Wideband tetraskelion dielectric resonator antenna

Irfan Ali, Mohd Haizal Jamaluddin, Abinash Gaya
Wireless Communication Centre, School of Electrical Engineering, Universiti Teknologi Malaysia, Malaysia

Article Info

Article history:

Received Jan 5, 2020
Revised Mar 6, 2020
Accepted Mar 22, 2020

Keywords:

5G
Dielectric resonator antenna
Q-factor
Tetraskelion
Wideband

ABSTRACT

In this paper, a wideband tetraskelion dielectric resonator antenna with a low profile and high gain for the upcoming fifth generation (5G) communication applications is presented. The proposed DR antenna has been designed at the operating frequency of 26 GHz. The designed antenna is etched on Rogers RT/Duroid 5880 substrate of dielectric constant ε_r=2.2, with a thickness of 0.254mm. The DR material having a relative dielectric constant (ε_r) of 10 is used for a proposed design. The antenna was fed by using a 50-ohm microstrip line with slot coupling. The simulation and optimization have been performed by using the commercial software CST Microwave studio. The proposed structure exhibits a wide impedance bandwidth of 19.6% for |S11|< -10 dB from 24.5 to 29.6 GHz and peak gain of 9 dBi with the efficiency of 95% for complete bandwidth. The results show that an antenna is low profile and can be used for 5G wireless communication Applications

Copyright © 2020 Institute of Advanced Engineering and Science.
All rights reserved.

Corresponding Author:

Mohd Haizal Jamaluddin,
Wireless Communication Centre,
School of Electrical Engineering,
Universiti Teknologi Malaysia,
Johor Bahru 81310, Malaysia.
Email: haizal@fke.utm.my

1. INTRODUCTION

The rapid growth of wireless communication systems leads the researchers and antenna designers to design new and better antennas with a low profile, highly efficient, small size and wide bandwidth that can satisfy the demands of the constant growth of wireless devices. In recent years, dielectric resonator antenna (DRA) is most widely used in the modern wireless communication applications because of their various advantages of a lightweight, low profile, low loss, inexpensive, large bandwidth, and ease of fabrication [1-7]. Also, DRAs have high radiation efficiency, as they are not suffered from metallic losses or surface waves [8]. Moreover, DRA is feed by using various feeding techniques like microstrip feed line [9], coaxial probe feed [10, 11], aperture slot coupling [12, 13], and co-planar waveguide (CPW) [14]. Furthermore, DRA comes in various shapes of rectangular [15, 16], cylindrical [17, 18], hemispherical [19], and triangular [20]. The rectangular shape is the basic and most commonly used in the literature because of the salient features of design flexibility, simple in structure and ease of fabrication.

Since the last two decades, investigations have been focused on the enhancement of bandwidth of DRA, and thus, different methods have been used to improve the bandwidth of DRAs. These methods use fractal approach [21], stacking DRAs [22, 23], or various other DR geometries such as H-shaped [24], T-shaped [25], L-shaped [26], Z-shaped [27] and so on. By using these techniques, compactness and wideband is achieved. In this paper, tetraskelion geometry based dielectric resonator antenna excited by aperture coupled feeding is investigated and designed. The tetraskelion DRA produces a wide bandwidth of 19.6% (5.1 GHz) from 24.5 GHz to 29.6 GHz. This paper is organized into the following sections: Section 2 presents the tetraskelion DRA design configuration. Section 3 describes the results and discussion in details. Finally, a conclusion is presented in Section 4.

2. ANTENNA CONFIGURATION

The resonant frequency (f_o) of rectangular dielectric resonator antenna is given by [28]:

$$f_o = \frac{c}{2\pi\sqrt{\varepsilon_r}}\sqrt{k_x^2 + k_y^2 + k_z^2}$$

Where 'f_o' is the resonant frequency of RDRA, 'ε_r' is the relative permittivity of DRA, 'c' is the speed of light. The proposed DR structure is made of ECCOCK HiK TEK dielectric material. The dielectric constant (ε_r) of material is 10 and dissipation factor ($tan\delta$) of 0.002 is chosen for the proposed antenna design. The proposed structure of the DRA is depicted in Figure 1. The DRA is placed on the square-shaped ground plane with dimensions of $LXW = 11mm \times 11mm$. The proposed tetraskelion DRA is fed by microstrip feed line with narrow aperture slot in the ground plane. The feed line is placed on the bottom side of the substrate and the slot is etched in the ground plane. Rogers substrate having dimensions of $L_s \times W_s$=11mm ×11 mm with a dielectric constant of 2.2, and substrate thickness of h_s=0.254 mm. The antenna is designed at the operating frequency of 26 GHz. The optimized dimensions of the tetraskelion DRA are given in Table 1.

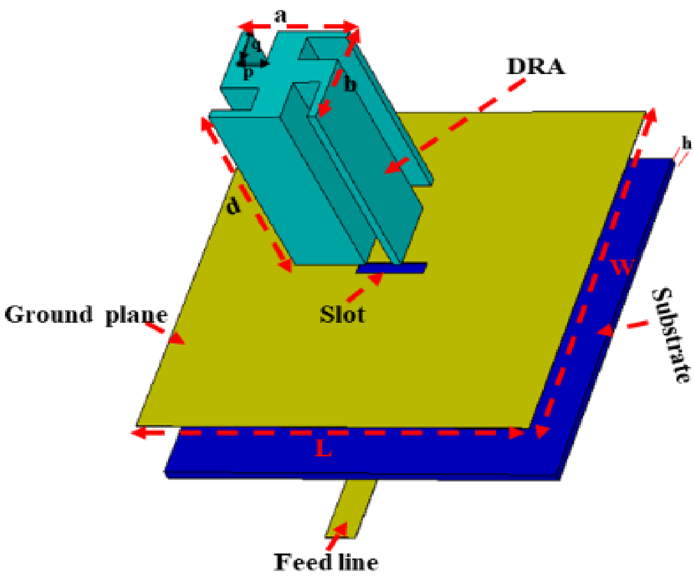

Figure 1. The geometry of the proposed tetraskelion DRA

Table 1. Optimized dimensions of the proposed antenna design

Antenna Parts	Parameters	Description	Dimensions(mm)
Ground Plane	L	Length of ground	11
	W	Width of ground	11
	$\boldsymbol{h_g}$	Thickness of ground	0.0154
Substrate (Rogers RT/Duroid 5880)	L_s	Length of substrate	11
	W_s	Width of substrate	11
	$\boldsymbol{h_s}$	Height of substrate	0.254
	ε_{rs}	The dielectric constant of the substrate	2.2
	tan δ	Loss tangent	0.0009
DRA	**a**	Length of DRA	2.98
	b	Width of DRA	2.98
	d	Thickness of DRA	6.26
	ε_{rd}	The dielectric constant of DRA	10
	tan δ	Loss tangent	0.002
Feed line	L_f	Length of feed	6.65
	W_f	Width of feed	0.85
Slot	L_{slot}	Length of slot	1.9
	W_{slot}	Width of slot	0.36
Stub	$\boldsymbol{l_{stub}}$	Length of stub	1

3. RESULTS AND DISCUSSIONS

The tetraskelion DRA fed by microstrip line through an aperture is designed at 26 GHz. The proposed antenna structure is simulated and optimized by using the CST Microwave Studio software. The square-shaped DRA is modified by introducing the air gap slots to achieve the tetraskelion shaped DRA. The insertion of air gap slots reduces the Q-factor and thus, improves the bandwidth of proposed DRA. The bandwidth and Q-factor are inversely proportional to each other. Figure 2 shows the reflection coefficient versus frequency of the tetraskelion DRA. The simulated results show that the proposed DRA resonates at 26 GHz, offering a wide impedance bandwidth of 5.1 GHz (19.6%) for $|S_{11}|$<-10 dB from 24.5 GHz to 29.6 GHz. The simulated plot of gain versus frequency as well as radiation efficiency versus frequency is shown in Figure 3. The peak gain at 26 GHz frequency is 9 dBi. The peak radiation efficiency of 95% is achieved at 26 GHz. Figure 4 shows the VSWR versus frequency of the proposed DRA. It can be observed from the plot that the VSWR is less than 2 for the complete bandwidth. The simulated normalized radiation pattern (yz-plane and xz-plane) are shown in Figure 5. The simulated results are taken at 26 GHz. The results show that the proposed antenna radiates in the broadside direction. Table 2 shows the summarizing table of the simulated results. From the table, it can be seen that the proposed tetraskelion DRA not only achieved a wider impedance bandwidth but also high gain and high radiation efficiency.

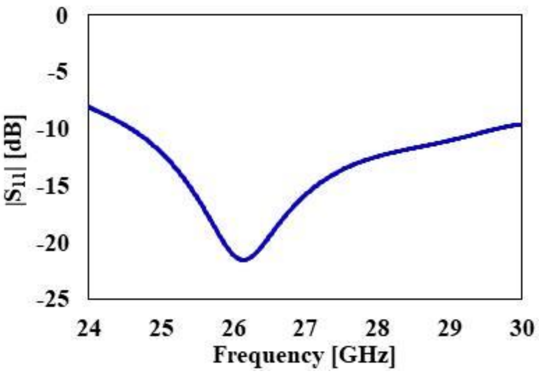

Figure 2. Simulated reflection coefficient of the proposed DRA

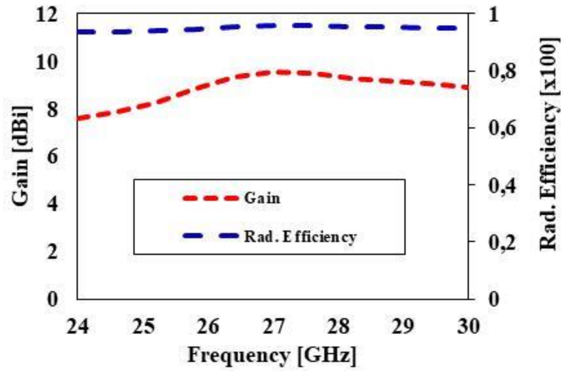

Figure 3. Simulated gain and efficiency versus frequency of the proposed DRA

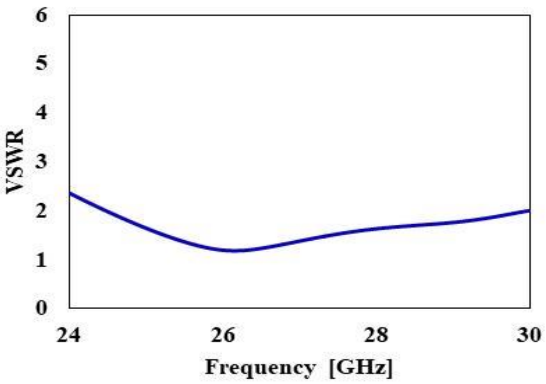

Figure 4. Simulated VSWR versus frequency of the proposed tetraskelion DRA

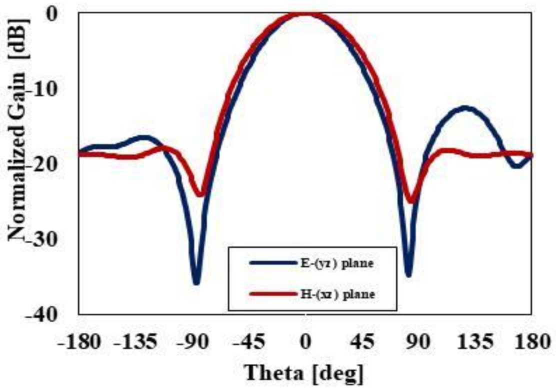

Figure 5. Simulated normalized radiation pattern in the E-plane and H-plane of the DRA at 26 GHz

Table 2. Summary of Simulated results of Proposed tetraskelion Structure DRA

Antenna	f_o (GHz)	BW (%)	Gain (dBi)	Efficiency (%)
Tetraskelion DRA	26	19.6	9	95

BW, bandwidth in percentage; f_o, resonant frequency in GHz

4. CONCLUSION

In this paper, a wideband tetraskelion dielectric resonator antenna fed by microstrip strip line through slot coupling is proposed for the 5G communication applications. The DRA resonates at 26 GHz, and simulated results show that the proposed structure yields a wide impedance bandwidth of 5.1 GHz (19.6%), ranging from 24.5 GHz to 29.6 GHz. Furthermore, DRA has obtained a high gain of 9 dBi with a radiation efficiency of 95%. As a result, the proposed DRA structure is suitable and can be used for future 5G wireless communication applications.

ACKNOWLEDGEMENTS

The authors would like to thank the Universiti Teknologi Malaysia Grant HiCoE 4J415 and UTM Grant (TDR Grant 05G20 and GUP 19H56) for supporting this research work.

REFERENCES

[1] A. A. Id, J. Jung, Y. Yang, K. Lee, S. Yi, and K. C. Hwang, "A 3-D Meandered Probe-Fed Dual-Band Circularly Polarized Dielectric Resonator Antenna," *sensors*, pp. 1-11, 2018.

[2] A. Iqbal, A. Smida, O. A. Saraereh, and Q. H. Alsafasfeh, "Cylindrical Dielectric Resonator Antenna-Based Sensors for Liquid Chemical Detection," *sensors*, pp. 2-10, 2019.

[3] I. Ali, M. H. Jamaluddin, M. R. Kamarudin, A. Gaya, and R. Selvaraju, "Wideband and high gain dielectric resonator antenna for 5G applications," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 8, no. 3, pp. 1-6, 2019.

[4] I. Ali, M. H. Jamaluddin, M. R. Kamarudin, A. Gaya, and M. H. Dahri, "'Gain enhancement of dielectric resonator antenna for millimeter wave applications," *Telecommunication Computing Electronics Control (TELKOMNIKA)*, vol. 17, no. 4, pp. 1670-1673, 2019.

[5] A. Petosa, *Dielectric Resonator Antenna Handbook*. Norwood, MA:Artech House, 2007.

[6] K.M.Luk and K.W.Leung, *Dielectric Resonator Antennas*. Bal dock, U.K.: Research Studies Press, 2003.

[7] P. F. Hu, Y. M. Pan, X. Y. Zhang, and S. Y. Zheng, "A Compact Filtering Dielectric Resonator Antenna with Wide Bandwidth and High Gain," *IEEE Trans. Antennas Propag.*, vol. 64, no. 8, pp. 3645-3651, 2016.

[8] W. M. Abdel-Wahab, S. Safavi-Naeini, and D. Busuioc, "High gain/ efficiency 2D-dielectric resonator antenna array for low cost mm-wave systems," *IEEE Antennas Propag. Soc. AP-S Int. Symp.*, pp. 1682-1684, 2011.

[9] J. S. Wight, A. Petosa, R. K. Mongia, and A. Ittipiboon, "Design of microstrip-fed series array of dielectric resonator antennas," *Electron. Lett.*, vol. 31, no. 16, pp. 1306-1307, 1995.

[10] M. Khalily, M. K. A. Rahim, and A. A. Kishk, "Bandwidth enhancement and radiation characteristics improvement of rectangular dielectric resonator antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 393-395, 2011.

[11] Abinash Gaya, M.H. Jamaluddin and I. Ali, "Performance Analysis of a Dielectric Resonator Antenna with Different Feeding Technique for 5G Communication," in *International Conference on Electrical Engineering and Informatics (ICon EEI)*, pp. 92-97, 2018.

[12] S. Fakhte, H. Oraizi, L. S. Member, L. Matekovits, and S. Member, "High Gain Rectangular Dielectric Resonator Antenna using Uniaxial Material at Fundamental Mode," *IEEE Trans. Antennas Propag.*, vol. 65, no. 1, pp. 342-347, 2017.

[13] I. Ali, M. H. Jamaluddin, M. R. Kamarudin, A. Gaya, and S. Raghuraman, "Perforated Dielectric Resonator Antenna Operating on Higher Order Mode," *2018 IEEE Int. RF Microw. Conf.*, pp. 250-253, 2018.

[14] K. S. Ryu and A. A. Kishk, "UWB dielectric resonator antenna having consistent omnidirectional pattern and low cross-polarization characteristics," *IEEE Trans. Antennas Propag.*, vol. 59, no. 4, pp. 1403-1408, 2011.

[15] T. A. Denidni and Z. Weng, "Rectangular dielectric resonator antenna for ultrawideband applications," *Electron. Lett.*, vol. 10, no. 24, pp. 250-251, 2009.

[16] I. Ali, M. H. Jamaluddin, A. Gaya, and H. A. Rahim, "A Dielectric Resonator Antenna with Enhanced Gain and Bandwidth for 5G Applications," *sensors*, vol. 20, no. 3, pp. 1-12, 2020.

[17] X. S. Fang and K. W. Leung, "Linear-/circular-polarization designs of dual-/wide-band cylindrical dielectric resonator antennas," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 2662-2671, 2012.

[18] Y. F. W. ; T. A. D. ; Q.-S. Z. ; G. Wei, "Design of high gain, broadband cylindrical dielectric resonator antenna," *Electron. Lett.*, vol. 49, no. 24, pp. 1506-1507, 2013.

[19] K. W. Leung, K. M. Luk, K. Y. A. Lai, and D. Lin, "Theory and experiment of an aperture-coupled hemispherical dielectric resonator antenna," *IEEE Trans. Antennas Propag.*, vol. 43, no. 11, pp. 1192-1198, 1995.

[20] H. Y. Lo, K. W. Leung, K. M. Luk, and E. K. N. Yung, "Low profile equilateral-triangular dielectric resonator antenna of very high permittivity," *Electron. Lett.*, vol. 35, no. 25, pp. 2164, 1999.

[21] S. Dhar, R. Ghatak, B. Gupta, and D. R. Poddar, "A wideband minkowski fractal dielectric resonator antenna," *IEEE Trans. Antennas Propag.*, vol. 61, no. 6, pp. 2895-2903, 2013.

[22] A.A. Kishk ; B. Ahn ; D. Kajfez, "Broadband stacked dielectric resonator antennas," *Electron. Lett.*, vol. 25, no. 18, pp. 1232-1233, 1989.

[23] Y. M. Pan and S. Y. Zheng, "A Low-Profile Stacked Dielectric Resonator Antenna with High-Gain and Wide Bandwidth," *IEEE Antennas Wirel. Propag. Lett.*, vol. 15, pp. 68-71, 2016.

[24] X. Liang, T. A. Denidni, and S. Member, "H-Shaped Dielectric Resonator Antenna for Wideband Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 7, pp. 163-166, 2008.
[25] Q. Rao, T. A. Denidni, and A. R. Sebak, "Broadband Compact Stacked T-Shaped DRA With Equilateral-Triangle Cross Sections," *IEEE Microw. Wirel. COMPONENTS Lett.*, vol. 16, no. 1, pp. 7-9, 2006.
[26] T. A. Denidni, S. Member, Q. Rao, A. R. Sebak, and S. Member, "Broadband L-Shaped Dielectric Resonator Antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 4, pp. 453-454, 2005.
[27] Mahmoud Niroo-Jazi. Tayeb A. Denidni, Zibin Weng, "Z-Shaped Dielectric Resonator Antenna for Ultrawideband Applications," *IEEE Trans. Antennas Propag.*, vol. 58, no. 12, pp. 4059-4062, 2010.
[28] R. K. Mongia and A. Ittipiboon, "Theoretical and experimental investigations on rectangular dielectric resonator antennas," *IEEE Trans. Antennas Propag.*, vol. 45, no. 9, pp. 1348-1356, 1997.

BIOGRAPHIES OF AUTHORS

Irfan Ali received the B.E degree in Telecommunications from the Mehran University of Engineering and Technology (MUET), Pakistan, in 2010 and the master's degree in Telecommunications Engineering from NED University of Engineering and Technology in 2014. He is currently pursuing the Ph.D. degree with the Wireless Communication Centre (WCC), Universiti Teknologi Malaysia (UTM). He is a student member in IEEE. His research interests include microstrip patch antennas, dielectric resonator antennas, MIMO antennas, mutual coupling analysis.

Mohd Haizal Jamaluddin received bachelor's and master's degrees in electrical engineering from Universiti Teknologi Malaysia, Malaysia, in 2003 and 2006, respectively, and the Ph.D. degree in signal processing and telecommunications from the Université de Rennes 1, France, in 2009, with a focus on microwave communication systems and specially antennas such as dielectric resonator and reflectarray and dielectric dome antennas. He is currently an Associate Professor with the Wireless Communication Centre, School of Electrical Engineering, and Universiti Teknologi Malaysia. His research interests include dielectric resonator antennas, printed microstrip antennas, MIMO antennas and DRA reflectarray antennas. He has published more than 100 papers in reputed indexed journals and conference proceedings.

Abinash Gaya is a PhD Student at Wireless Communication Centre (WCC), UTM Johor Bahru. He has been involved in the Design and Development of Dielectric Resonator Antennas for 5G Communications at WCC. He is also working towards Design of Phased Array Antenna system for 5G Base Stations. He is a student member in IEEE.