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DESIGN OF CPW FED TWO LAYERED RECTANGULAR DIELECTRIC RESONATOR ANTENNA FOR 5G MOBILE COMMUNICATIONS

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ABSTRACT

In this research, a dielectric resonator antenna (DRA) is designed to operate in the frequency bands of fifth-generation mobile communications. The antenna consists of two rectangular dielectric resonators arranged in two layers. Each DR has its own height and relative dielectric constant. The relative dielectric constant of the lower and the upper resonators are 9.8 and 10.8 respectively. The DRA is fed by a 50 ohm coplanar waveguide (CPW) type feeder. The dielectric resonators and the CPW system are placed on FR-4 substrate with dielectric constant of 4.7 and 1.5 mm thickness. The operating frequency covers the band from (24-31) GHz with voltage standing wave ratio (VSWR) equal or less than two. The antenna shows good radiation performance with linear maximum gain of about (5-7) dBi over the designated frequency band. The antenna is categorized as miniaturized and low profile antenna.

Keywords: Dielectric resonator antenna (DRA); Coplanar waveguide (CPW); Radiation pattern, 5G antennas; Low profile antenna

1. INTRODUCTION

The increasing demands to the data rate of modern communications excites the development of 5G mobile technology. The 5G technology frequency bands specified by Federal Communications Commission (FCC) are (24-28) GHz (FCC, 2020). The metallic loss of microstrip antennas decrease their gain and efficiency at millimeter wavelength. The antennas designed for 5G applications must have good radiation properties with good efficiency characteristics. Dielectric Resonator Antenna (DRA) are highly recommended; where DRAs are the most prominent option for these millimeter wavelengths.

In literature, many articles suggest DRA antennas for different generations of mobile applications. A dielectric-resonator-on-patch to improve the bandwidth of DRAs was presented in (Esselle, 2001). The antenna is simple low-profile antenna operate in the range from (5.150-5.825) GHz. A technique for improving the performance of a CPW fed low permittivity DRA has been proposed by (Rao, Denidni, 2005). The proposed antenna was simply matched by changing the location of the dielectric resonator on the coupled slot and the

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resonant frequencies can be adjusted easily. In (Aldo, Apisak, 2010) an excellent historical overview of the evolution and usage of the DRAs has been provided. The overview period include the last two decades of the last century and the first decade of the present century. The paper high spotted the flexibility and adaptability that DRAs can offer. DRAs can be considered to outfit a wide range of necessities for different communication applications, from very high frequency to extremely high frequencies. A dielectric ceramic substrate to be used in design and fabrication of 5G millimeter wave antennas was proposed by (Ashiqur, NG M, Afaz, Touhidulalam, Mandeep, Mohammad, 2016). The antenna operate in the range of (27.2-29.8) GHz with radiation efficiency 93% and average gain of 5.4 dBi. The overall antenna size was $1.32\lambda \times 1.32\lambda \times 0.094\lambda$. In (Kai, Hang, 2015) the wideband circularly polarized DRA using a rotated-stair dielectric resonator with axial ratio bandwidth of 18.2% has been introduced. The proposed antenna has good radiation pattern and high gain performance. This antenna can be one pretty contestant for recent 5G Wi-Fi band wireless communication systems in the range of (5.1-5.9) GHz. A reduced size rectangular DRA for multiple input multiple output (MIMO) systems was presented in (Jamal, Mohd, Mohsen, Muhammad, Irfan, Aghuraman, 2015). The suggested antenna is designed to operate among several long term evolution (LTE) bands. The antenna shows a 264 MHz matching bandwidth with return loss less than 10dB and separation of 18 dB at 1.8 GHz was achieved. In (Nor, Jamaluddin, Kamarudin, Khalily, 2016) a modified feeding line was introduced to motivate the DRA with permittivity of 10 that leads to a wideband operation. The antenna was designed for 5G millimetre wave applications and operate at 28 GHz. The antenna was realized and fixed on a substrate of dielectric constant 2.2 and loss tangent of 0.0009. In the work of (Sharawi, Podilchak, Hussain, Yahia, 2017), a millimetre-wave cylindrical dielectric resonator (DR) was used to design MIMO antenna system to support 5G communications. The antenna consist of two linear arrays, each array contains (4) cylindrical DR antenna operating at 30 GHz. Maximum gain obtained was about 7 dBi with good efficiency of radiation is obtained. In (Allabouche, Bobrovs, Fererro, Lizzi, Ribero, el Amrani, el Idrissi, Elbakali, 2017) CST microwave studio and HFSS were used to design and simulate a rectangular DRA for 5G mobile communication. The result shows that the antenna was resonated at dual frequency bands with good impedance matching at (10.5) GHz and (17) GHz respectively. The antenna shows high radiation efficiencies and adequate gains at both frequencies. In (shahadan, Jamaluddin, Kamarudin, Yoshihide, Khalily, Muzammil, Dahlan, 2017) a steerable higher order mode DRA array be able to steer from -32^{o} to +32^{o} at 15 GHz was presented. The designed antenna

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array revealed a high gain of 9.25 dBi and the bandwidth was about 1.3 GHz. The antenna is regarded as appropriate for 5G Internet of Things (IoT) applications. In (Ahmed, 2019) a compact size CPW-fed broadband U-shaped DRA was recommended for WLAN and WiMAX applications. The operating band was from 3.22 to 5.92 GHz with 59 % bandwidth efficiency.

In this study, a low profile CPW fed two layer DRA is presented. The antenna is proposed for 5G mobile applications and other wireless systems at the 26-30 GHz band. The proposed antenna can be simply tuned to the desired band with proper coupling between the feeder and the RDR. A parametric study using CST Microwave Studio Simulator (by Dassault Systèmes Simulia) was conducted for several combination values of the RDR heights, the feeder length and the length of the CPW ground in order to observe various effects to the radiation and gain performance as well as the matching impedance bandwidth for VSWR less than two. The paper is organized as follow: section 1 present an introduction and review for the design and performance of different DRAs, the antenna configuration and dimensions are stated in section 2, section 3 contains the simulation results and the parametric study of the presented antenna, the radiation performance of the proposed antenna is stated in section 4, finally the conclusion is given in section 5.

2. ANTENNA DESIGN AND CONFIGURATION

The proposed antenna structure is illustrated in Figure 1. The antenna consist of two layered dielectric resonators (DRs). The two resonator elements DR-1 and DR-2 are made of a microwave Rogers TMM10 Laminate and RT/Duroid 6010 LM Laminate from Rogers Corporation. They have a relative dielectric constant of 9.2 and 10.8 respectively. The DRs are fed by 50 ohm CPW line. The dimensions of the lower and upper resonators are $a \times b \times d_1$ and $a \times b \times d_2$, where d_1 and d_2 are the heights of the resonators, where a=7.2 mm, b=11.7 mm, d_1=1.3 mm and d_2=0.9 mm. The resonators and the CPW are laid on FR-4 substrate of 4.7 dielectric constant and 1.5 mm thickness. The antenna is designed and simulated using CST Microwave Studio software.

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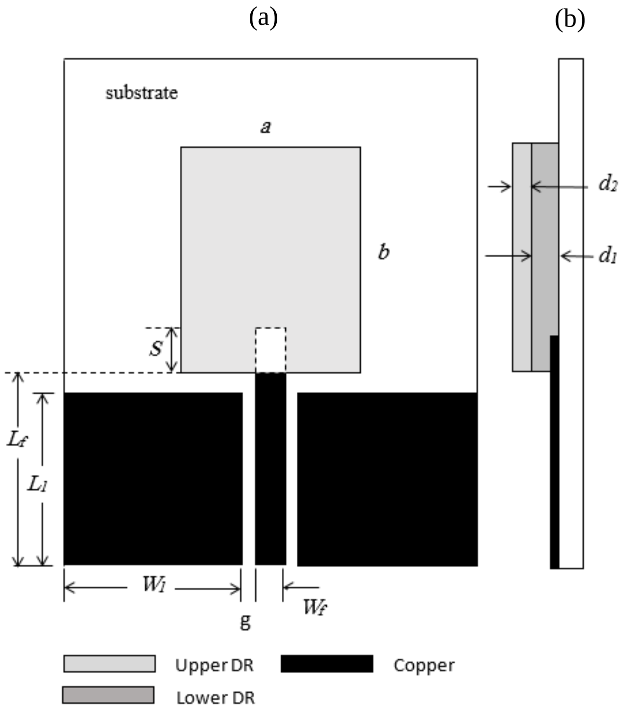

Fig. (1): Antenna configuration: (a) Top view, and (b) Side view.

The overall dimension of the substrate is 23mm×30mm. The DRA has been firstly designed by using the dielectric waveguide model. The resonance frequency of the dielectric resonator antenna is defined as (Mongia, Ittipiboon, 1997):

$$f_r = \frac{c}{2\pi\sqrt{\varepsilon_r}} \times \sqrt{k_x^2 + k_y^2 + k_z^2} \quad (1)$$

$$k_x = \frac{m\pi}{a}; k_y = \frac{n\pi}{b}; k_z = \frac{\ell\pi}{2d}$$

Where c is free space light speed, ε_r is DR relative dielectric constant of the dielectric resonator and $k(x,y,z)$ represent the wave numbers in the x, y, and z directions. The frequency response of the antenna with only DR-1 is shown in Figure 2.

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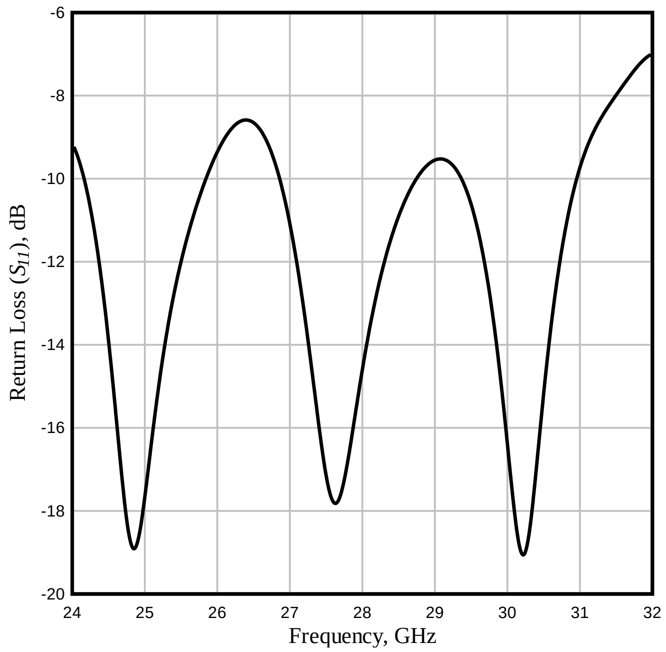

Fig. (2): The return loss of single DR-1 antenna against frequency.

3. SIMULATION RESULTS AND PARAMETRIC STUDY

The optimized dimension parameters shows that the feeder extension (*S*) under the DR has a huge influence on the impedance matching against the operating frequency band. A parametric study have been done by sweeping the parameter (*S*) from (0-1.5) mm in steps of 0.5 mm. The simulation results of the return loss (S_{11}) against frequency for different values of *S* are shown in Figure 3. Fig. 3 shows that when *S* =0.5, the designed frequency band can be achieved. This band covers the frequency range of new 5G band from 24-28 GHz with voltage standing wave ratio less or equal 2 and have been showed in Figure 4.

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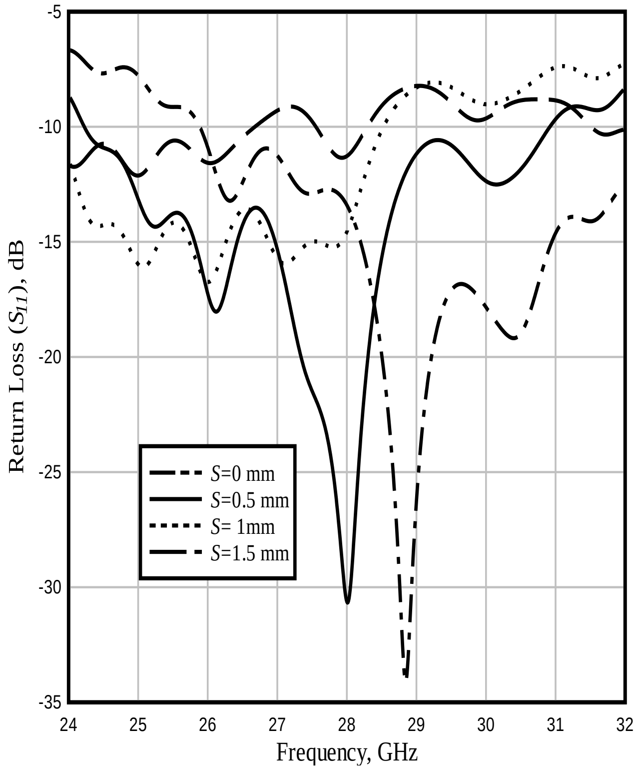

Fig. (3): The return loss in dB against frequency for different values of S.

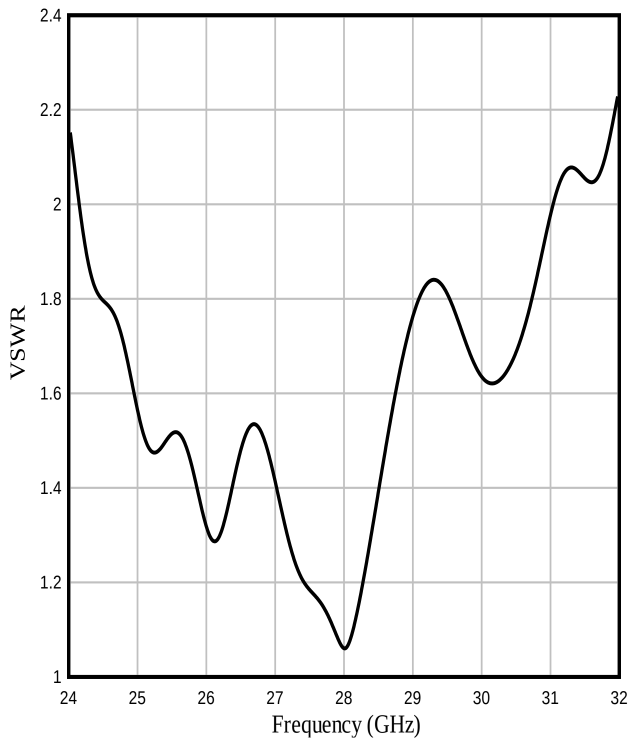

Fig. (4): VSWR vs. frequency for the proposed antenna operate at 5G band.

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The antenna is modified to operate in 5G band from 24 GHz to 30 GHz by adding a second layer DR-2 that stacked with DR-1. This band contain the licensed 24.25-24.45GHz, 24.75-25.25GHz, 27.5-28.35GHz, 24.5-27.5GHz, 26GHz, 26.5-27.5GHz, 26.5-29.5GHz, 27.5-29.5GHz, and 24.25-27.5GHz allocated or targeted around the world (Qualcomm, 2017).Several simulations and dimension optimizations were carried out using full wave electromagnetic simulator. The antenna geometrical dimensions after optimization are given as: W_f =3mm, g =0.3mm, W_1 =8.2mm, L_1 =10mm, L_f =13.9mm, and S =0.5mm, d_1 =1.3mm, and d_2 =0.9mm.

4. RADIATION PERFORMANCE OF THE PROPOSED ANTENNA

Every The simulated gain for the proposed layered DRA for frequencies within 5G band, obtained using CST software are shown in Figure 5. The gain is linearly changed within the designated band. The simulated radiation patterns in terms of E-plane (ϕ=90^{o}) and H-plane (θ=90^{o}) are shown in Figure 6. The radiation patterns have a broadside shape with gain about (5-7) dBi that meets the 5G requirements.

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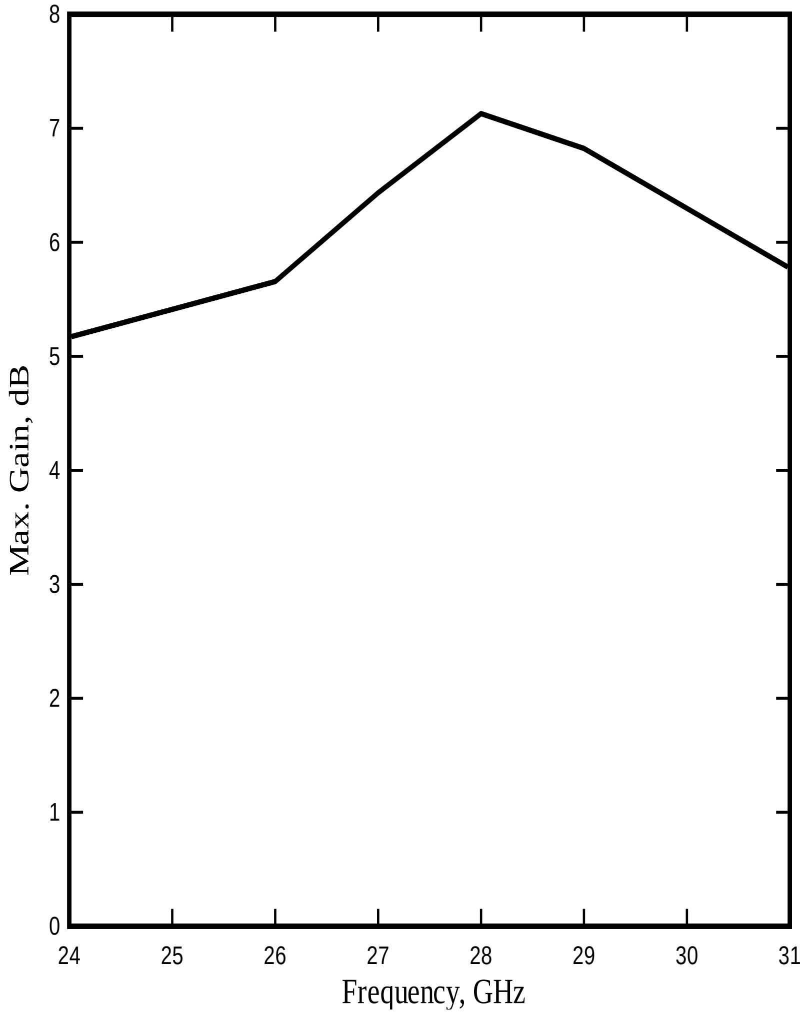

Fig. (5): Maximum gain (dB) versus frequency (GHz).

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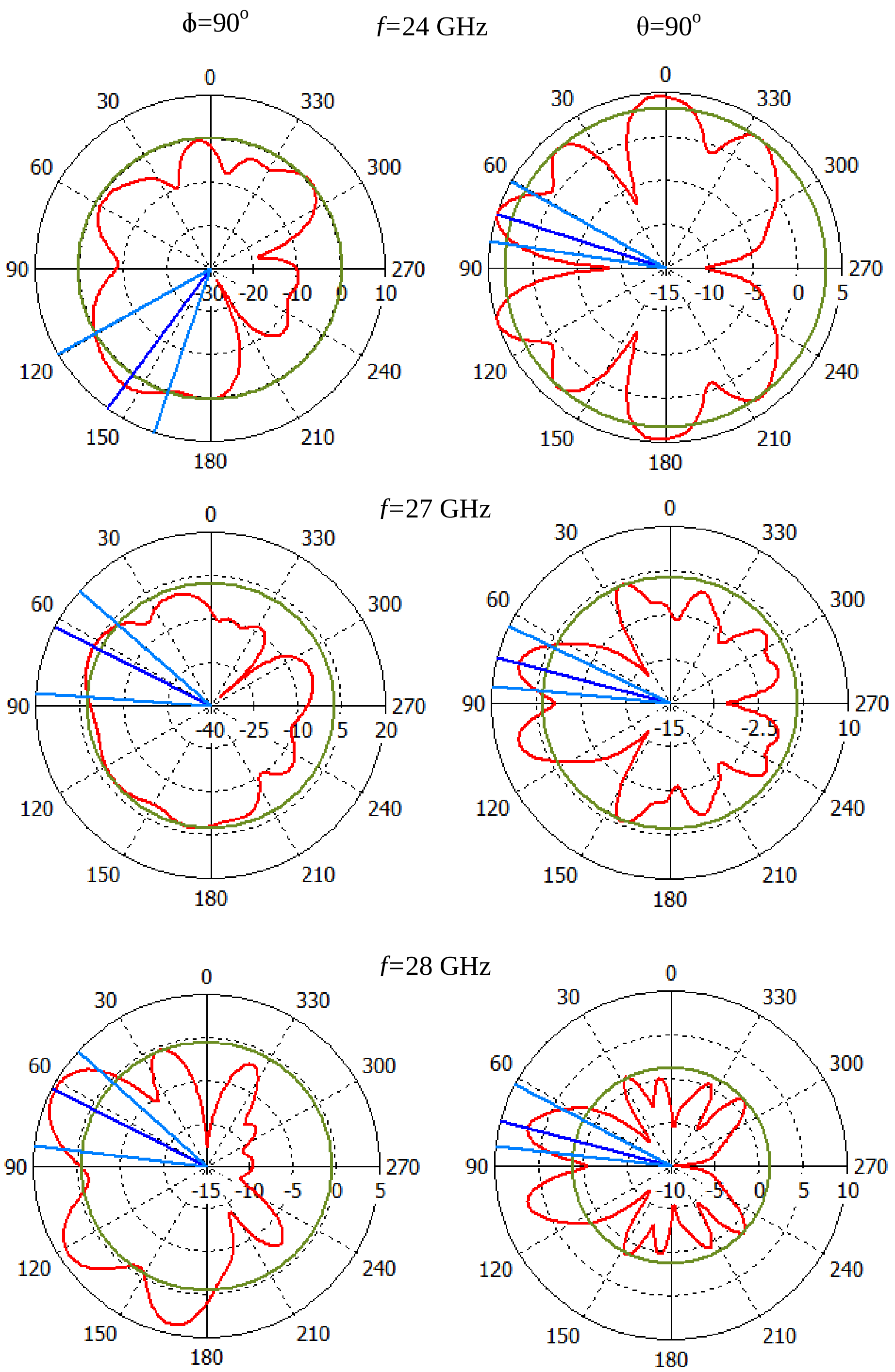

Fig. (6): Radiation pattern of the antenna in E-plane ϕ=90° and H-plane θ=90°.

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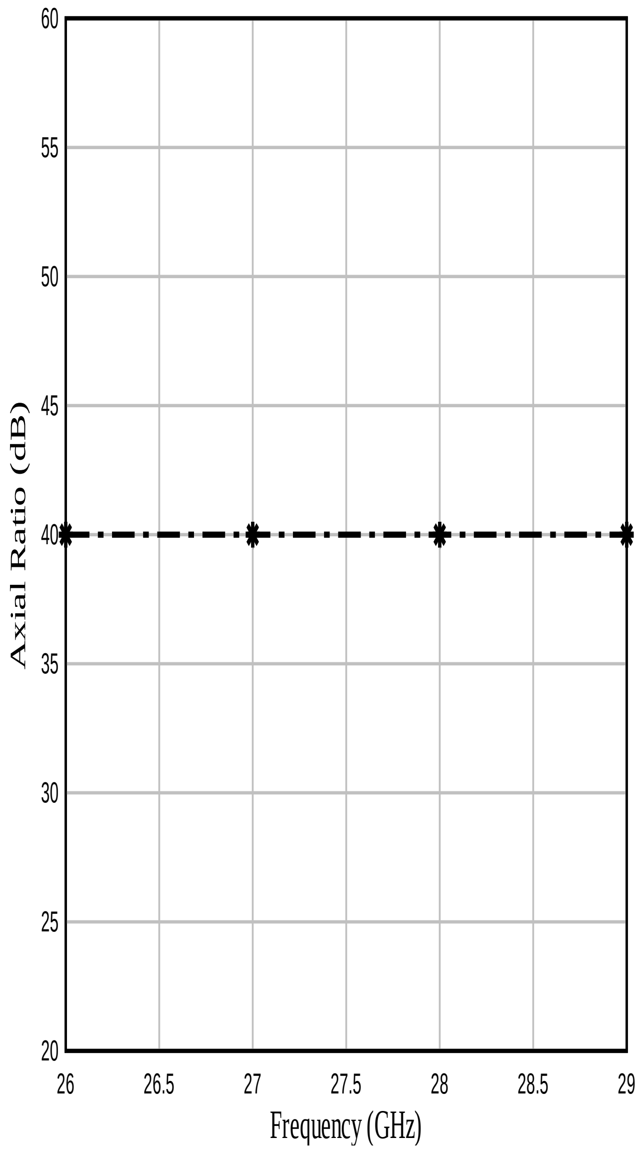

Fig. (7): The axial ratio of the radiation pattern of the proposed antenna.

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Table 1 compares the presented DRA with some other designs of the DRA that used the rectangular dielectric resonators. The proposed designs achieved a compact size and low profile characteristics as well as bandwidth efficiency of 25.4%.

Table (1): Comparison with some other designs.

Reference Number	Frequency Band, GHz	Substrate Size, mm^2	DR Size mm^3
This work	24-31	23×30	7.2×11.7×2.2
(Allabouche, Et Al., 2017)	10.5-17	40×40	14×15×4.04
(Shahadan, Kamarudin, Et Al., 2017)	15	20×20	7.5×7.5×1.8
(Mani, Edeswaran, 2017)	3.65-4.45 4.7-5.6	70×70	46×46×6.2
(Abushakra, Al-Zoubi, 2017)	4.5-9.3	35×35	9×13.65×12.8
(Al-Azzal, Et Al., 2018)	5.1-34.6	40×40	$\pi(4.5)^2\times11$

5. CONCLUSIONS

In this study, a DRA consist of two stacked rectangular layers with a CPW feed structure was proposed. The antenna work on 5G communication frequencies. The antenna offers an impedance bandwidth of more than 7 GHz with a bandwidth efficiency of about 25% and covers the band (24-31) GHz with good radiation behavior across the entire designated antenna band. The antenna achieved a good gain performance with a maximum value of (7 dBi) that meets the 5G requirements. The overall dimensions of the proposed dielectric resonator antenna is 7.2×11.7×2.2 mm^3 placed on substrate with 23×30×1.5 mm^3. This antenna can be considered simple in design, with good performance and compact size.

REFERENCES

Abushakra, F., & Al-zoubi, A. (2017). Wideband Vertical T-shaped Dielectric Resonator Antennas Fed by Coaxial Probe. *Jordan Journal of Electrical Engineering (JJEE), 3*(4), 250-258.

Ahmed, E. S., (2019). Broadband CPW-Fed U-Shaped Dielectric Resonator Antenna for Wireless and WiMAX/WLAN Applications. *The Eurasia Proceedings of Science, Technology, Engineering &*

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Corresponding author: Department of Communication Engineering, University of Technology, Iraq.

Mathematics (EPSTEM), ISSN: 2602-3199, *6*, 18-24.

Al-Azzal, A. A., Malalla, N. A., Harackiewicz, F. J., & Han, k. (2018). Stacked Conical-Cylindrical Hybrid Dielectric Resonator Antenna for Improved Ultrawide Bandwidth. *Progress in Electromagnetics Letters*, *79*, 79-86.

Aldo, P, & Apisak, I. (2010). Dielectric Resonator Antennas: A Historical Review and the Current State of the Art. *IEEE Antennas and Propagation Magazine*, *52*(5), 91-116.

Allabouche, K., Bobrovs, V., Fererro, F., Lizzi, L., Ribero, J-M., El Amrani, N., El Idrissi, M. J., & Elbakali, M. (2017). Multiband rectangular dielectric resonator antenna for 5G applications. *International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS-2017)*, 19-20 April, Moroco.

Ashiqur, R., Ng M. Yi., Afaz U. A., Touhidulalam, M., Mandeep J. S., & Mohammad, T. I. (2016). A Compact 5g Antenna Printed on Manganese Zinc Ferrite Substrate Material. *IEICE Electronics Express*, *13*(11), 1-5.

Esselle, K. P. (2001). A dielectric-resonator-on-patch (DROP) antenna for broadband wireless applications: concept and results. *IEEE Antennas and Propagation Society International Symposium*, 8-13 July, Boston, MA, USA.

FCC, (2020). The FCC's 5G fast plan. https://www.fcc.gov/5G.

Jamal, N., Mohd, H. J., Mohsen, K., Muhammad R. K., Irfan, U., & Raghuraman, S. (2015). A Reduced Size Dual Port MIMO DRA with High Isolation for 4G Applications. *International Journal of RF and Microwave Computer-Aided Engineering*, *25*(6), 495-501.

Kai, X. W., & Hang, W. (2015). A Circularly Polarized Antenna by Using Rotated-Stair Dielectric Resonator. *IEEE Antennas and Wireless Propagation Letters*, *14*, 787-790.

Mani, S., & Edeswaran, L. (2017). High Gain Multiband Stacked DRA for WiMax and WLAN Applications. *American Journal of Applied Sciences*, 14(8), 779-785.

Mongia, R. K., & Ittipiboon, A. (1997). Theoretical and experimental investigations on rectangular dielectric resonator antennas. *IEEE Trans. Antennas & Propagation*, *45*(9), 1348–1356.

Nor N. M., Jamaluddin, M. H., Kamarudin M. R., & Khalily M. (2016). Rectangular Dielectric Resonator Antenna Array for 28GHz Applications. *Progress In Electromagnetics Research C*, *63*, 53-61.

Qualcomm: Spectrum for 4G and 5G, Qualcomm Technologies, Inc., Qualcomm, December 2017.

Rao, Q., & Denidni, T. A. (2005). On Improving Impedance Matching of A CPW Fed Low Permittivity Dielectric Resonator Antenna. *Progress In Electromagnetics Research, PIER*, *53*, 21–29.

Emad.S.Ahmed@uotechnology.edu.iq
Corresponding author: Department of Communication Engineering, University of Technology, Iraq.

Sharawi, M. S., Podilchak, S., Hussain, M. T., & Yahia M. M. (2017). Dielectric Resonator Based MIMO Antenna System Enabling Millimeter-Wave Mobile Devices. *IET Microwaves, Antennas and Propagation*, DOI: 10.1049/iet-map.2016.0457.

Shahadan, N. H., Jamaluddin, M. H., Kamarudin, M. R., Yoshihide, Y., Khalily, M., Muzammil, J., & Dahlan, S. H. Steerable Higher Order Mode Dielectric Resonator Antenna With Parasitic Elements for 5G Applications. I*EEE Access*, *5*, 22234-22243.

Shahadan, N. H., Kamarudin, M. R., Jamaluddin, M. H., & Yamada, Y. (2017). Higher-order Mode Rectangular Dielectric Resonator Antenna for 5G Applications. *Indonesian Journal of Electrical Engineering and Computer Science*, *5*(3), 584-592.

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