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Gain enhancement of dielectric resonator antenna for millimeter wave applications

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Abstract

In this paper, dielectric resonator antenna (DRA) with enhanced gain operating on the higher order mode ($TE^{x}_{\delta 15}$) is presented. The dielectric resonator antenna with dielectric constant ε_r of 10 and loss tangent of 0.002 is used. The DRA is fed by microstrip line through an aperture slot. The proposed antenna is designed at 26 GHz and achieved a gain of 7.9 dBi with corresponding simulated radiation efficiency of 93%. The impedance bandwidth of 1.5 GHz from 25.1 GHz to 26.6 GHz has been achieved. The reflection coefficient, antenna gain, radiation patterns, and efficiency of the antenna are studied. Simulations are performed using CST microwave studio, and their results are presented.

Keywords: *dielectric resonator antenna (DRA), high gain, higher order mode (HOM), millimeter wave (mm-wave)*

1. Introduction

Rapid growth of wireless communication technology in millimeter wave (mm-wave) frequency spectrum have got tremendous attention. Due to the scarcity of frequency spectrum below 6 GHz, millimeter wave frequency band ranging from 10 GHz to 100 GHz is considered as a potential candidate for the next generation 5G technology. According to Friss formula, the free space loss increases as the frequency increases [1]. Therefore, there is a need of designing new antennas that are not only more efficient and compact in design but also offer higher gain to compensate the additional incremental losses at higher frequencies.

During the last few years, the two main classes of antennas such as microstrip patch antenna (MSA) and dielectric resonator antenna (DRA), are under investigation at higher frequencies for the modern communication systems. MSA is good choice for the modern communication systems because of their characteristics of light weight, low profile, small size and simplicity of manufacturing [2]. However, microstrip antenna suffers from low gain and very narrow bandwidth. In addition, the radiation efficiency of the microstrip patch antenna reduced significantly due to the metallic losses and surface wave excitation at higher frequencies. In contrast to MPAs, DRAs have high gain and wider bandwidth. Furthermore, DRAs are characterized by high radiation efficiency in the absence of surface waves and metallic losses [3] because it is simply made of dielectric material. Other substantial advantages and appealing features include Light weight, low cost, compact size, low profile, low loss, and ease of excitation [4]. Therefore, Dielectric resonator antennas have received great attention [5] by the antenna research community as an attractive alternative of microstrip antennas. As a result, DRAs are considered as a very promising candidate to be used for the next generation 5G technology at millimetre wave frequencies.

The DRA is a 3-D structure, allowing designers to have more degree of freedom in design than the 2-D and 1-D structure such as microstrip patch antennas and monopole antennas [6]. It comes in various shapes such as cylindrical, triangular, and hemispherical, rectangular [7, 8]. Additionally, several different types of feeding mechanisms can be used to excite DRAs such as microstrip feed lines [9], probe feeding [10], coplanar waveguides (CPWs) [11], and an aperture-coupled microstrip transmission line [12].

Over last three decades, numerous approaches have been suggested to enhance the gain of the dielectric resonator antennas by the previous researchers. These approaches

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include stacked DRA [13–17], integration of additional structures [18,19], modifying the shape of the DRA [20, 21] operating in the lower order mode. However, the proposed approaches have major drawbacks of large volume, complexity in structure and the increased cost, which may not be suitable for the modern communication applications. Recently, higher order modes operation technique has been adopted to enhance the gain of the DRA. Higher order mode technique have been already adopted in both rectangular [22] and cylindrical [23] shaped DRAs to enhance the gain at 11 GHz and 7 GHz, respectively. In this paper, square shaped DRA operating with higher order $TE^{x}_{\delta 15}$ mode as shown in Figure 1, has been proposed to improve gain at 26 GHz frequency. The paper is organized as follows. In Section II, the configuration of the proposed DRA is described. The simulated results of prototype design are discussed in Section III. Finally, a conclusion is drawn in Section IV.

2. Antenna Configuration

The configuration of the proposed dielectric resonator antenna is shown in Figure 1. The DRA has a relative dielectric constant of ε_r and dimensions of length a, width b, and height d. The DR is excited by 50Ω microstrip line fed by a slot aperture coupled on Rogers substrate of dielectric constant $(\varepsilon_r)\ of\ 2.2$ and thickness hs. The dielectric wave-guide model is used to analyze the rectangular DRA. The resonant frequency, f_o of the $TE^{x}_{\delta mn}$ mode can be predicted by means of the following transcendental [24]:

$$k_x \tan\left(\frac{k_x d}{2}\right) = \sqrt{(\varepsilon_r - 1)k_o^2 - k_x^2}$$

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_o^2$$

$$k_0 = \frac{2\pi f_o}{c},\ k_y = \frac{m\pi}{b},\ k_z = \frac{n\pi}{d}$$

where "ε_r" is the dielectric constant of the DRA, k_o denotes free-space wave number, c is the speed of light (in free space). The dimensions of the proposed structure are given in Table 1.

Table 1. Optimized Dimensions of the Proposed Antenna

S.No.	Parameters	Dimensions
1	Substrate $Rogers\ RT5880$ $(\varepsilon_r = 2.2)$ $(L_s \times W_s \times h_s)$	$11.5 \times 11.5 \times 0.254$
2	Ground plane $(L_g \times W_g \times h_g)$	$11.5 \times 11.5 \times 0.0175$
3	Dielectric resonator antenna $(\varepsilon_r = 10)$ $(a \times b \times d)$	$2.98 \times 2.98 \times 6.26$
4	Slot $(ls \times ws)$	0.33×2.02
5	Length of stub (s)	1.36
6	Type of Feed	Aperture coupled

Unit: mm

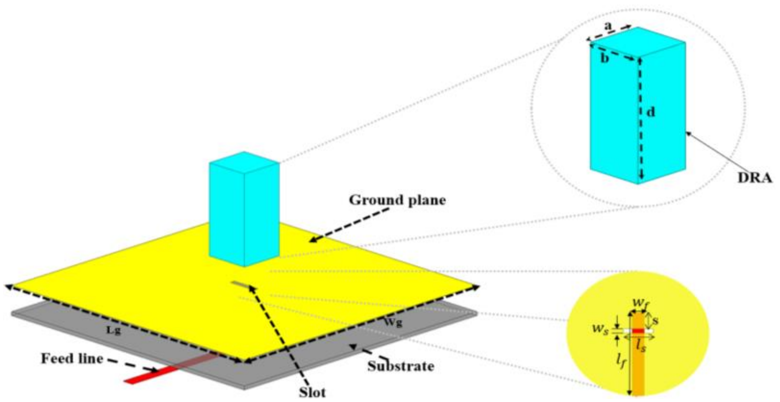

Figure 1. Geometry of the proposed DRA

3. Results and Discussions

In this section, simulated results of proposed design are discussed. The objective is to design a single element DRA with improved gain operating on higher order $TE^{x}_{\delta 15}$ mode at mm-wave frequency. The proposed DRA antenna is simulated by using the CST Microwave studio. The reflection coefficient versus frequency of the DRA structure is shown in Figure 2. With reference to the figure, the $|S_{11}| < -10\ dB$,bandwidth is about 5.7% (25.1-26.6 GHz). The plot of the gain and efficiency versus frequency is presented in Figure 3. It can be seen from the plot that, antenna offers a gain of 7.9 dBi and efficiency of 93% at 26 GHz. The far field radiation pattern is depicted in Figure 4 whereas the normalized radiation pattern in both E(yz) and H(xz) plane are shown in Figure 5. A broadside direction radiation pattern in E- planes and H-planes. A comparison of the proposed DRA with previously reported structures is tabulated in Table 2. From the table, it can be seen that, proposed structure demonstrates more gain compared to the gain of [25] and [26], whereas it is relatively low profile as compared to the design of [25].

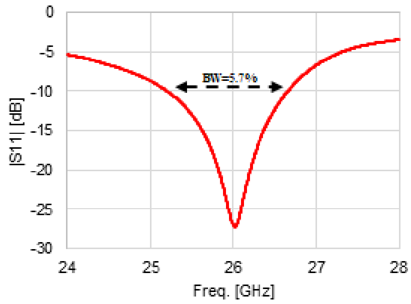

Figure 2. Simulated |S11| of the DRA operating on $TE^{x}_{\delta 15}$ mode

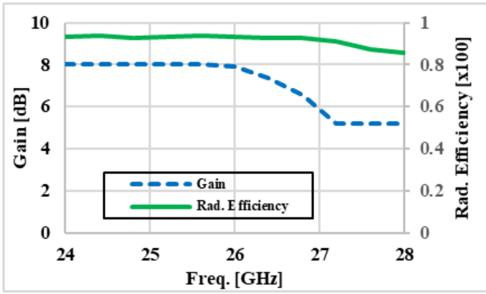

Figure 3. Simulated gain and efficiency Vs frequency of the DRA operating on $TE^{x}_{\delta 15}$

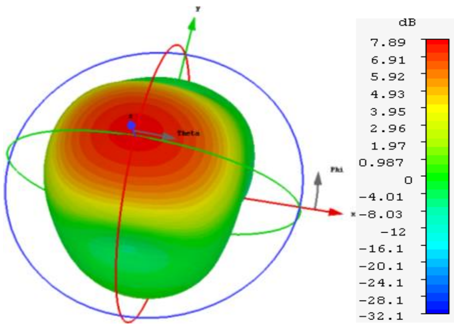

Figure 4. Simulated 3D radiation pattern at 26 GHz

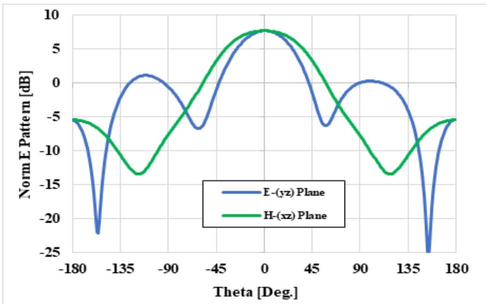

Figure 5. Simulated radiation pattern of the DRA, E(yz) plane and H(xz) plane at 26 GHz

Table 2. Comparison of the Proposed Structure with the Previous Work

Ref	ε_r	Shape	mode	f_o (GHz)	BW (%)	Gain (dB)	Eff. (%)	Area (λ^2)	Height (λ)
[25]	10	Rect.	$TE^{y}_{\delta 15}$	24	5.75	5.8	NM		0.5λ
			$TE^{y}_{\delta 19}$		3.4	6.3	NM	1.6λ × 1.6λ	0.9λ
[26]	10	Rect.	$TE^{x}_{\delta 13}$	135	7	6.2	46		0.6λ
			$TE^{x}_{\delta 15}$		7	7.5	42	0.4λ × 0.4λ	1λ
PS	10	Rect.	$TE^{x}_{\delta 15}$	26	5.7	7.9	93	1λ × 1λ	0.6λ

ε_r—dielectric constant of the DRA, Rect.—Rectangular,f_o—resonant frequency (GHz), BW—Bandwidth (%), Gain—simulated in dBi, Eff. —Efficiency (%) NM—Not Mentioned, PS—Proposed Structure

4. Conclusion

Dielectric resonator antenna with enhanced gain operating on higher order mode is proposed in this paper. The enhanced gain of dielectric resonator antenna is achieved by higher order ($TE^{x}_{\delta15}$) mode operation. The simulated results show that, a gain of 7.9dBi achieved for DRA operating at the frequency of 26 GHz. The impedance bandwidth of 1.5 GHz from 25.1 GHz to 26.6 GHz has been achieved.

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