American Journal of Applied Sciences

Original Research Paper

High Gain Multiband Stacked DRA for WiMax and WLAN Applications

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Article history
Received: 06-03-2017
Revised: 05-06-2017
Accepted: 02-08-2017

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Abstract: Dielectric resonator antennas find widespread applications in high speed wireless systems because of low loss, compact size and light weight. In this study, performance of a multiband Dielectric Resonator Antenna (DRA) with higher gain and improved radiation efficiency for 3.8 GHz band Wi-Max, fixed point satellite links and 4.8GHz band 5G services and 5GHz wireless networks is presented. The proposed design consists of stacked rectangular dielectric resonator fed by a microstrip line placed above grounded Arlon substrate. Simulation results of the proposed DRA shows dualband operation from 3.65 to 4.45GHz and 4.7 to 5.6GHz with impedance bandwidth of 20.25 and 17.47% respectively. The gain and directivity of the DRA is 8.22 and 8.17dB respectively.

Keywords: Dielectric Resonator, High Gain, DRA, Stacked DRA, Grounded Substrate, Arlon

Introduction

Low profile antenna design with Microstrip line and Dielectric resonators has been under extensive research over the last two decades. Microstrip antennas find widespread applications in contemporary wireless devices as they are compact, cost effective and easy to fabricate and integrate with Microwave Integrated Circuits (MIC). But they are characterized with low gain, lower impedance bandwidth and presence of surface waves. Hence for high gain and large bandwidth requirements, Dielectric Resonator Antenna (DRA) is preferred over microstrip antennas. The first dielectric resonator antenna was developed by Stuart Long in the early eighties (Long *et al*., 1983; McAllister *et al*., 1983). A DRA consists of a high permittivity dielectric material (from 6 to 100) placed over a ground plane and fed by a coaxial probe or a microstrip line or coplanar waveguide or a slot in the ground plane (Petosa *et al*., 1998; Kumar and Gupta, 2014).The resonant frequency and impedance bandwidth for a dielectric resonator antenna is a function of shape, permittivity and aspect ratio of the dielectric material.

The DRA has a wider impedance bandwidth compared to the microstrip antenna. It is easily possible to achieve a fractional or impedance bandwidth of 10% with a dielectric resonator antenna (Mongia and Bhartia, 1994; Almpanis *et al*., 2010). Radiation from the DRA is through the entire surface except the ground plane whereas the microstrip antenna radiates through the edges of the patch (Sahaya Anselin Nisha, 2017). Since surface waves are absent in the DRA, they have higher efficiency and reduced distortions in the radiation pattern (Buerkle *et al*., 2005; Soren *et al*., 2014; Diao *et al*., 2015). Extensive theoretical and experimental investigations have been carried out with various shapes such as rectangular, circular and hemispherical structure and materials (Majeed *et al*., 2015; Embong and Mansor, 2015; Xie *et al*., 2016; Khan *et al*., 2016).

A multiband DRA with cylindrical dielectric resonator and modified microstrip line feed is presented in (Sharma *et al*., 2017). It achieved peak resonance at 2.5, 3.4, 5.0, 5.45 and 5.8 GHz with fractional or impedance bandwidth of 9.8, 4.6, 7.8, 1.9 and 3.4% at respective frequencies. The gain of the antenna varies between 2.6dBi at 2to a maximum gain of 9.0dBi at 5.7GHz. Rashidian and Shafai (2016), a polymer and metal strip based DRA is investigated. It has peak resonance at 8.6GHz with impedance bandwidth of 10%, 5.7dBigain and 90% efficiency. The dimensions of the antenna is smaller than $\lambda/6$. A modified slot fed rectangular DRA proposed in (Amin *et al*., 2016) achieved a maximum gain of 10.2dB at 4.7GHz and broader bandwidth from 3.5 to 4.945GHz. Pan and Zheng

(2006), a multilayer DRA with aperture feed is investigated. It is characterized by single band operation with 40% impedance bandwidth and 10dBi gain. A notched cylindrical DRA excited by a monopole patch for Ultra Wideband (UWB) applications is investigated in (Li *et al*., 2016). The maximum gain of the antenna is 6.5dBi and achieves 90% radiation efficiency. In general, microstrip line fed DRAs has low radiation efficiency (Petosa *et al*., 2000). The objective of this work is to improve the efficiency and gain of this type of DRAs.

Proposed Antenna Configuration

To improve the coupling performance between the microstrip feed line and the dielectric resonator, two different permittivity substrates are used to construct the dielectric resonator (Li *et al*., 2016). The proposed antenna consists of a grounded Arlon dielectric substrate of dimension 70mm×70mm×0.9mm with permittivity ε_r=3.8. The radiating element is a stacked rectangular dielectric resonator composed of RT Duroid 5880 and a parasitic dielectric material made of mica with ε_r=15. The dimensions of the RT Duroid and mica layer are 46mm×46mm×3mm and 46mm×46mm×3.2mm respectively. The structure of the proposed antenna is shown in Fig. 1.

The aperture consists of a rectangular slot in the RT Duroid layer and fed by a microstrip line beneath it. This aperture behaves like a magnetic current running parallel to the length of the slot, which excites the magnetic fields in the DRA. The length (ls) and width (ws) of the aperture is kept according to equation 1 and 2. The stub length is chosen to beλ_g/4. The dimensions of the DRA are determined using the dielectric waveguide modelequations for the desired resonant frequency (Luk and Leung, 2003; Petosa, 2007):

$$l_s = \frac{0.4\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$w_s = 0.2 l_s \tag{2}$$

$$\varepsilon_{eff} = \frac{H_{eff}}{\frac{h_a}{\varepsilon_a} + \frac{h_m}{\varepsilon_m} + \frac{h_{rt}}{\varepsilon_{rt}}} \tag{3}$$

$$H_{eff} = h_a + h_m + h_{rt} \tag{4}$$

Where:

λ_0	=	Free space wave length
λ_g	=	Theguide wave length in the substrate
ε_{eff}	=	The effective dielectric constant of multi layer dielectric resonator
H_{eff}	=	The effective height of the dielectric resonator
h_a, h_m and h_{rt}	=	The height of Arlon, Mica and RT-duroid dielectric segments
'a' is the length and 'b'	=	The height of the resonator(b= $h_{m+}h_{rt}$).
m and n	=	Represent mode number

The resonant frequency 'F_r' of a rectangular DRA is approximated by equation 5 where k_x, k_y and $k_z$denotes wave number in x, y and z directions respectively (Petosa, 2007):

$$F_r = \frac{c}{2\pi\sqrt{\varepsilon_{eff}}}\sqrt{k^2x + k^2y + k^2z} \tag{5}$$

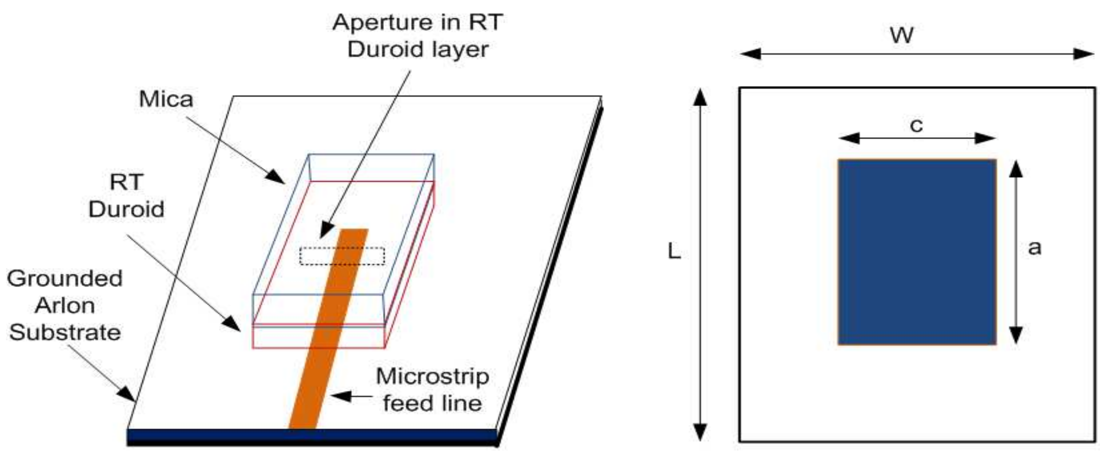


Fig. 1. Geometry of the proposed DRA

DOI: 10.3844/ajassp.2017.779.785

$$k_z = \sqrt{\varepsilon_{eff} k_0^2 - k_x^2 + k_y^2} \quad (6)$$

$$kx = \frac{m\pi}{a}\left(1 + \frac{2}{ak_0\sqrt{\varepsilon_{eff} - 1}}\right)^{-1} \quad (7)$$

$$ky = \frac{n\pi}{a}\left(1 + \frac{2}{bk_0\sqrt{\varepsilon_{eff} - 1}}\right)^{-1} \quad (8)$$

$$k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c} \quad (9)$$

In this design, microstrip line feed with aperture coupling is used for the dielectric resonator. The length of the microstrip stub can be varied to cancel out the reactive component of the slot, thus allowing for an impedance match to the DRA.

Results and Discussion

The proposed antenna design is analysed with Ansys HFSS tool and performance results of various antenna parameters are discussed below.

Return Loss and Bandwidth

The reflection coefficient of the proposed antenna as a function of frequency is shown in Fig. 2. Peak resonance is obtained at 3.95, 4.9 and 5.35 GHz with impedance bandwidth of 21.5and 17.78%. Figure 3 shows the Voltage standing wave ratio plotted as a function of frequency. VSWR values obtained at the peak resonant frequencies are 1.03, 1.40 and 1.22 respectively.

Gain and Directivity

The gain and directivity of the proposed stacked DRA antenna is shown in Fig. 4. The peak gain observed is 8.23dB and directivity is 8.174dB at resonant frequencies. The efficiency of the proposed antenna turns out to be 99.3%. Figure 5 shows plot of gain in dB as a function of theta:

$$Efficiency = \frac{Gain}{Directivity} \times 100\% \quad (10)$$

Two Dimensional Radiation Characteristics

The proposed DR antenna exhibits bidirectional radiation pattern for various values of theta and phi. Figure 6 shows the two dimensional radiation pattern at 0, 90 and 180 degrees for peak resonance frequencies. Table 1 summarizes the performance parameters of other recent DRA architectures along with the proposed design. The proposed antenna exhibits higher gain (>8dBi) and efficiency with dual resonance.

E-Field and H-Field Distribution

Electric Field, Magnetic field and surface wave characteristics of the proposed antenna are shown in Fig. 7 and 8. Simulated values of surface voltage and current density distribution at 5 GHz is shown below.

From the results it is observed that maximum E-field or voltage distribution on the surface of the feed line of the antenna is 34.8V/m and H-field or current distribution is 0.42A/m.

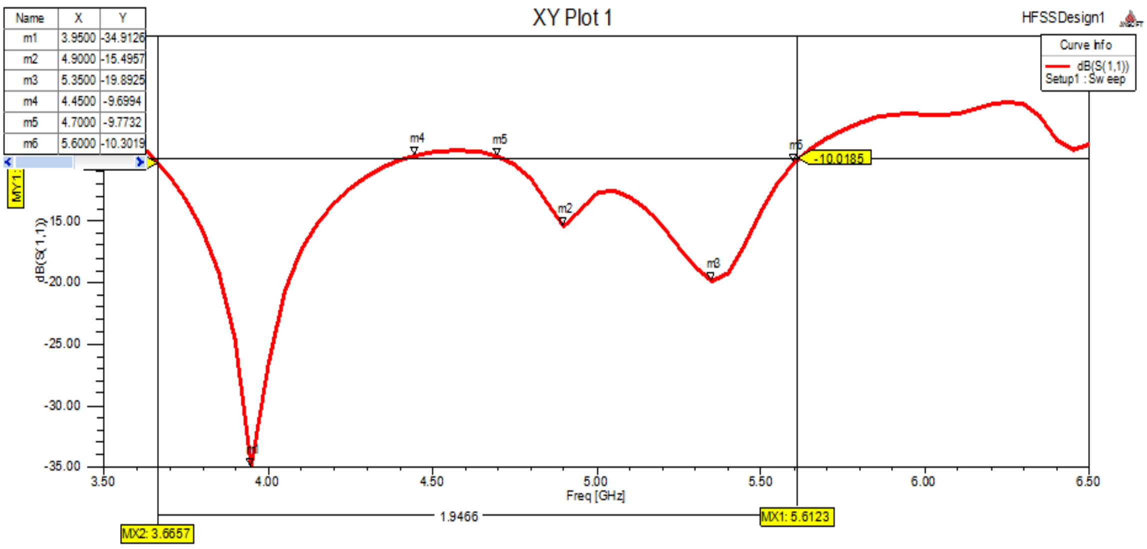


Fig. 2. Return loss Vs. frequency

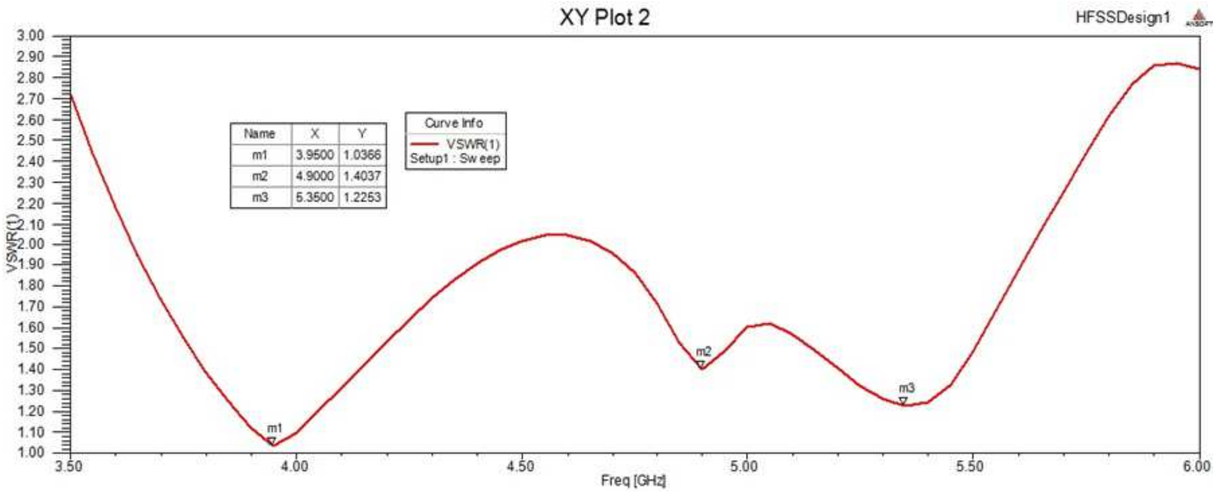
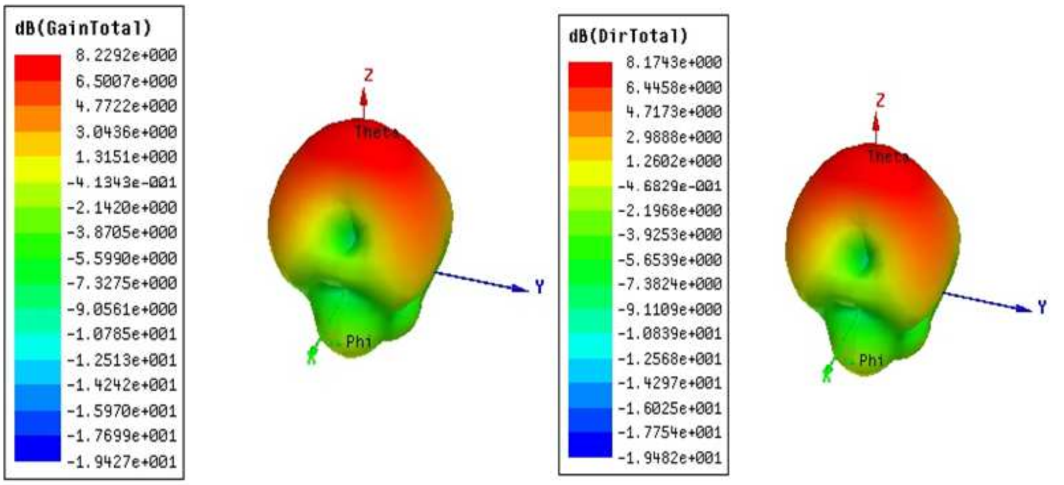


Fig. 3. VSWR Vs. frequency



(a) (b)

Fig. 4. 3D Gain and Directivity of proposed antenna (a) Gain and (b) Directivity

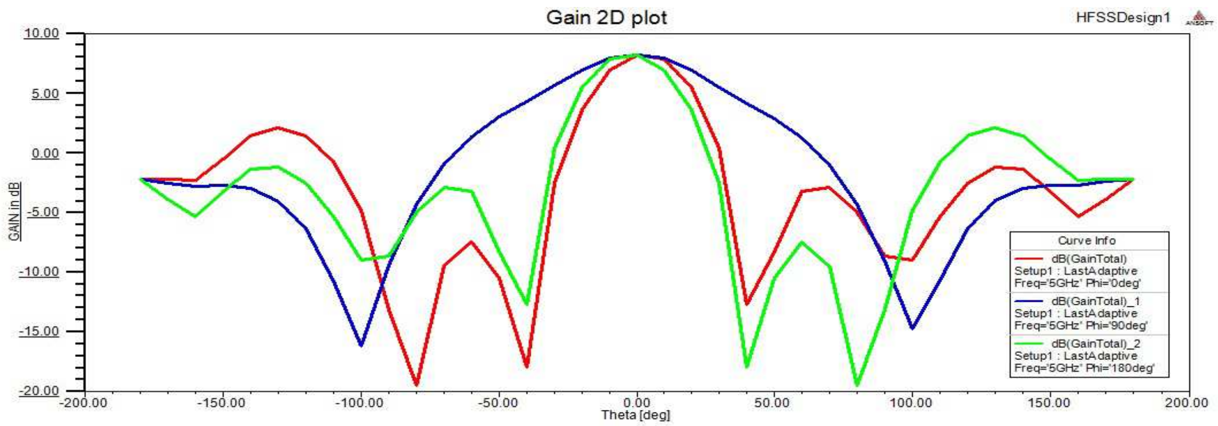


Fig. 5. Gain of proposed antenna as a function of Theta at different values of phi

DOI: 10.3844/ajassp.2017.779.785

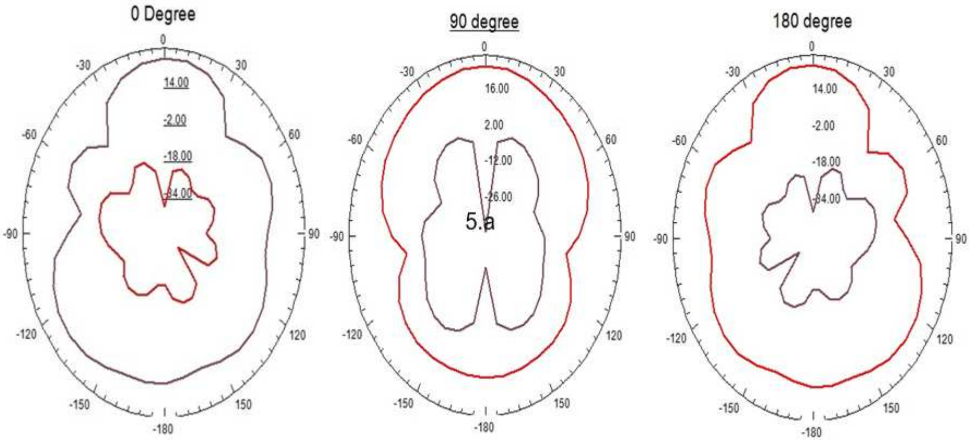


Fig. 6. 2D radiation pattern of the proposed antenna at 0, 90 and 180 degrees

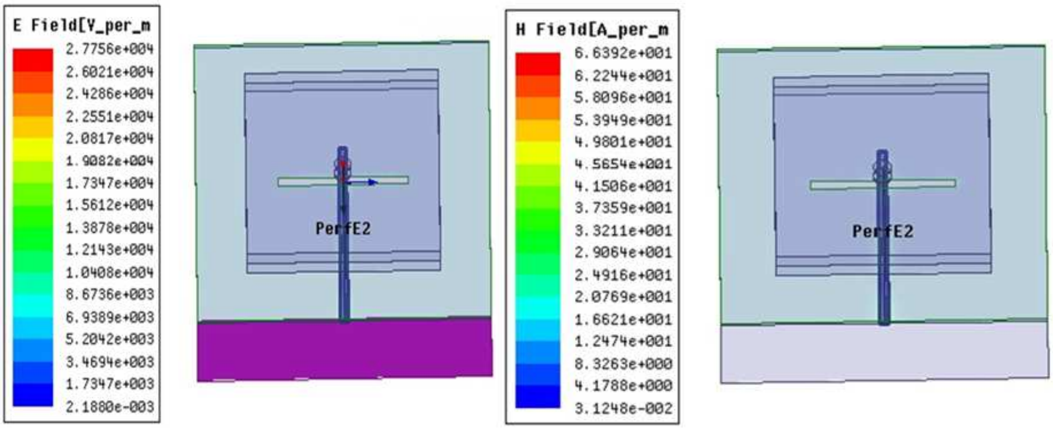


Fig. 7. Field distribution on the proposed structure (a) E-Field (b) H-Field

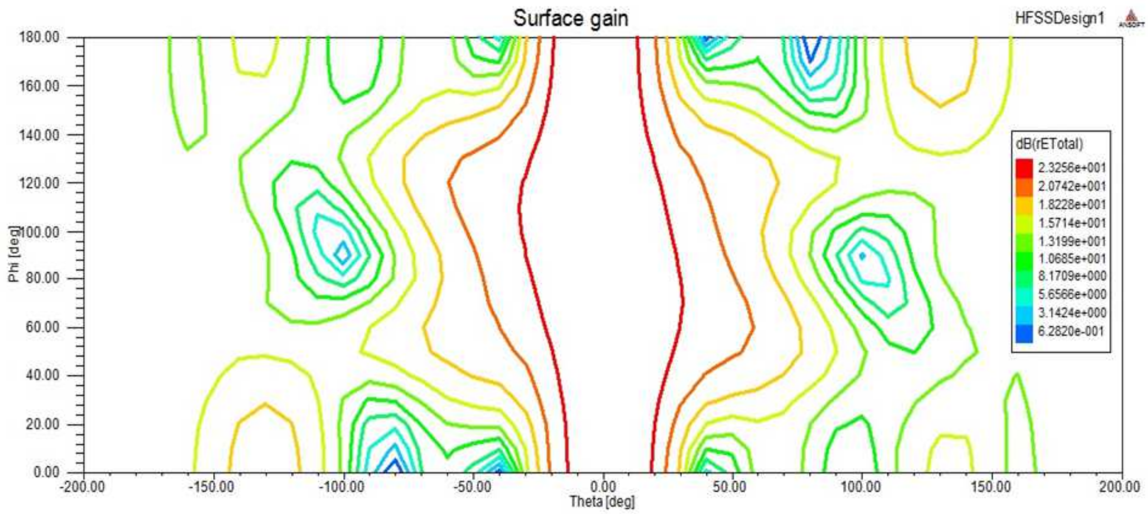


Fig. 8. Gain contour plot of proposed antenna

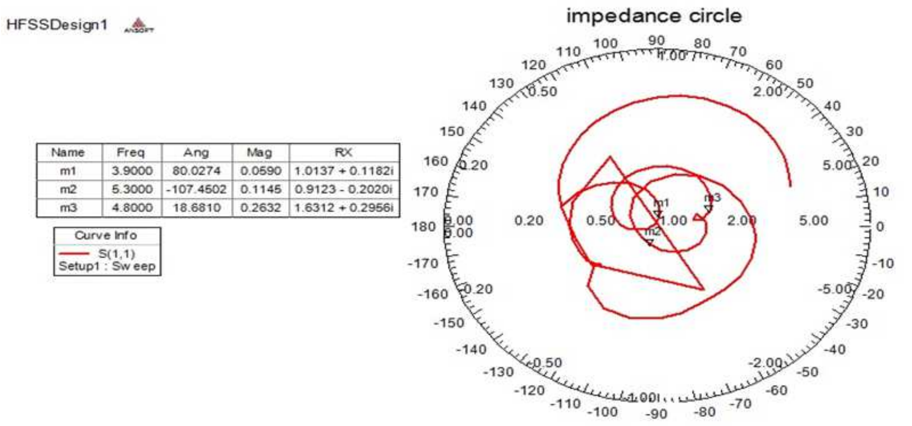


Fig. 9. Impedance variation Vs. frequency of the proposed antenna

Table 1. Recent advances in DRA

Antennas	Operating Band (GHz)	Impedance bandwidth (%)	Maximum Gain (dBi)	Radiation efficiency (%)
Proposed design	3.65 to 4.45 and 4.7 to 5.6GHz	20.25 and 17.47	8.22	99%
Design in (Pan and Zheng, 2006)	3.97-5.98GHz	40	10.5dbi	95%
Design in (Rashidian and Shafai, 2016)	8 to 8.6GHz	10	5.7dBi	90%
Design in (Sharma *et al*., 2017)	2.5-2.76, 3.38-3.54, 4.9-5.3, 5.5-5.61 and 5.78-5.98GHz	7.7	9dBi	-
Design in (Li *et al*., 2016)	2.9-6.7GHz	75	6.5dBi	90%

Impedance

The impedance circle shows the variation of beam angle value and running impedance of the antenna for each resonant frequency. Figure 9 shows that normalized impedance at peak resonance frequencies 3.9 4.6 and 5.3GHz falls in the unity circle of the smith chart justifying good impedance matching characteristics of the proposed design.

Conclusion

The proposed work illustrates a stacked technique for achieving high radiation efficiency and high gain DRA with dualband resonance. The proposed antenna has achieved 99% radiation efficiency and more than 8dB gain in both the resonant bands. Impedance performance of the antenna lies in the unity circle making it suitable for practical applications such asWi-Max, fixed point to point and fixed satellite services operating in 3.8 to 4.2band and 4.84.99GHz 5G mobile services and 5GHz wireless networks.

Acknowledgement

The authors thank the management of Sathyabama University for the motivation and encouragement provided to carry out research activities. We also thank the reviewers for providing valuable comments and suggestions.

Author's Contributions

Sugadev Mani: Contributed to design and simulation analysis of the proposed antenna.

Logashanmugam Edeswaran: Contributed to the material selection for different layers to improve efficiency of the proposed antenna.

Ethics

The corresponding author confirms both the authors have read and approved the manuscript and no ethical issues involved.

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