

Gain enhancement of dielectric resonator antenna for millimeter wave applications

Irfan Ali¹, Mohd Haizal Jamaluddin^{*2}, M. R. Kamarudin³, Abinash Gaya⁴, M. H. Dahri⁵

^{1,2,4,5}Wireless Communication Centre, School of Electrical Engineering,
Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia

³Centre for Electronic Warfare Information and Cyber, Cranfield Defence and Security,
Cranfield University, Defence Academy of the United Kingdom, Shrivenham SN6 8LA, UK

*Corresponding author, e-mail: haizal@fke.utm.my

Abstract

In this paper, dielectric resonator antenna (DRA) with enhanced gain operating on the higher order mode ($TE_{\delta 15}^x$) 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)

Copyright © 2019 Universitas Ahmad Dahlan. All rights reserved.

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

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 $TE_{\delta 15}^x$ 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 50 Ω microstrip line fed by a slot aperture coupled on Rogers substrate of dielectric constant (ϵ_r) of 2.2 and thickness h_s . The dielectric wave-guide model is used to analyze the rectangular DRA. The resonant frequency, f_o of the $TE_{\delta mn}^x$ mode can be predicted by means of the following transcendental [24]:

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

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

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

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 <i>Rogers RT5880</i> ($\epsilon_r = 2.2$) ($L_s \times W_s \times h_s$)	11.5 × 11.5 × 0.254
2	Ground plane ($L_g \times W_g \times h_g$)	11.5 × 11.5 × 0.0175
3	Dielectric resonator antenna ($\epsilon_r = 10$) ($a \times b \times d$)	2.98 × 2.98 × 6.26
4	Slot ($l_s \times w_s$)	0.33 × 2.02
5	Length of stub (s)	1.36
6	Type of Feed	Aperture coupled

Unit: mm

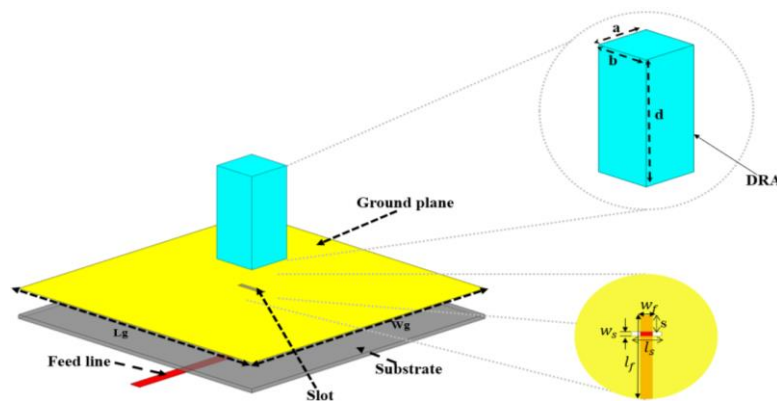


Figure 1. Geometry of the proposed DRA

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 $TE_{\delta 15}^x$ 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].

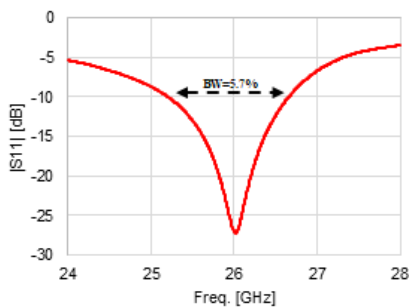


Figure 2. Simulated $|S_{11}|$ of the DRA operating on $TE_{\delta 15}^x$ mode

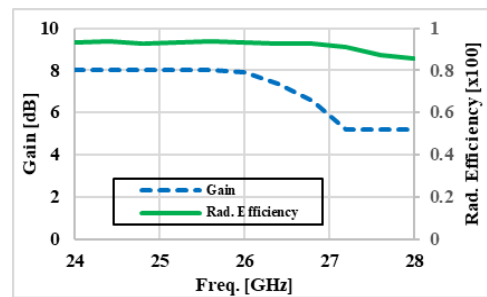


Figure 3. Simulated gain and efficiency Vs frequency of the DRA operating on $TE_{\delta 15}^x$

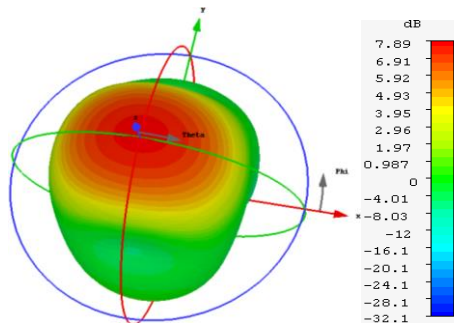


Figure 4. Simulated 3D radiation pattern at 26 GHz

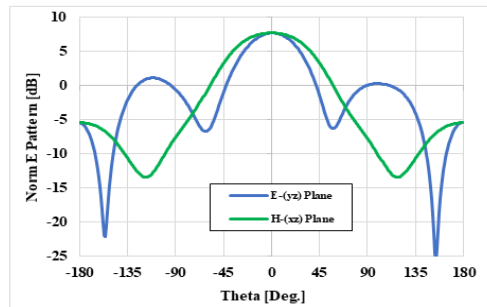


Figure 5. Simulated radiation pattern of the DRA, E(yz) plane and H(xz) plane at 26 GHz

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

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

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 ($TE_{\delta 15}^x$) 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.

References

- [1] Shahadan NH, Jamaluddin MH. Steerable Higher Order Mode Dielectric Resonator Antenna With Parasitic Elements for 5G Applications. *IEEE access*. 2017; 5: 22234-43.
- [2] Mongia RK, Bhartia P. Dielectric resonator antennas—A Review and General Design Relation for Resonant Frequency and Bandwidth. *Int J Microw Millim Wave Comput Eng*. 1994; 4(3): 230-47.
- [3] Lai Q, Almpanis G, Fumeaux C, Benedickter H, Vahldieck R. Comparison of the radiation efficiency for the dielectric resonator antenna and the microstrip antenna at Ka band. *IEEE Trans Antennas Propag*. 2008; 56(11): 3589-92.
- [4] Petosa A. Dielectric Resonator Antenna Handbook. Norwood, MA: Artech House. 2007: 308.
- [5] Nasir J, Jamaluddin MH, Khalily M, Kamarudin MR, Ullah I, Selvaraju R. A reduced size dual port MIMO DRA with high isolation for 4G applications. *Int J RF Microw Comput Eng*. 2015; 25(6): 495-501.
- [6] Leung KW, Lim EH, Fang XS. *Dielectric resonator antennas: From the basic to the aesthetic*. Proc IEEE. 2012; 100(7): 2181-93.
- [7] McAllister MW, Long SA, Conway GL. Rectangular dielectric resonator antenna. *Electron Lett*. 1983; 19(6): 218-9.
- [8] Nor NM, Jamaluddin MH, Kamarudin MR, Khalily M. Rectangular Dielectric Resonator Antenna Array for 28 GHz Applications. *Prog Electromagn Res*. 2016; 63: 53-61.
- [9] Shahadan NH, Kamarudin MR, Jamaluddin MH. Investigation on Feeding Techniques for Rectangular Dielectric Resonator Antenna in Higher-Order Mode for 5G Applications. *Appl Mech Mater*. 2015; 781: 41-4.
- [10] Huynh AP, Jackson DR, Long SA, Wilton DR. A study of the impedance and pattern bandwidths of aperture-coupled cylindrical dielectric resonator antennas. *IEEE Antennas Wirel Propag Lett*. 2011; 10: 1313-6.
- [11] Ryu KS, Kishk AA. UWB dielectric resonator antenna having consistent omnidirectional pattern and low cross-polarization characteristics. *IEEE Trans Antennas Propag*. 2011; 59(4): 1403-8.
- [12] Chair R, Kishk AA, Lee KF. Wideband stair-shaped dielectric resonator antennas. *IET Microwaves. Antennas Propag*. 2007; 1(2): 299-305.
- [13] Luk KM, Leung KW, Chow KY. Bandwidth and Gain Enhancement of a Dielectric Resonator Antenna With the Use of a stacking element. *Microw Opt Technol Lett*. 1997; 14(4): 215-7.
- [14] Pan YM, Zheng SY. A Low-Profile Stacked Dielectric Resonator Antenna with High-Gain and Wide Bandwidth. *IEEE Antennas Wirel Propag Lett*. 2016; 15: 68-71.
- [15] Fakhte S, Oraizi H, Matekovits L, Dassano G. Cylindrical Anisotropic Dielectric Resonator Antenna With Improved Gain. *IEEE Trans Antennas Propag*. 2017; 65(3): 1404-9.
- [16] Kishk AA. Directive Yagi-Uda dielectric resonator antennas. *Microw Opt Technol Lett*. 2005; 44(5): 451-3.
- [17] Hwang Y, Zhang YP, Luk KM, Yung EKN. Gain-enhanced miniaturised rectangular dielectric resonator antenna. *Electron Lett*. 1997; 33(5): 350-2.
- [18] Cicchetti R, Faraone A, Miozzi E, Ravanelli R, Testa O. A High-Gain Mushroom-Shaped Dielectric Resonator Antenna for Wideband Wireless Applications. *IEEE Trans Antennas Propag*. 2016; 64(7): 2848-61.
- [19] Nasimuddin, Esselle KP. Antennas with dielectric resonators and surface mounted short horns for high gain and large bandwidth. *IET Microw Antennas Propag*. 2007; 1(3): 723-8.
- [20] Haji-hashemi MR, Moradian M. *Dielectric resonator antenna based on fudgeflake geometry*. Antennas and Propagation Society International Symposium. 2006: 1325-8.
- [21] Patel P, Mukherjee B, Mukherjee J. *Rectangular Dielectric Resonator Antenna for wideband and high gain applications*. Microwave Conference (APMC), 2014 Asia-Pacific. 2014: 8-10.
- [22] Petosa A, Thirakoune S. Rectangular dielectric resonator antennas with enhanced gain. *IEEE Trans Antennas Propag*. 2011; 59(4): 1385-9.
- [23] Guha D, Banerjee A, Kumar C, Antar YMM. New technique to excite higher-order radiating mode in a cylindrical dielectric resonator antenna. *IEEE Antennas Wirel Propag Lett*. 2014; 13:15-8.
- [24] Legier J, Kennis P, Toutain S, Citerne J. Resonant frequencies of rectangular dielectric resonators. *IEEE Trans Microw Theory Tech*. 1980; 28(9): 1031-4. Available from: <http://adsabs.harvard.edu/abs/1980ITMTT.28.1031L>
- [25] Pan YM, Leung KW, Luk KM. Design of the millimeter-wave rectangular dielectric resonator antenna using a higher-order mode. *IEEE Trans Antennas Propag*. 2011; 59(8): 2780-8.
- [26] Hou D, et al. D-band on-chip higher-order-mode dielectric-resonator antennas fed by half-mode cavity in CMOS technology. *IEEE Antennas PropagMag*. 2014; 56(3): 80-89.