown in Fig. 1(a) with its cross-sectional view shown in Fig. 1(b). It consists of two different dielectric materials with coaxial feed. The permittivities, radius, height and probe height of the proposed dual-band cylindrical dielectric resonators are ε_{r1}, ε_{r2}, r, h, and h_p, respectively. The proposed antenna is placed on a finite ground plane and fed by a $50\,\Omega$ coaxial probe. To achieve the best possible antenna performance, parametric analysis is carried out (with commercially available materials parameters) to investigate the characteristics of the dual-band cylindrical DRA using permittivity variation in φ-direction fed by coaxial probe. The following results have been observed with parametric analysis: (i) if probe is kept at lower permittivity

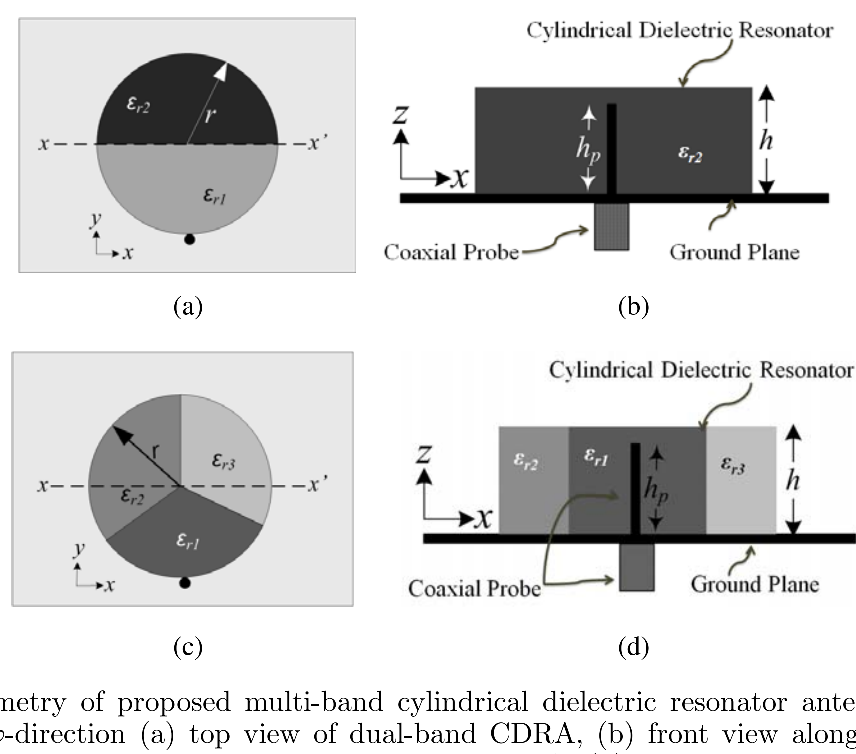


Figure 1. Geometry of proposed multi-band cylindrical dielectric resonator antenna using varying permittivity in φ-direction (a) top view of dual-band CDRA, (b) front view along xx' of dual-band CDRA, (c) top view of triple-band with equal sector CDRA, (d) front view along xx' of triple band with equal sector CDRA.

section of dual-band CDRA, then matching at both the frequencies and proper dual band response can be achieved, (ii) increasing the permittivity of higher permittivity section results in decreasing the resonance frequency of first band as well as its bandwidth, (iii) coaxial probe height of DRA changes the matching of dual-band response without altering the resonance frequencies of dual-band DRA.

The commercially available materials are used for physical realization of proposed antenna. The materials chosen are: RT/Duroid 6010 and RT/Duroid 6006 having the dielectric constants 10.2 and 6.15, respectively. It is observed that the proposed dual-band antenna (design parameters: $\varepsilon_{r1} = 6.15$, $\varepsilon_{r2} = 10.2$, $r = 20$ mm, $h = 11.4$ and $h_p = 11$ mm) resonates at two different frequencies 3.68 GHz and 4.95 GHz with bandwidths of 3.61 to 3.76 GHz and 4.81 to 5.18 GHz, respectively.

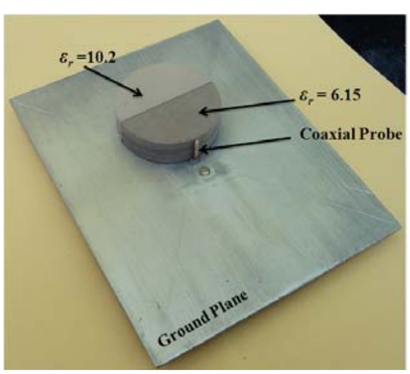
2.1.1. Results & Discussions

The fabricated dual-band CDRAs is shown in Fig. 2(a). The dual-band CDRAs are fabricated using commercially available microwave laminates and machined with Abrasive Water Jet & Cutting Machine (OMAX 2652). The simulated and measured input reflection coefficients of the proposed dual-band are shown in Fig. 2(b). A little mismatch between simulated and measured input reflection coefficients is seen due to fabrication imperfections i.e., sector fitting and machining of microwave laminates. The proposed dual-band CDRA with permittivity variation along azimuth direction shows the measured dual-band nature at 3.66 GHz and 4.94 GHz with bandwidth of 4.64% and 8.09%, respectively.

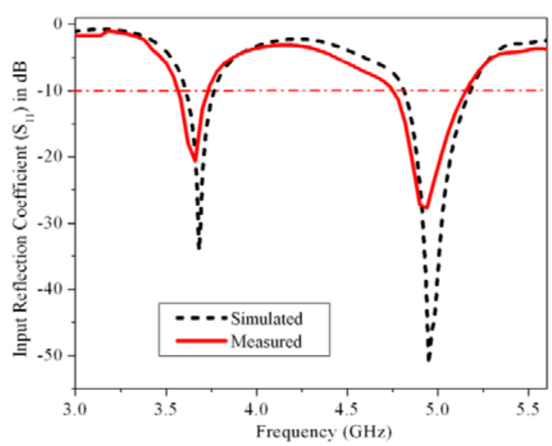
The distributions of E-field and H-field in dual-band CDRA are shown in Figs. 3(a) and 3(b), respectively.

It can be seen from the E- and H-field distributions that $HE_{11\delta}$ mode no longer exists in dual-band DRA. Although $HE_{11\delta}$ mode is supposed to be excited due to coaxial probe excitation used at circumference of proposed dual-band CDRA with varying permittivity in φ-direction, permittivity variation in φ-direction in cylindrical DRA disturbs the $HE_{11\delta}$ mode profile in dual-band CDRA, and each sector shows a different mode in working band as shown in Fig. 3; hence dual-band performance has been observed. On the other hand, axial and radial directions did not influence much the mode profile in working band, hence provides wideband performance in CDRA [18, 19].

The radiation pattern of the proposed dual-band CDRA is measured in a far-field environment where horn antenna is used as a reference antenna. Fig. 4 and Fig. 5 show the simulated and measured normalized radiation patterns of the proposed dual-band CDRA. The simulated and measured radiation patterns of the proposed dual-band antenna in YZ, XZ and XY-planes at 3.66 GHz and 4.94 GHz with co-polar and cross-polar components in each plane have been shown in Fig. 4 and Fig. 5. The measured peak gains at frequencies 3.66 GHz and 4.94 GHz are 8.27 dB and 9.25 dB, respectively.

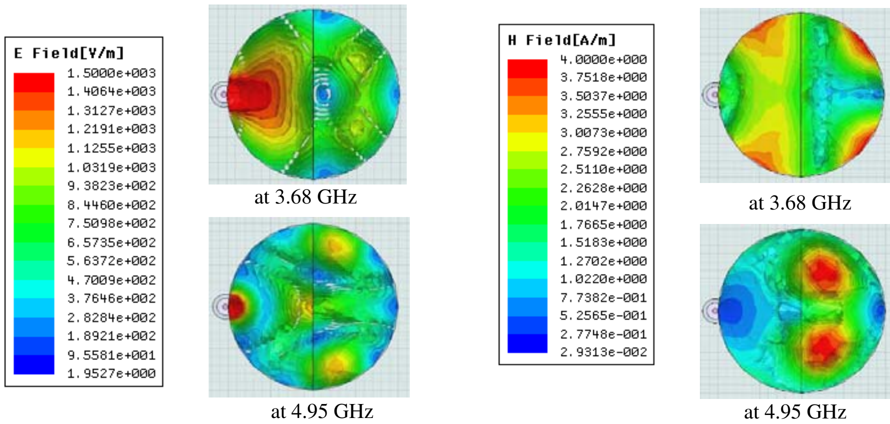


(a)



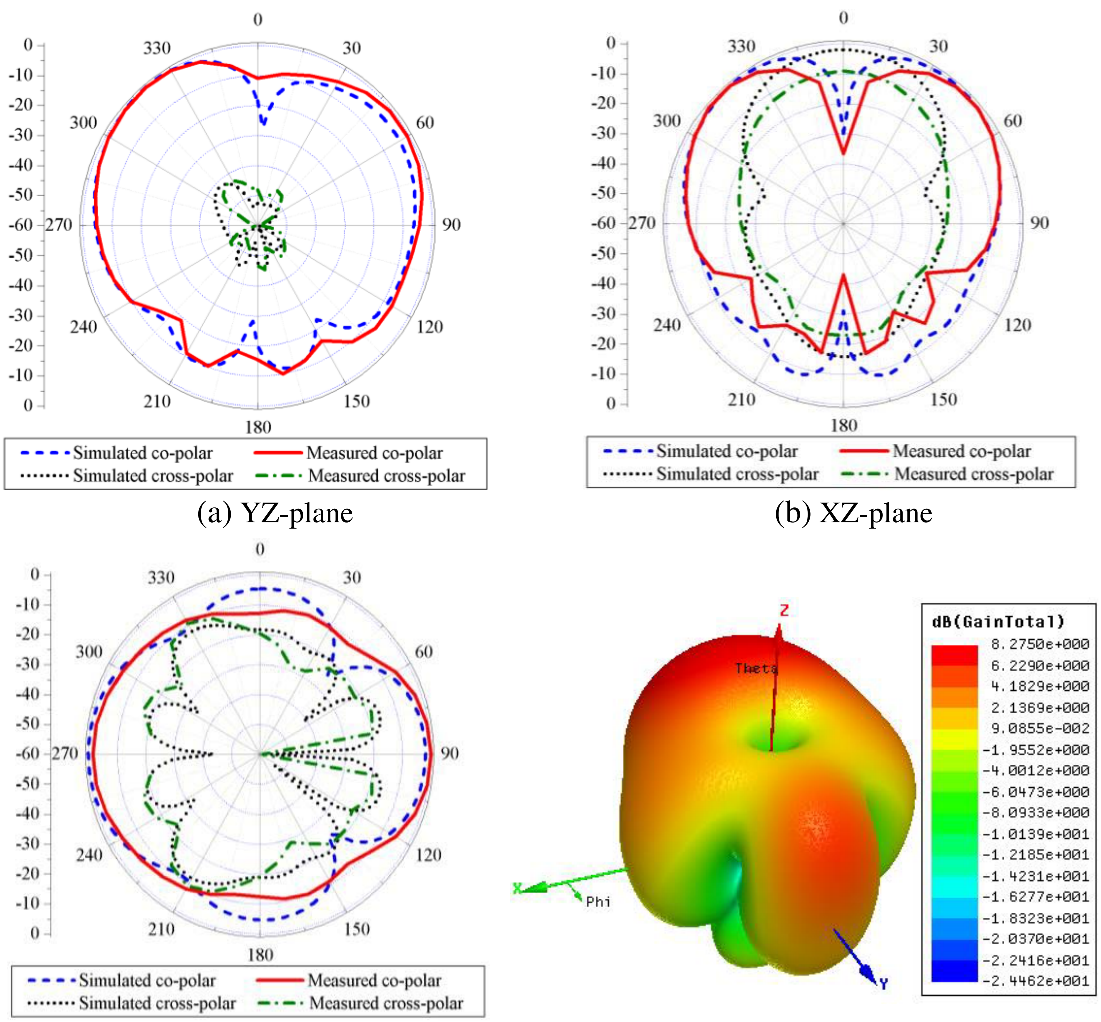
(b)

Figure 2. Experimental results of dual band CDRA (a) fabricated dual-band CDRA using permittivity variation in azimuth direction [$\varepsilon_{r1} = 6.15$, $\varepsilon_{r2} = 10.2$, $r = 20$ mm, $h = 11.4$ and $h_p = 11$ mm]. (b) Comparison of simulated and measured input reflection coefficient of proposed dual-band CDRA.



(a) Electric field distribution (b) Magnetic field distribution

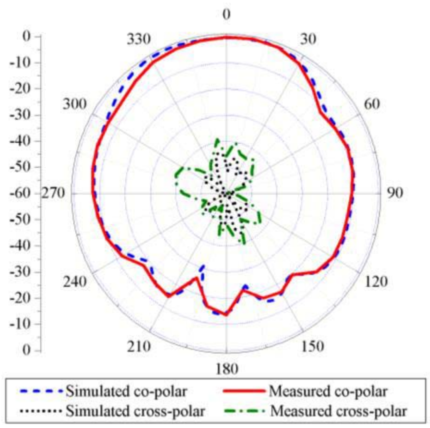
Figure 3. Simulated field distribution for dual-band CDRA using permittivity variation in azimuth direction.



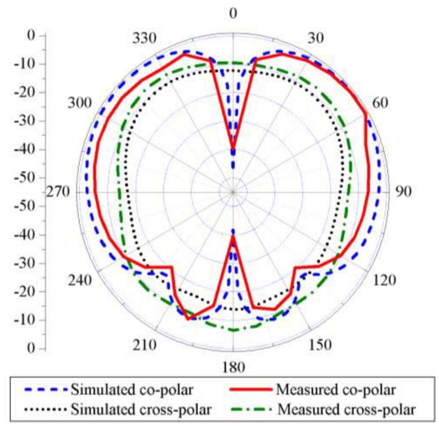
(a) YZ-plane (b) XZ-plane

(c) XY-plane (d) 3D gain pattern at 3.66 GHz

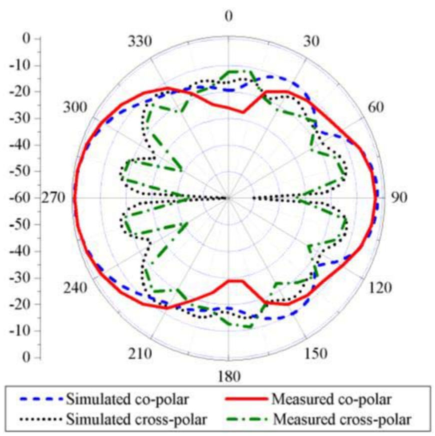
Figure 4. Simulated and measured radiation pattern of proposed dual-band CDRA with varying permittivity in azimuth direction at 3.66 GHz.



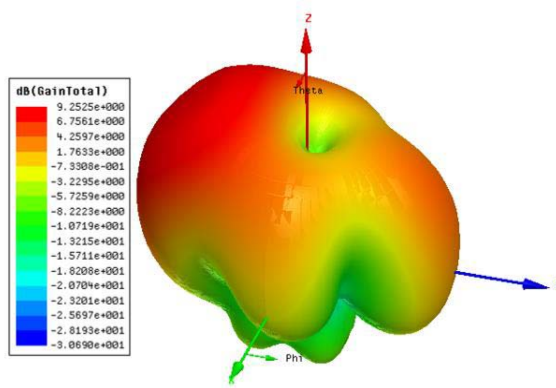
(a) YZ-plane



(b) XZ-plane



(c) XY-plane



(d) 3D gain pattern at 4.94 GHz

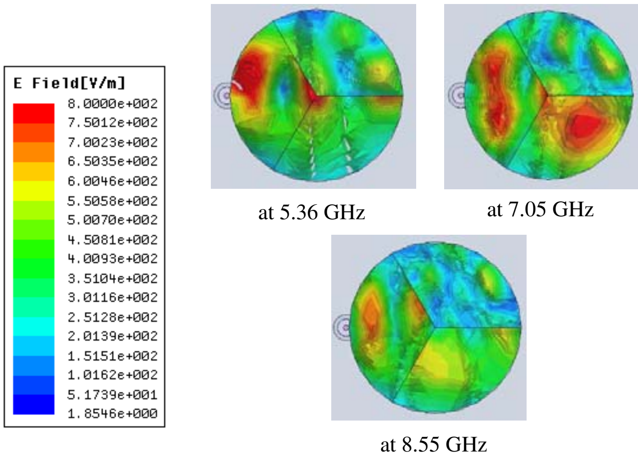
Figure 5. Simulated and measured radiation pattern of proposed dual-band CDRA with varying permittivity in azimuth direction at 4.94 GHz.

2.2. Triple-Band CDRA with Equal Sectors

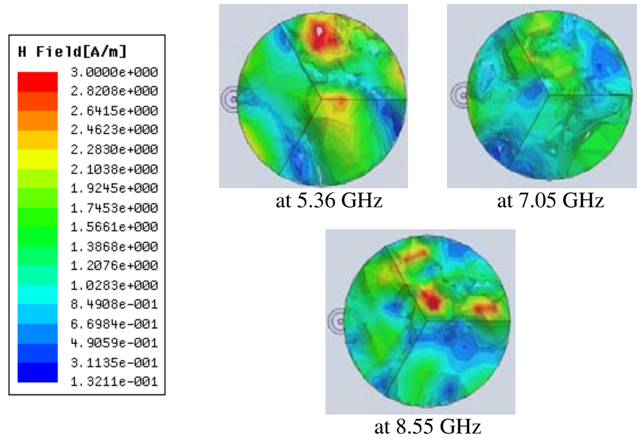
In this section, triple-band cylindrical DRA with equal sectors by using varying permittivity in φ-direction fed by coaxial probe is proposed and analyzed. The proposed triple-band DRA structure is shown in Fig. 1(c) with its cross-sectional view shown in Fig. 1(d). It consists of three different dielectric materials with coaxial feed. The permittivites, DR radius, DR height and probe height of the proposed triple-band cylindrical DR are ε_{r1}, ε_{r2}, ε_{r3}, r, h, and h_p, respectively. Similar to a dual-band antenna, parametric analysis has been carried out to investigate the characteristics of the proposed triple-band antenna. Again following observations have been made with parametric analysis of triple-band antenna: (i) permittivity plays a significant role in deciding the resonance frequency and its bandwidth. It has been seen here that lower and higher permittivity sections affect more to higher and lower resonances, respectively; (ii) it is difficult to control the individual resonance and its bandwidth with single parameter due to the complex nature of structure; (iii) by controlling the height of coaxial probe of DRA, matching of triple-band response can be adjusted.

To validate the concept, simulation study is performed with commercially available materials. The materials used are: Rogers 5880 ($\varepsilon_{r3} = 2.2$), Rogers 6010 ($\varepsilon_{r2} = 10.2$) and FR4 ($\varepsilon_{r1} = 4.4$). It is observed that the proposed antenna with commercially available materials resonates at three different frequencies at 5.36 GHz, 7.05 GHz and 8.55 GHz, respectively. The simulation study on triple-band CDRA constructed by using two quarter-split and one half-split DR has been reported in [20].

Figures 6(a) and 6(b) show the distributions of E-field and H-field in triple-band CDRA with equal sectors at 5.36 GHz, 7.05 GHz and 8.55 GHz. Again, similar phenomena have been observed as previously

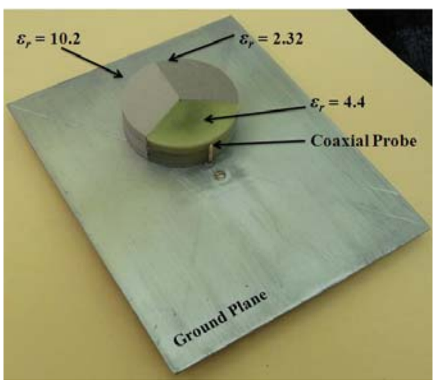


(a) Electric field distribution

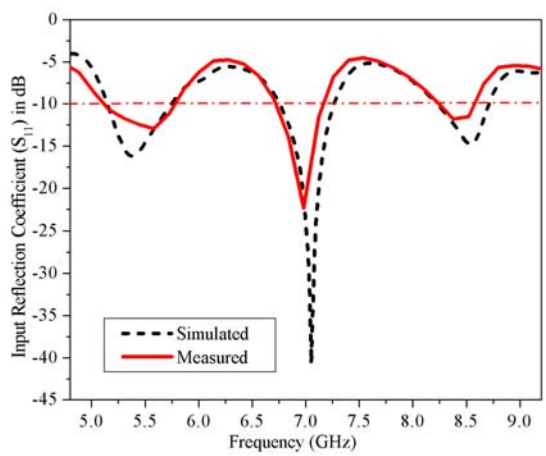


(b) Magnetic field distribution

Figure 6. Field distribution in triple-band CDRA with equal sectors using permittivity variation in azimuth direction.



(a)



(b)

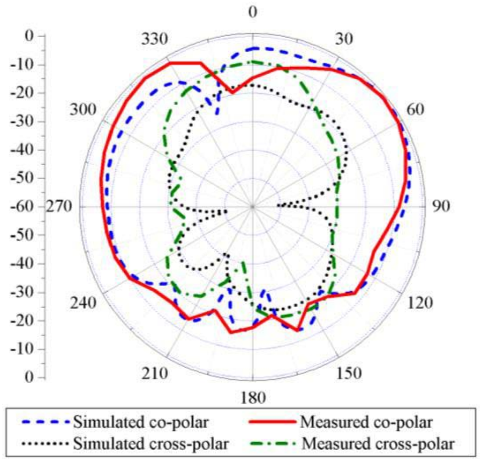
Figure 7. Experimental results (a) 3D view of fabricated triple-band CDRA using equal sectors [$\varepsilon_{r1} = 4.4$ (FR4), $\varepsilon_{r2} = 10.2$ (RT Duroid 6010), $\varepsilon_{r3} = 2.32$ (RT Duroid 5880), $r = 20$ mm, and $h = 14.2$ mm and $h_p = 8.8$ mm]. (b) Comparison of simulated and measured input reflection coefficient of proposed triple-band with equal sectors CDRA.

discussed dual-band CDRA i.e., permittivity variation in ϕ-direction in cylindrical DRA disturbs the $HE_{11\delta}$ mode profile in triple-band CDRA, and each sector shows a different mode in working band as shown in Fig. 6, hence triple-band performance has been observed.

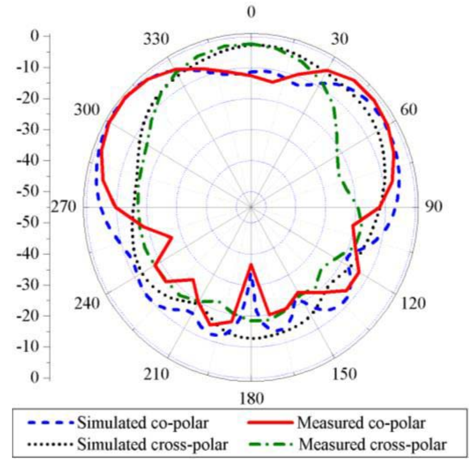
2.2.1. Experimental Results and Discussion

The fabricated triple-band with equal sectors CDRAs is shown in Fig. 7(a). The simulated and measured input reflection coefficients of the proposed triple-band with equal sectors CDRAs are shown in Fig. 7(b). The measurement of the proposed antenna shows triple-band nature at 5.47 GHz, 6.97 GHz and 8.45 GHz with impedance bandwidth of 12.06%, 6.45% and 4.02%, respectively.

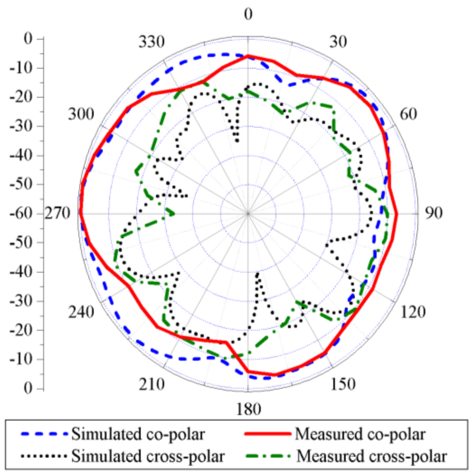
The radiation patterns are measured in conventional planes in a far-field zone. The radiation patterns of the proposed triple-band CDRA at frequencies 5.47 GHz, 6.97 GHz and 8.55 GHz are shown in Fig. 8, Fig. 9 and Fig. 10, respectively. The measured gains at 5.47 GHz, 6.97 GHz and 8.55 GHz are 6.58 dB, 8.98 dB and 9.18 dB, respectively.



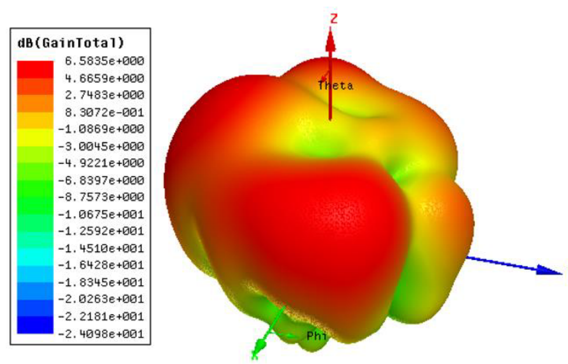
(a) YZ-plane



(b) XZ-plane

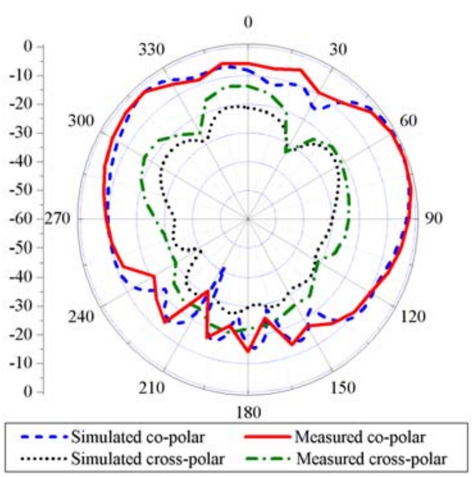


(c) XY-plane

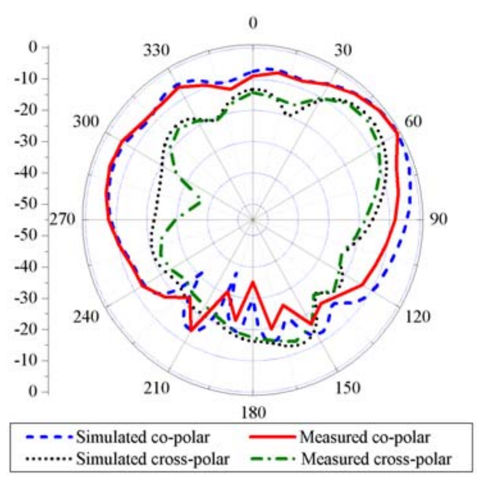


(d) 3D gain pattern at 5.47 GHz

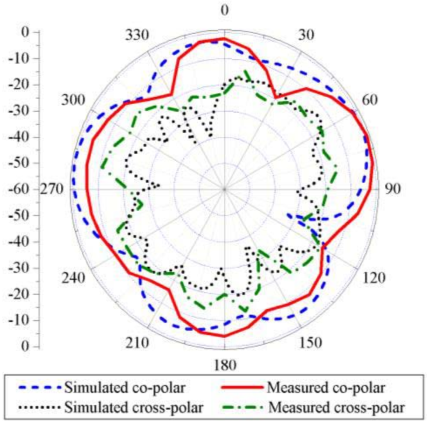
Figure 8. Simulated and measured radiation pattern of proposed triple-band with equal sectors CDRA with varying permittivity in azimuth direction at 5.47 GHz.



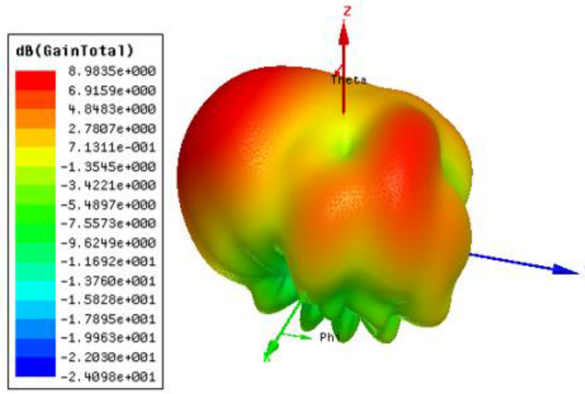
(a) YZ plane



(b) XZ-plane

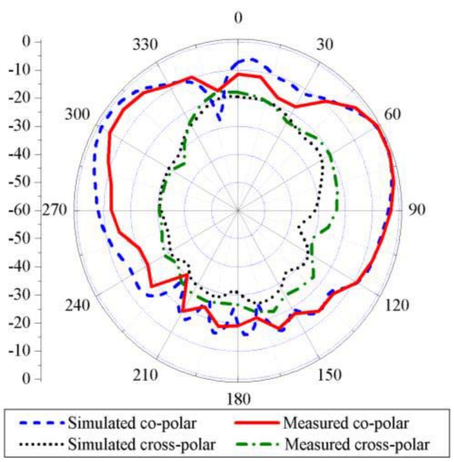


(c) XY-plane

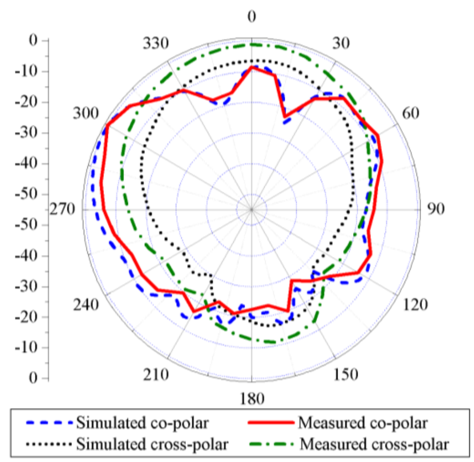


(d) 3D gain pattern at 6.97 GHz

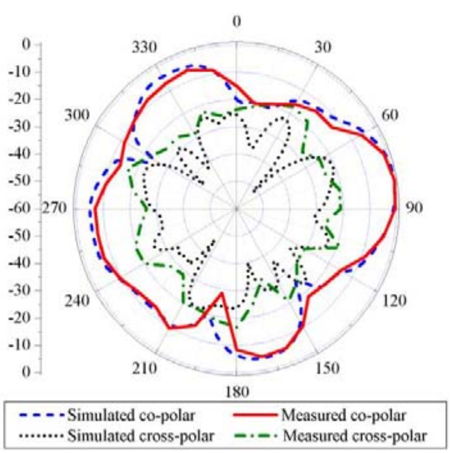
Figure 9. Simulated and measured radiation pattern of proposed triple-band with equal sectors CDRA with varying permittivity in azimuth direction at 6.97 GHz.



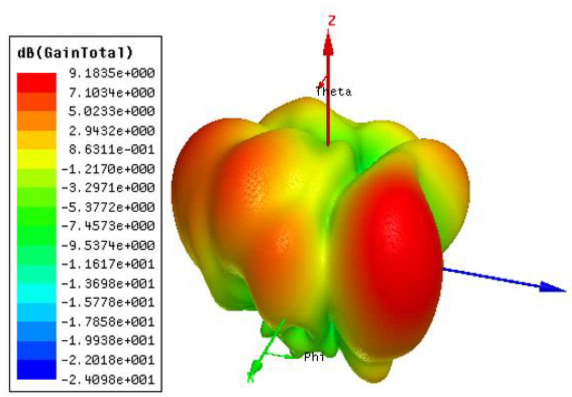
(a) YZ-plane



(b) XZ-plane



(c) XY-plane



(d) 3D gain pattern at 8.55 GHz

Figure 10. Simulated and measured radiation pattern of proposed triple-band with equal sectors CDRA with varying permittivity in azimuth direction at 8.55 GHz.

3. CONCLUSION

A dual- and triple-band cylindrical dielectric resonator antenna (CDRA) using varying permittivity in azimuth-direction fed by coaxial probe is proposed in this paper. The proposed structure is constructed using different materials having different permittivites in azimuth direction in cylindrical dielectric resonator (DR). The operating band can be scaled up or down by adjusting the design parameters. Dual-band and triple-band with equal segment CDRA have been fabricated using commercially available microwave laminates to validate the simulation results. In terms of radiation pattern, dual-band CDRA shows less cross-polar influence around 40 dB down in the direction of maximum radiation in yz-plane.

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