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Gain enhancement in cubic DRA with modified microstrip feed for WLAN applications

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Abstract: In this paper, a modified microstrip slot aperture feed is introduced which generates $TE_{\sigma 13}$ modes in a cubic dielectric resonator antenna resulting in a high gain (simulated = 10.5 dB and measured = 9 dB). The proposed feed can be realized by replacing the rectangular stub of microstrip slot aperture feed with a circular metallic stub of radius 3 mm. The proposed feed excites the dielectric resonator antenna around a resonant frequency of 5.78 GHz covering 5.725–5.850 GHz WIFI band. The antenna exhibits an impedance bandwidth of 130.2 MHz, and 135 MHz in simulations and measurements respectively, and a stable gain throughout the 5.78 GHz WIFI band with a maximum of 9 dB in measurements.

Keywords: dielectric resonator antenna, WLAN, microstrip slot aperture feed, 5.78 GHz WIFI band

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

Dielectric Resonators find their applications as a High-Q element in microwave filter and oscillator designing [1]. During early 80's the dielectric resonator was first adopted as an antenna element, called dielectric resonant antenna (DRA), using the waveguide model. The major property of DRA is that it presents low conductor losses as compared to its metallic counterparts at high frequencies [2, 3]. Furthermore, due to the presence of 3D structure an extra degree of freedom is obtained in exciting different modes in a single antenna element thus resulting in high gains as compared to those achieved with metallic antennas. Moreover, it is easy to generate resonant modes required for different application with rather simplicity. Design equations for DRA are available in [4]. Normally, when DRA is excited in its fundamental modes it can achieve maximum gain up to 5 dB only.

To improve the antenna gain, different techniques have been proposed in the literature. For example, stacking DRA elements technique is demonstrated in [5, 6]. In this technique, different permittivity DRA materials are joined together to enhance antenna gain and band-width [6].

Practically, some fabrication issues have been found in stacking techniques so integrated techniques [7, 8] were considered. For example, peak broadside gain is achieved by using uniaxial anisotropic materials in RDRA [7], and cylindrical DRA

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is integrated within a cylindrical electromagnetic band gap (EBG) substrate [8]. These integrated techniques are not easy for fabrication so the technique of exciting a DRA in higher order modes [9, 10, 11, 12] was reported. RDRAs were excited in their higher order modes to achieve higher gain [9]. Gain of the omnidirectional cylindrical DRA is enhanced from 1.71 dB to 4.06 dB by exciting it in TM_{015} modes [10]. In [11] band-width of the RDRA has been enhanced up to 40% by using TE_{111} mode together with TE_{113} modes. In [12] an RDRA is operated to be working in TM modes. Moreover, some feeding techniques [13, 14] had been used to excite antenna in orthogonal/higher order modes to enhance antenna band-width, and gain. For example, a bevel feeding patch structure is introduced in [13] to excite the antenna in higher order modes to achieve broad band-width and gain up to 7 dB. In [14] a dual-mode quadrature fed wideband DRA with relatively good gain is presented. The feeds used in [13, 14] are very useful in obtaining good results but are slightly complex in structure and may have fabrication issue.

In this paper, a high gain cubic DRA excited by modified microstrip slot aperture feed is presented for 5.78 (5.725–5.850) GHz WIFI band [15] applications. This modified microstrip slot aperture feeding technique and simple cubic DR excites the $TE_{\sigma 13}$ modes internally in the DRA. Thus, antenna attains high gain (simulated = 10.5 dB and measured = 9 dB) and impedance bandwidth simulated = 130.2 MHz (centered at 5.78 GHz), measured = 135 MHz (centered at 5.80 GHz). The proposed antenna has a very simple structure that can be fabricated easily, while exhibits higher gain than the reference antennas.

2 Antenna configuration and design

The antenna consists of a Dielectric Resonator, a ground plane with slot, a substrate and a microstrip feed line. The dielectric resonator is excited by the means of a slot cut in the ground plane of a microstrip. The electromagnetic field from the microstrip line is coupled to the slot aperture which in turns excites the dielectric resonator. The resonator and slot dimensions are selected such that the $TE_{\sigma 13}$ mode is internally excited in the DRA. The ground plane with slot is placed such that it is sandwiched between the dielectric resonator and the substrate. The feed line consists of a standard 50-ohm microstrip line terminated into a circular stub for the enhancement of antenna bandwidth. The slot usually presents high impedance at its center. The termination of microstrip feed line in to circular stub makes it possible to match the impedance of feed line with that of the slot in a wide range of frequencies.

The geometry of the proposed antenna is shown in Fig. 1. The cubic DRA section is realized by using Taconic CER-10 material having $\varepsilon_r = 12.53$, loss tangent = 0.0024 with dimensions of each side $h_{DR} = 25.2$ mm. A Rogers RO 4003 with $\varepsilon_r = 3.8$, and dimensions $L_{sub} = 100.8$ mm, $W_{sub} = 50.4$ mm and $h_{sub} = 0.5$ mm is used to support the microstrip line and slotted ground plane for the feed section. The length and width of microstrip line are $L_f = 75.6$ mm, $w_f = 1.2$ mm respectively, whereas the radius of circular stub = 3 mm. The slot has width and length of $W_s = 1.1$ mm, $L_s = 22$ mm respectively.

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3 Parametric study

It was discussed in previous section that the extension of microstrip line beyond the slot aperture is chosen to be in a circular shape. To show how the use of circular stub at the end of microstrip feed line works better than that of a conventional rectangular stub simulation were carried out using CST 2015. Fig. 2(a) presents the comparative simulated band widths corresponding to normalized areas of proposed circular metallic strip/stub and conventional rectangular stub. It may be mentioned that while changing one parameter of the antenna, all the other parameters were kept constant. Fig. 2(b) illustrates the antenna performance in terms of peak gain when circular metallic strip/stub and rectangular stub are used. It is clear from Fig. 2(a, b) that antenna exhibits larger bandwidth and gain in case of a circular metallic strip/stub attached to the microstrip feed line.

The circular metallic strip/stub is characterized by its radius and the antenna can be tuned by varying the circular metallic strip/stub radius. The effect of changing the radius of circular metallic strip/stub on return loss and peak gain is illustrated in Fig. 2(c) and (d) respectively. It is clear from the Fig. 2(c, d) that proposed antenna shows better return loss and gain performance when a circular metallic strip/stub of 3 mm radius is used instead of conventional rectangular stub.

4 Experimental results and discussion

Based on optimized dimensions, a prototype simple cubic DRA with modified microstrip feed was fabricated to confirm the simulation (CST 2015) results previously shown in Fig. 1(c)–(d). Cubic DR was fixed on top of the ground plane of the substrate with the help of cotton thread ($\varepsilon_r = 1.3$).

The measurement of the reflection coefficient for the proposed antenna was performed by Rohde & Schwarz ZVB 20 vector network analyzer. Fig. 3(a) shows the measured and simulated return loss of the proposed antenna. It is clear from the figure that the simulated 5.78(5.7200–5.8502) GHz and measured 5.80(5.725–5.860) GHz bandwidth of the antenna is almost same however slight error (0.34%) in resonant frequencies can be seen. This error may be attributed to manufacturing tolerances. In Fig. 3(b) measured and simulated antenna gain is shown. It is clear from the figure that maximum measured antenna gain is 9 dB at 5.80 GHz and maximum simulated gain is 10.5 dB at 5.75 GHz. The antenna gain

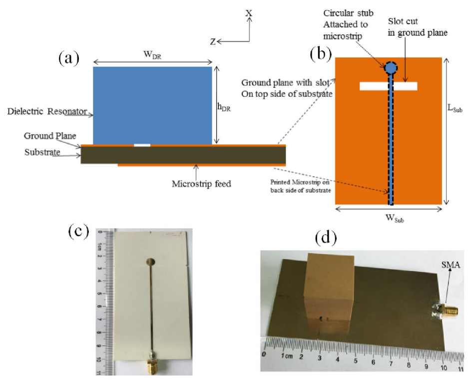

Fig. 1. Structure of the proposed Cubic DRA. (a) side view. (b) Back-side view. (c) Fabricated Back-side view. (d) Fabricated 3D view.

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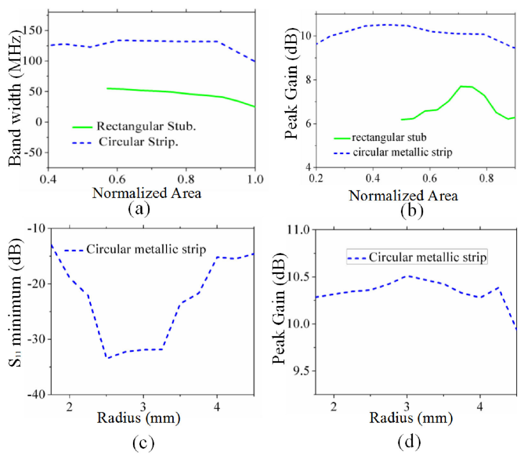

Fig. 2. Comparison of conventional rectangular stub and proposed circular metallic strip. (a) Simulated band width. (b) Simulated peak gain. (c) Simulated S_{11} minimum for the radius of metallic strip. (d) Simulated peak gain for the radius of metallic strip.

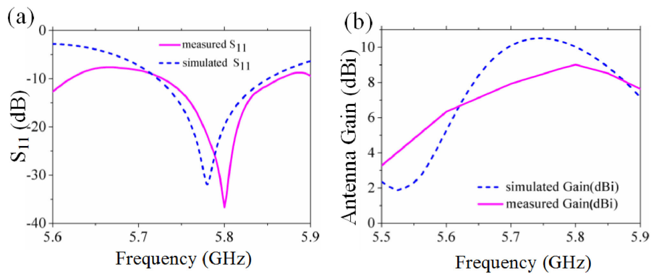

Fig. 3. Simulated and measured reflection coefficient and gain of the proposed antenna.

has up to 14.2% error but these measured results are still in our acceptable range as we see the same error in [10] up to 23% in measured and simulated gain. This difference is due to imperfections in the experimental setups such as DR cutting, DR fixing on the ground plane, small air gaps between the DR and modified slot aperture and DR material (Taconic CER-0).

The simulated and measured far-field radiation patterns in XZ-plane at phi = 0 deg. and YZ-plane at phi = 90 deg. obtained by exciting the cubic DRA through modified microstrip slot aperture feed are shown in Fig. 4 at 5.80 GHz frequencies which shows antenna is steering an electromagnetic beam in that direction.

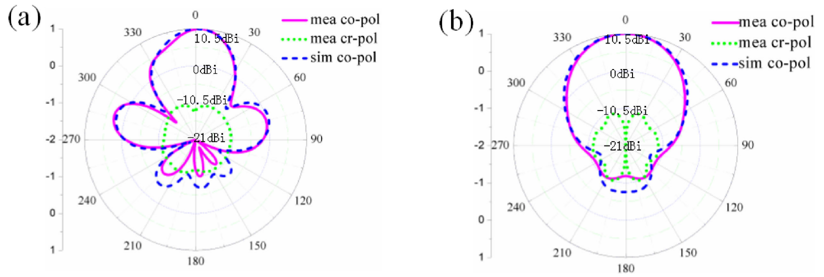

Fig. 4. Normalized measured and simulated far field radiation patterns at 5.80 GHz. (a) In XZ-plane at phi = 0 deg. (b) In YZ-plane at phi = 90 deg.

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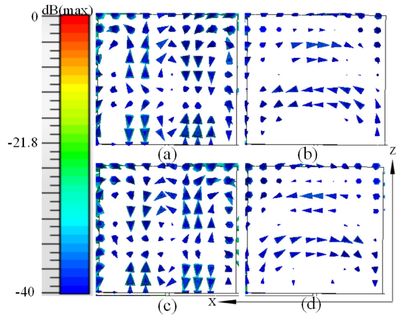

Fig. 5. Simulated E-fields distribution inside cubic DR at 5.78 GHz XZ-Plane. (a) phase 0. (b) phase 90. (c) phase 180. (d) phase 270.

Table I. Comparison of proposed cubic DRA with reference antennas.

S.No	Shape of DR.	ε_r	Feed Type.	R_f (GHz)	Sim/mea Gain (dB)	Ref:
1.	3-Discs stack	12.3	Coaxial Prob	10	8.7	[4]
2	Rectangular (unidirectional mat)	10	Aperture coupled slot.	3.5	Mea. = 8.4	[6]
3	Cylindrical	35.5	Coaxial Prob	2.3	Sim. = 9.5 Mea. = 8.4	[7]
4	Cylindrical	10	Coaxial Prob	5.8	Sim = 4.06 Mea = 3.12	[9]
5	**Simple Cubic**	**12.53**	**Modified microstrip slot aperture feed.**	**5.78**	**Sim = 10.5** **Mea = 9.0**	**Proposed antenna**

It has been observed by plotting the electric field distribution inside the cubical DR (vertical slice) as shown in Fig. 5 that cubic DR is radiating in $TE_{\sigma 13}$ modes at 5.78 GHz. The excitation of these higher order $TE_{\sigma 13}$ modes is responsible for the higher gain in the antenna. Table I compares the proposed simple cubic DRA to many reference antennas. It is clear from the table that the modified microstrip slot aperture feed adopted in the proposed antenna results in better performance in terms of antenna gain as compared to the all reference antennas.

5 Conclusions

A potentially simple antenna is introduced in this letter which employs a single cubic dielectric resonator segment. The antenna exhibits a high gain value (10.5 dB simulated, 9 dB measured) and a common bandwidth of 130 MHz (centered at 5.78 GHz), covering the whole 5.78 GHz (5.725–5.850 GHz) WIFI band for WLAN applications. A microstrip fed slot aperture is used to excite the $TE_{\sigma 13}$ mode in the dielectric resonator. A circular stub is attached to the microstrip feed line to enhance the impedance bandwidth. The generation of $TE_{\sigma 13}$ mode in the resonator is responsible for achieving higher gain value. It was demonstrated that the antenna exhibits high and stable gain as well as reasonable bandwidth and is a good candidate for the 5.78 GHz WIFI applications.

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