Multi-band Hybrid Aperture-Cylindrical Dielectric Resonator Antenna for Wireless Applications

Chandravilash Rai, Amit Singh, Sanjai Singh and Ashutosh Kumar Singh

Abstract In this article, multi-band hybrid aperture-cylindrical dielectric resonator antenna (CDRA) is presented. Regular pentagon-shaped aperture is used to generate to radiating mode ($HEM_{11\delta}$ and $HEM_{12\delta}$ mode). Lower-frequency band is linearly popularized, and upper-frequency band is dual popularized (combination of linear and circular). In both of the structure (spoon-type microstrip line and rectangular-type microstrip line), spoon-type microstrip line is resonated at frequency band 6.40–7.50 GHz with fractional bandwidth 15.82% and rectangular-type microstrip line at band 6.95–7.75 GHz with fractional bandwidth 11.26%, and VSWR is calculated nearly at resonance frequency.

Keywords Cylindrical dielectric resonator antenna (CDRA) · Aperture coupled · Multi-band · Rectangular microstrip line · Spoon-type microstrip line

1 Introduction

Dielectric resonator antenna (DRA) was first proposed by Robert Richtmyer and after him in 1983, L. C. Long et al. design and testing of DRA. Simultaneously, many researchers tried their luck in the improvement of this antenna. DRA has been the most popular in the last 30 years due to some smart features like high gain, large bandwidth, high radiation efficiency and no metallic losses in high frequency [1].

DRA can be of any shape and size but cylindrical and rectangular DRA are most popular choice because of additional degree of freedom which means small and thick DRA can be used same as large and thin DRA [1]. In this paper, we have used cylindrical dielectric resonator antenna (CDRA) due to easy manufacturing and availability. Another feature of CDRA has three modes (TEmnp, TMmnp, HEmnp) which is useful to achieve the desirable radiation pattern [2].

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Dual band/multi-band antenna is most popular in wireless communications due to advantage like a single antenna can be used for different applications. Systematically reduce the interference, free of orientation in transistor and receiver [2]. Mainly three techniques are used to obtain dual characteristics (liner and circular polarization) in DRA: First is the addition of parasitic element, second is hybrid DRA (combination of more than one element), and third one is higher mode generating [3, 4]. Some researchers (Leung and Fang) proposed a dual band circular polarized antenna but main problem of this antenna is feeding, and after that hybrid aperture coupled antenna are more popular [5].

In this proposed work, multi-band, hybrid aperture CDRA is used. Mainly two important feature of this proposed antenna, first is hybrid mode generated (HEM11δ and HEM12δ) and second one is spoon-type microstrip line generate additional λ/4 path delay orthogonal electric field at 6.95 GHz. The proposed antenna is useful at different frequency band 6.45–7.4 GHz and 6.90–7.60 GHz.

2 Geometry and Design of Antenna

Figure 1 shows systematic diagram of proposed DRA; first Fig. 1a shows the spoon-like microstrip line and second Fig. 1b has rectangular microstrip line; both of the antennas are simulated on the marginal cost FR4 epoxy substrate with ($\varepsilon_{\mathrm{r\,sub}} = 4.4$, tan $\delta = 0.02$), height $h = 1.6$ mm, length $L_{\mathrm{G}} = 50$ mm and width $W_{\mathrm{G}} = 50$ mm substrate is etched in the shape of regular pentagon. Microstrip line (50 Ω) is deposited below the substrate. A material alumina is used to make CDRA ($\varepsilon_{\mathrm{r\,CDRA}} = 9.8$, tan $\delta = 0.002$) with radius $R = 13$ and height $H = 12$. Table 1 shows the optimized dimension of parameter of proposed antenna.

In CDRA, the resonance frequency of the hybrid mode $\mathrm{HEM}_{11\delta}$ is calculated by the following formulas [6]:

$$f_{\mathrm{r}} = \frac{6.321c}{2\pi R\sqrt{\varepsilon_{\mathrm{reff}}} + 2}\left[0.27 + 0.36\left(\frac{R}{2H_{\mathrm{eff}}}\right) + 0.02\left(\frac{R}{2H_{\mathrm{eff}}}\right)^{2}\right] \tag{1}$$

where R is the radius, $\varepsilon_{\mathrm{eff}}$ is the effective permittivity, H_{eff} is the height of CDRA but H_{eff} effective height, and effective permittivity ($\varepsilon_{\mathrm{eff}}$) can be calculated by formulas

$$\varepsilon_{\mathrm{r\,eff}} = \frac{H_{\mathrm{eff}}}{\frac{H}{\varepsilon_{r\mathrm{CDRA}}} + \frac{H_{\mathrm{s}}}{\varepsilon_{r\,\mathrm{sub}}}} \tag{2}$$

There are no stabile formulas for calculating the resonance frequency of $\mathrm{HEM}_{12\delta}$ mode so resonance frequency of mode $\mathrm{HEM}_{12\delta}$ finding with help of mode $\mathrm{HEM}_{11\delta}$

$$\mathrm{fHEM}_{12\delta} \geq 1.9\mathrm{fHEM}_{11\delta} \tag{3}$$

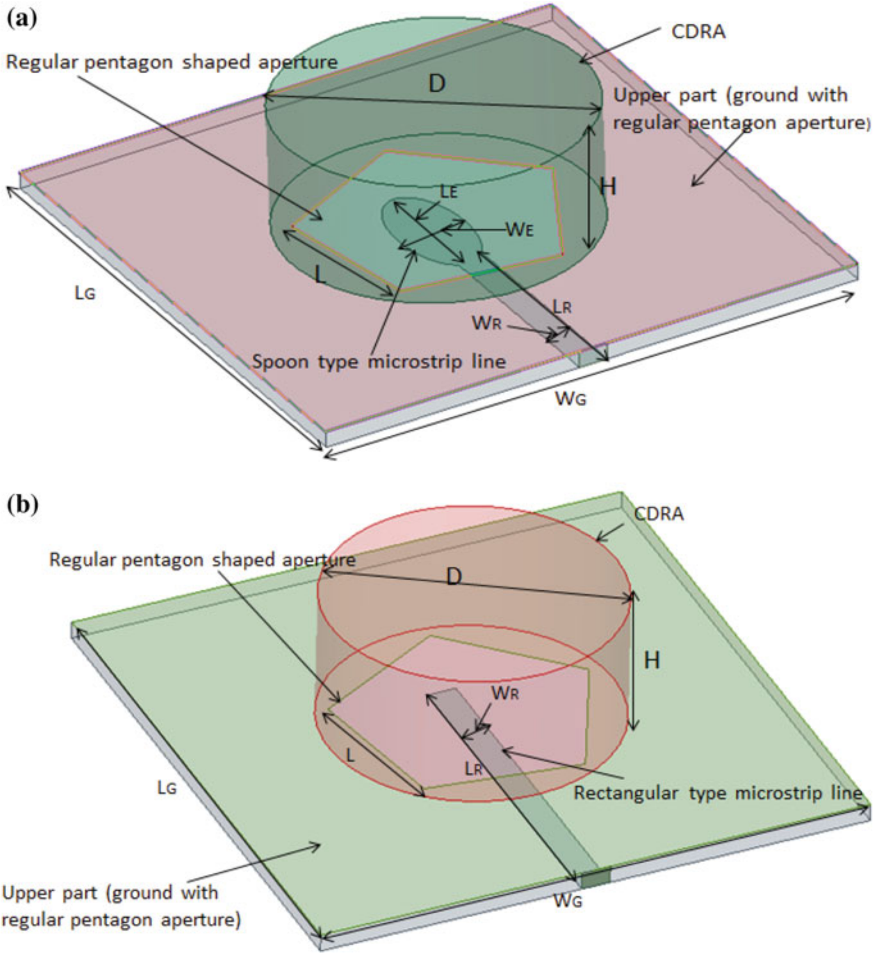


Fig. 1 **a** Systematic diagram of spoon-type microstrip line proposed radiator, **b** systematic diagram of rectangular-type microstrip line proposed radiator

but the resonance frequency of $HEM_{12\delta}$ highly depends on aspect ratio ($D/2H$) aperture (L) in regular pentagon shape derived from the radius of circle ($R = 12$).

3 Working of Antenna

The Ansoft HFSS EM simulator has been used in the investigation of proposed radiator. Figure 2 shows the return loss graph of proposed antenna with regular pentagon aperture with spoon-type microstrip line structure and rectangular microstrip

Table 1 Optimized dimension of different parameter of proposed antenna

Symbol (spoon type)	Dimension (mm)	Symbol (rectangular type)	Dimension (mm)
L_G	50	L_G	50
W_G	50	W_G	50
H	12	H	12
D	26	D	26
W_R	2.6	W_R	2.6
L_R	24	L_R	3.1
W_E	2		
L_E	3.1		

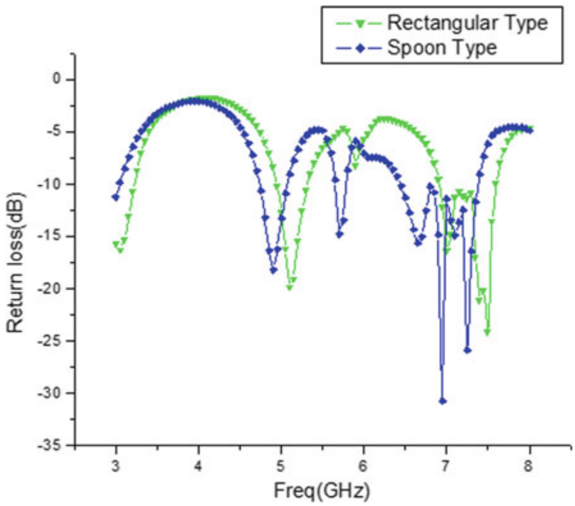


Fig. 2 Return loss versus frequency curve

line structure. Here, spoon-type microstrip line is responsible for multi-band generation. In the below figure, both antennas resonate at lower-frequency band at 4.9 and 5.10 GHz due to CDRA and upper band at 6.95 and 7.50 GHz due to shape of spoon-type and rectangular-type microstrip line. It is fact that the excitation principle of CDRA acts as a horizontally situated magnetic dipole for $HEM_{11\delta}$ mode generation [7]. Pentagon-shaped slot regularly places as a horizontally placed magnetic dipole. For generation $HEM_{12\delta}$ mode in CDRA feeding structure is playing role for horizontally placed electric dipole [7]. Proposed antenna resonate at 4.90 GHz in mode $HEM_{11\delta}$ and 5.10 GHz in mode $HEM_{12\delta}$ show in Fig. 3, electric field line *X*-polarized and *Y*-polarized are excited by regular pentagon aperture shape, so its generate $HEM_{11\delta}$ and $HEM_{12\delta}$ mode. Where, $HEM_{11\delta}$ is strong coupling and $HEM_{12\delta}$ is week coupling.

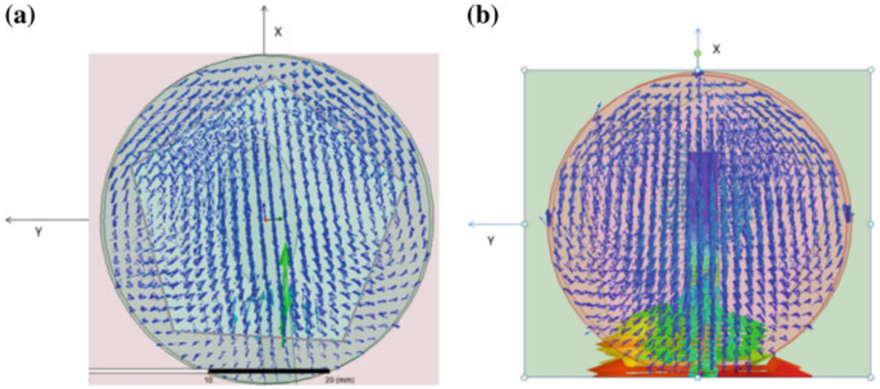


Fig. 3 E-field distribution in CDRA **a** at 6.95 GHz in spoon type, **b** at 7.50 GHz in rectangular type

4 Result and Discussion

Optimized result of return loss is shown in Fig. 2, where spoon-type microstrip is resonating in multi-band and rectangular type is resonating at dual band but bandwidth of spoon type is large. Field pattern is shown in Fig. 4 where co and cross polarization nearly maintain 3 dB difference. Figure 5 shows that both types of simulated result gain are more than 0 dB at 6.95 and 7.50 GHz, and Fig. 6 shows the VSWR closed to 1.

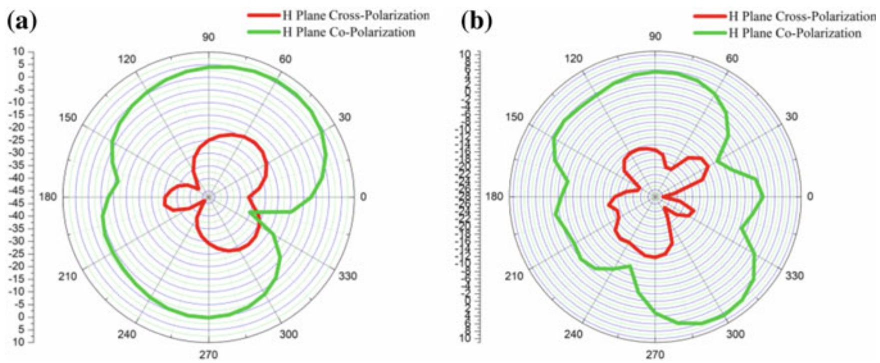


Fig. 4 Far field pattern representation **a** at 6.95 GHz in spoon type, **b** at 3.68 GHz in rectangular type

Fig. 5 Total gain versus frequency curve

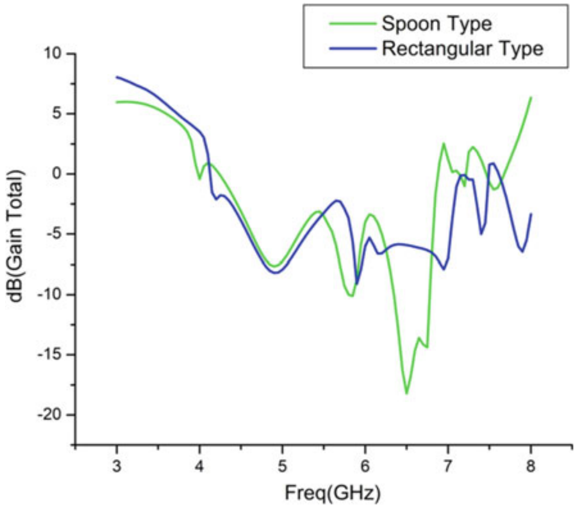
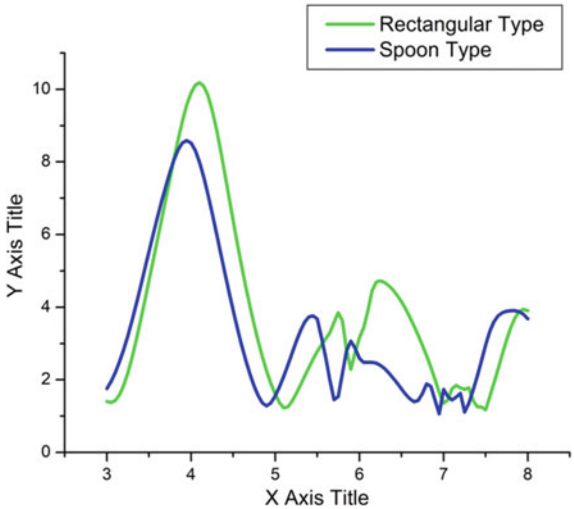


Fig. 6 VSWR versus frequency curve



5 Conclusion

This manuscript presents a multi-band hybrid aperture CDRA, dual band characteristic is achieved by rectangular-type micro strip line, and multi-band is achieved by spoon-type micro strip line. In this work, hybrid mode is achieved by regular pentagon-shaped aperture. The main purpose of this antenna is wireless communication.

References

1. A. Petosa, *Dielectric Resonator Antenna Handbook* (Artech House, Norwood, 2007)
2. K.M. Luk, K.W. Leung, *Dielectric Resonator Antenna* (Research Studies Press Ltd., Baldock, Hertfordshire, 2003)
3. H.M. Chen, Y.K. Wang, Y.F. Lin, S.C. Lin, S.C. Pan, A compact dual-band dielectric resonator antenna using a parasitic slot. IEEE Antennas Wirel. Propag. Lett. **8**, 173–176 (2009)
4. Y. Din, K.W. Leung, On the dual-band DRA-slot hybrid antenna. IEEE Trans. Antennas Propag. **57**, 624–630 (2009)
5. Y.F. Li, H.M. Chen, C.H. Lin, Compact dual-band hybrid dielectric resonator antenna with radiating slot. IEEE Antennas Wirel. Propag. Lett. **8**, 6–9 (2009)
6. H.S. Ngan, X.S. Fang, K.W. Leung, Design of dual-band circularly polarized dielectric resonator antenna using a high-order mode, in *Proceedings of IEEE-APS APWC* (2012) 424–427
7. D. Guha, P. Gupta, C. Kumar, Dual band cylindrical dielectric resonator antenna employing $HEM_{11\delta}$ and $HEM_{12\delta}$ mode excited by new composite aperture. IEE Trans. Antennas Propag. **63**, 433–438 (2015)