

Wideband millimeter wave rectangular dielectric resonator antenna for 5G applications

Abinash Gaya, Mohd Haizal Jamaluddin, Irfan Ali

Wireless Communication Center (WCC), Universiti Teknologi Malaysia (UTM), Malaysia

Article Info

Article history:

Received Jan 7, 2020

Revised Mar 11, 2020

Accepted Mar 25, 2020

Keywords:

26GHz

5G

Dielectric resonator antenna

Millimeter wave

Probe feeding

ABSTRACT

A probe fed rectangular dielectric resonator antenna (DRA) is designed here for millimeter wave 5G applications. A wide bandwidth of 5GHz has been achieved with frequency range from 24.24GHz to 29.20GHz. The calculated percentage bandwidth is 19% centered at 26GHz. The DRA is fed by a probe with a microstrip line of unequal strip dimensions over the substrate. The measured gain of the antenna is 6.25dBi. The calculated radiation efficiency is 96%. The measured axial ratio bandwidth is from 24.08GHz to 23.90GHz, which is about 0.75 percentage bandwidth. The probe height above to the substrate is optimized to excite the DRA. The microstripline coupling is used to resonate the DRA at desired resonating frequency. The widebandwidth with high efficiency achieved here will make this antenna suitable for the 5G applications at band 30 GHz.

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

Corresponding Author:

Mohd Haizal Jamaluddin,

Wireless Communication Center,

Universiti Teknologi Malaysia, Malaysia.

Email: haizal@utm.my

1. INTRODUCTION

The tremendous demand in data rate have moved the attention of global frequency spectrum to millimeter wave frequency bands. Millimeter wave propagation can increase the data rate. The increase in demand, has focused to 5G (fifth generation) of mobile communications which may use mmWave (millimeter wave) frequencies to wider frequency spectrum and multi-Gigabit-per-second (Gbps) data rates [1]. In addition the high demand for network capacity, there are a number of factors which make 5G under demand, including the move to millimeter wave (mmWave) spectrum and the increasing integration of past and current cellular and WiFi standards to provide high-rate, low-latency experience for network users [2, 3]. As fifth generation (5G) is developed and implemented, the use of much greater spectrum allocations at mm-wave frequency bands needs highly directional beamforming antennas at both the mobile device and base station, longer battery life, lower outage probability, much higher bit rates in larger portions of the coverage area, lower infrastructure costs, and higher aggregate capacity for many simultaneous users in both licensed and unlicensed spectrum [4].

The metallic losses are very high so dielectric resonators are preferred at higher frequency bands. Dielectric resonators provide a high Q value with large value of permittivity. The mm wave communication needs non-metallic radiators to act as antennas. The rectangular Dielectric Resonators have practical advantages over other shapes. The mode degeneracy can be manipulated over the different dimensions of a rectangular Dielectric Resonator Antenna [5]. To fulfill the demands of 5G networks as larger capacity, higher data rate, better connectivity, more advanced reliability, new design patterns to make antenna design are demanded. The commonly declared 5G frequency band is 24.25-27.5 GHz. However, the bandwidth of the dielectric resonator antenna is inversely related to the dielectric constant and may limit the choice of values for a given application. By using a material with a high dielectric constant, the size of the dielectric resonator antenna can be significantly reduced, making it viable for low-frequency operations [6]. The most

commonly employed rectangular resonator mode in practice is the TE₁₁ mode. This mode is the counterpart of the TE₁₀₁ mode of a cylindrical resonator and can be easily excited by means of a loop, probe or microstrip conductor. It is therefore important to know the accuracy of the present method in predicting the resonant frequency of this mode [7]. Designing an antenna at millimeter wave, there can be several challenges to face. Using a much higher frequency, the size of the antenna will be very small and which lead to high fabrication skills and capability to implement with terminals [8]. The main advantage of the rectangular DRA is that it is characterized by three independent geometrical dimensions *a*, *b*, and *d* this offers more design flexibility as compared to the cylindrical DRA. Furthermore, the rectangular DRA is characterized by low cross-polarization level as compared to the cylindrical DRA [9, 10]. The coaxial probe feed. On the other hand, it allows the whole electric current to flow on the DRA surface and, thus, is more efficient in energy coupling [11, 12]. Here the simulations are carried out by HFSS and results of return loss, impedance, gain and radiation pattern are proposed. The optimized results of impedance match and return loss with different feed configurations also mentioned.

2. ANTENNA DESIGN AND OPTIMETRIC ANALYSIS

A ceramic type Dielectric Resonator antenna is used with permittivity $\epsilon_r=10$ over a substrate of Roger RT/Duroid 5880. The calculated dimensions of DRA are *a*=2.9mm, *b*=3.2mm and *h*=1.4mm mentioned in Table 1. The dimensions of the substrate are SubL=5.76mm, SubW=5.76mm, SubH=0.254mm. The loss tangent is 0.0009. The DRA antenna design is shown in Figure 1 with its probe feeding technique. The substrate used here is Rogers with thickness 0.254 mm. Figure 2 represents the top view of the design with coupled microstrip line. Here the TE₁₀₁ mode is excited whose resonant frequency can be calculated from equations mentioned below:

$$K_x \times \tan(K_x \times \frac{d}{2}) = \sqrt{(\epsilon_r - 1) \times K_0^2 - K_x^2}$$

Where

$$k_0 = \frac{2\pi}{\lambda_0} = \frac{2\pi f_0}{c}, k_y = \frac{\pi}{w} \text{ and } k_z = \frac{\pi}{b}$$

and

$$k_x^2 + k_y^2 + k_z^2 = \epsilon_r * k_0^2$$

where *a*, *b*, *d* indicates the dimensions of the DRA which is proportional to the square root of the dielectric constant values of the Ceramic based DRA. Where *c* is velocity of light in free space and *f*₀ is the operating frequency. The values of *a*, *b*, *d* can be calculated from the permittivity values used to design the antenna and the Q factor of the antenna. The rectangular DRA offers more degree of freedom to the antenna structure, so the number of modes generated can be studied. In generally with 50 ohm characteristics impedance and with all basic commonly used feeds, the characteristics modes are excited [13]. The excited mode here is TE₁₀₁. The ground plane is placed down to the substrate and is similar to the substrate dimensions. The probe height above to the substrate will radiate the fields to the DRA [14], so the probe height optimization can be done. The calculated dimensions of the substrate and the DRA dimensions are representing in Table 1.

A microstrip line with different dimensions is used to couple the energy radiated by the probe to the DRA [15]. The microstrip line dimensions are optimized to get the impedance match. The probe dimensions are shown in Table 2. The inner probe is placed very close to the DRA to avoid the airgap. The probe height is optimized with the impedance match, so that maximum radiated electric fields can be coupled to the DRA volume. The height of the DRA [16] is optimized further to get a high isolation values in the return loss. The impedance bandwidth is measured at the desizred resonating frequency.

Table 1. Antenna parameters

Variable	Dimensions (mm)
a	2.9
b	3.2
d	1.4
Sub_L	5.76
Sub_W	5.76
Sub_H	0.254

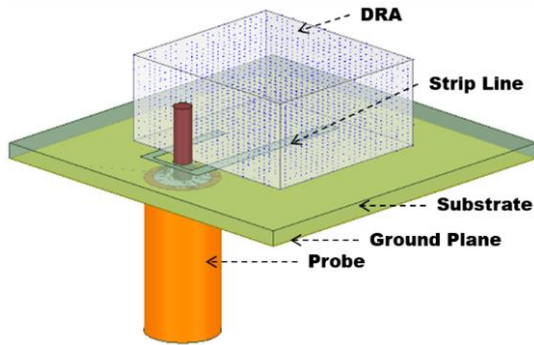


Figure 1. Probe-fed rectangular dielectric resonator antenna

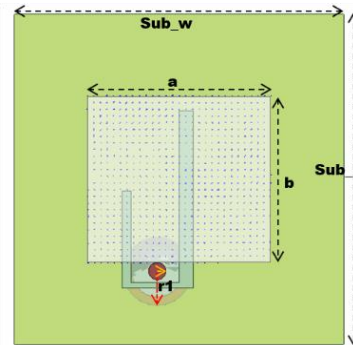


Figure 2. Probe fed with coupled microstrip line (top view)

Table 2. Feed parameters

Variable	Dimensions in mm
O_{rad}	0.6
i_{rad}	0.45
P_h	2.5
I_h	3.66

Figure 3(a) represents the electric field distribution over the DRA. The excited mode is TE_{1y1}. The fields coupled the DRA from the probe helps to excite the DRA to radiate efficiently. The coupled microstrip line are optimized to get maximum impedance bandwidth. The microstrip line coupling is rotated around the probe above to the substrate. The dimensions of the stripline are non uniform here. The stripline present closer to the probe couples the electric field radiated by the probe into the DRA to excite the DRA at designed frequency. The current distribution over the DRA can be Figure 3. The electric field distribution here is because of both the coupled transmission line and the inner conductor of the probe which is placed close to the DRA above the substrate [17]. The impedance bandwidth is also optimized with the position along XY plane and the height of the probe. The antenna behaves as circular at 24GHz only with a low polarization bandwidth and is linearly polarized at other frequencies.

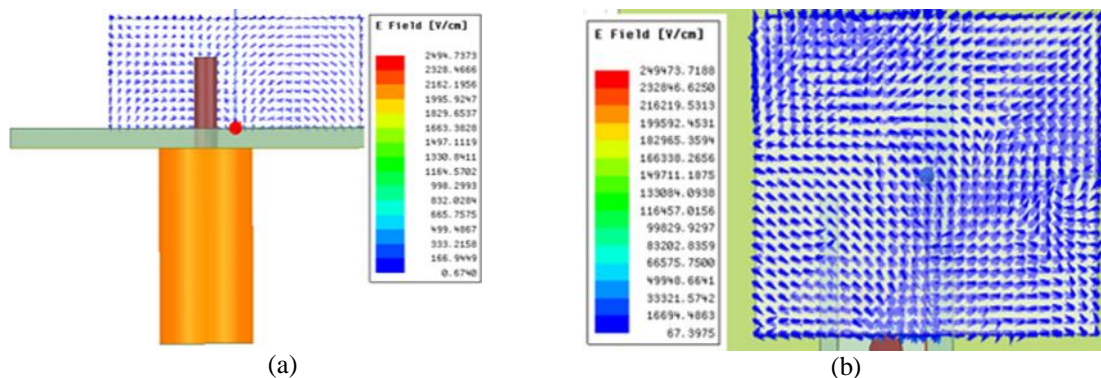


Figure 3. E field distribution over the DRA, (a) electric field over DRA, (b) top view of current distribution

3. RESULTS AND ANALYSIS

The DRA resonates from 24.24GHz to 29.20GHz with center frequency at 26GHz. The percentage bandwidth is 19% which is enough to use the antenna for millimeter wave 5G applications. The wide impedance bandwidth is matched with 50-ohm characteristics impedance to deliver maximum current to the antenna. The high isolation in the return loss happens because of the inner conductor of the probe which is placed close to the DRA surface. The results of return loss and impedance match are shown in Figure 4 and Figure 5 respectively.

The height of the inner conductor of probe is optimized to get a perfect impedance match to the coupled transmission line. The probe impedance is matched with the required characteristics impedance of the antenna i.e 50ohm. Figure 5 shows the input impedance of the antenna at desigred resonating frequency.

The fields coupled to the microstrip transmission line helps the DRA to get excite with maximum radiated energy. The calculated radiation efficiency of the antenna is 94 percentage, Figure 6 represents the fields radited by probe placed close to the DRA. The impedance match is uniform over the band of 24 Ghz to 28GHz, which results in a high isolation of the antenna.

The impedance measurement is optimized at different feed width of the coupled transmission line and at different position of the Dielectric Resonator. The position of the DRA [18] is varied with respect to the probe position. The airgap between the probe and the DRA [19, 20] varies the impedance match at the desigred resonating frequency. The input impedance match is shown in Figure 7.

The resonance depends on the distance of the inner conductor of the probe to the DRA [21]. As shown in Figure 8, different resonances occurred at desigred frequency by varying the DRA [22, 23] position which indirectly varies the distance from the inner conductor of the probe. The return loss isolation of -40dB is achieved at the resonating frequency of 26.2 GHz. The desigred resonance can be selected based on different position of the DRA. The simulated gain of the DRA is 6.24dBi is shown in Figure 9. The gain is measured at phi=0 degree and Phi=90 degree. An optimization of feed width of the strip line has been carried out here and its effect on the resonance has been shown in Figure 9. A continuous growth in the gain value at different frequencies has been presented, where the antenna achieves a maximum gain of 6.24dBi at and around 26GHz.

The desigred antenna here is a linerly polarized antenna but a low axial ratio bandwidth is observed at 24GHz. The measured axial ratio bandwidth at 5dB is from 24.08GHz to 23.90GHz, which is about 0.75 percentage bandwidth. The axial ratio bandwidth is shown in Figure 10. The desigred antenna here is highly linerly polarized. The radiation pattern of E and H plane is shown in Figure 11.

The simulated gain in dBi at different frequencies is presented in Figure 12. A continuous rise in gain value is maintained from 24GHz to 28GHz. There is a sharp increase in the gain value from 24GHz onwards. The placement of the DRA with respect to the probe height controls the impedance bandwidth of the DRA [24]. The E and H plane radiation pattern is shown in Figure 11. The DRA ehilbts circular polarization at 24GHz with a low polarization bandwidth and behaves linearly at other resonating frequencies. So, it can exhibit both linear and circular polarization through out its resonance [25].

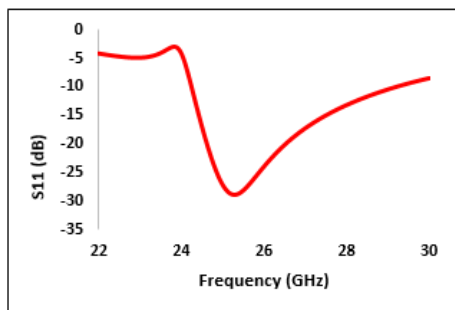


Figure 4. Return loss (dB) vs frequency (GHz)

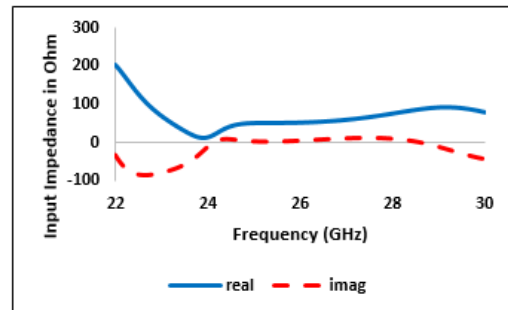
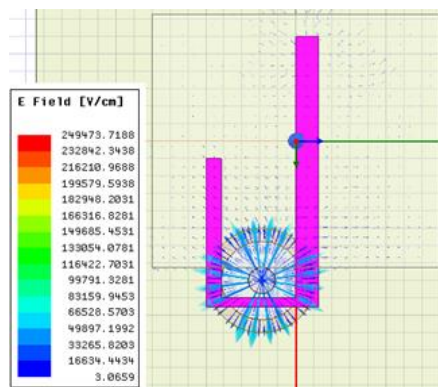
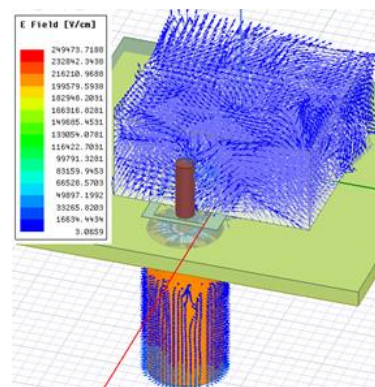


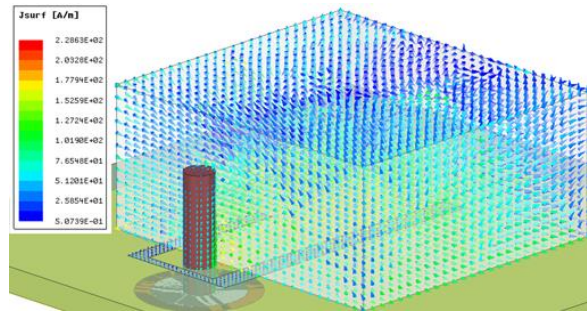
Figure 5. Input impedance in ohm vs frequency (GHz)



(a) E field over micro stripline



(b) E field over the probe



(c) surface current distribution

Figure 6. E field distribution over probe and DRA

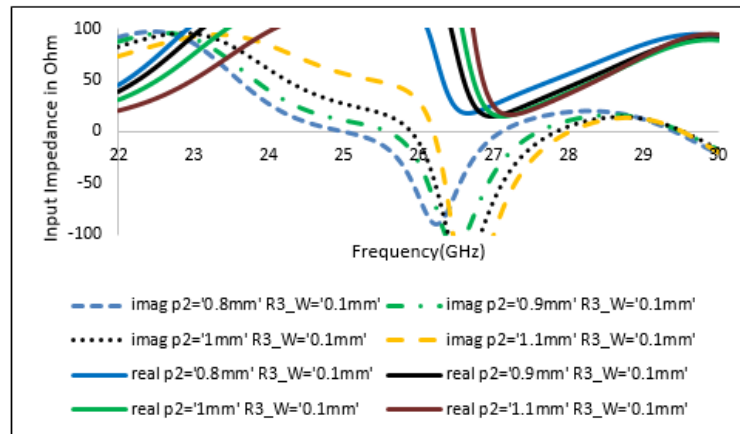


Figure 7. Input impedance in ohm vs frequency (GHz) at different feed position and feed width

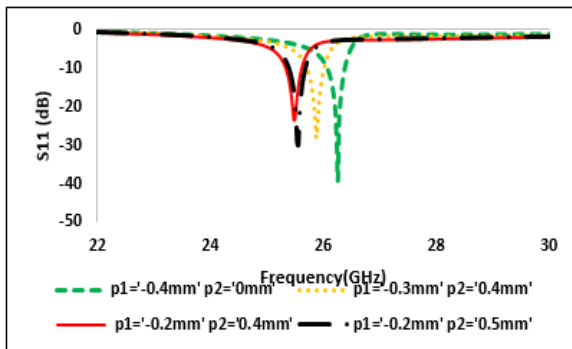


Figure 8. Return loss (dB) vs frequency (GHz)

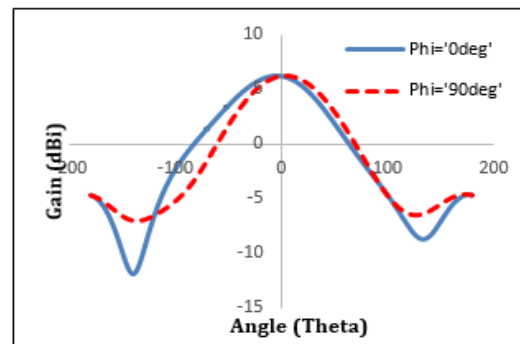


Figure 9. Gain (dBi)

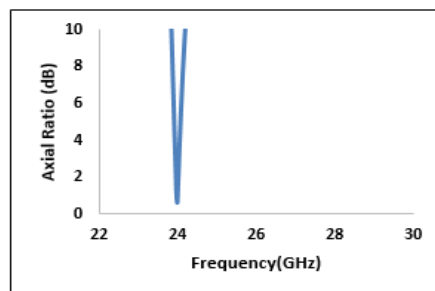


Figure 10. Axial ratio (dB) vs frequency (GHz)

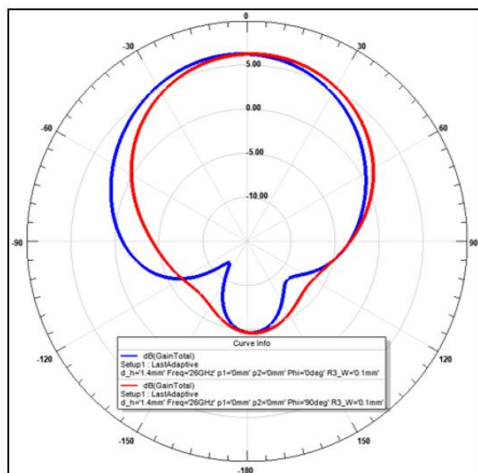


Figure 11. Radiation pattern at Phi=0 and Phi=90

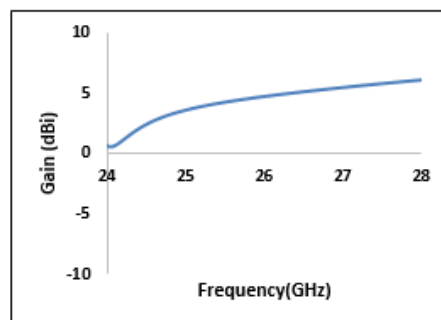


Figure 12. Gain (dBi) vs frequency (GHz)

4. CONCLUSION

The wideband DRA designed here can be used for mm wave 5G bands of 23GHz to 27 GHz. A percentage bandwidth of 19% has been achieved here with radiation efficiency of 96% and gain 6.24dBi. This probe fed DRA can be used for mm wave 5G applications. The measured axial ratio bandwidth at 5dB is from 24.08GHz to 23.90GHz, which is about 0.75 percentage bandwidth.

ACKNOWLEDGEMENTS

The Authors would like to thank The Ministry of Higher Education (MOHE) under FRGS (vote 4F283 and 4F733) and under Research University Grant (Votes 19H56 and 03G59) and Higher Center of Excellence Grant (Vote 4J220) for supporting this Research Work.

REFERENCES

- [1] T. S. Rappaport, Y. Xing, S. Member, and G. R. Maccartney, "Overview of Millimeter Wave Communications for Fifth-Generation (5G) Wireless Networks-with a focus on Propagation Models," in *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 12, pp. 6213-6230, 2017.
- [2] J. G. Andrews et al., "What Will 5G Be?," in *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065-1082, 2014.
- [3] A. Maltsev, I. Bolotin, A. Pudneyev, G. Morozov, and A. Davydov, "Performance Evaluation of the Isolated mmWave Small Cell," *2015 IEEE 26th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Hong Kong, pp. 2354-2358, 2015.
- [4] T. S. Rappaport et al., "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!," in *IEEE Access*, vol. 1, pp. 335-349, 2013.
- [5] A. Gaya, M. H. Jamaluddin, M. R. Kamarudin, and I. Ali, "A wideband dielectric resonator antenna with a cross slot aperture for 5G communications," *TELKOMNIKA (Telecommunication, Computing, Electronics and Control)*, vol. 17, no. 5, pp. 2218-2225, 2019.
- [6] A. Petosa and A. Ittipiboon, "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," in *IEEE Antennas and Propagation Magazine*, vol. 52, no. 5, pp. 91-116, 2010.
- [7] R. Kumar Mongia, A. Ittipiboon, R. K. Mongia, A. Ittipiboon, R. Kumar Mongia, and A. Ittipiboon, "Theoretical And Experimental Investigations on Rectangular Dielectric Resonator Antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 45, no. 9, pp. 1348-1356, 1997.
- [8] A. Gaya and I. Ali, "Performance Analysis of a Dielectric Resonator Antenna with Different Feeding Technique for 5G Communication," *2018 2nd International Conference on Electrical Engineering and Informatics (Icon EEI)*, Batam, Indonesia, pp. 92-97, 2018.
- [9] S. Keyrouz and D. Caratelli, "Dielectric Resonator Antennas: Basic Concepts, Design Guidelines, and Recent Developments at Millimeter-Wave Frequencies," *International Journal of Antennas and Propagation*, vol. 2016, 2016.
- [10] G. Almpanis, C. Fumeaux, and R. Vahldieck, "Offset cross-slot-coupled dielectric resonator antenna for circular polarization," in *IEEE Microwave and Wireless Components Letters*, vol. 16, no. 8, pp. 461-463, 2006.
- [11] K. W. Leung, "Conformal Strip Excitation of Dielectric Resonator," in *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 6, pp. 961-967, 2000.
- [12] K. X. Wang and H. Wong, "A Circularly Polarized Antenna by Using Rotated-Stair Dielectric Resonator," in *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 787-790, 2015.

- [13] S. T. Low and Z. Wu, "Microstrip-fed rectangular dielectric resonator antenna," *2003 High Frequency Postgraduate Student Colloquium (Cat. No.03TH8707)*, Belfast, Ireland, pp. 99-102, 2003.
- [14] R. K. Mongia, A. Ittipiboon, M. Cuhaci, and D. Roscoe, "Circularly polarised dielectric resonator," in *Electronics Letters*, vol. 30, no. 17, pp. 1361-1362, 1994.
- [15] M. Khalily, M. R. Kamarudin, and M. H. Jamaluddin, "A novel square dielectric resonator antenna with two unequal inclined slits for wideband circular polarization," in *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1256-1259, 2013.
- [16] I. Ali, M. H. Jamaluddin, M. R. Kamarudin, A. Gaya, and M. H. Dahri, "Gain enhancement of dielectric resonator antenna for millimeter wave applications," *TELKOMNIKA (Telecommunication, Computing, Electronics and Control)*, vol. 17, no. 4, pp. 1670-1673, 2019.
- [17] Y. Zhang, S. Member, A. A. Kishk, B. Alexander, S. Member, and A. W. Glisson, "*IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics, 2005.*", Honolulu, HI, pp. 371-375, 2005.
- [18] A. Petosa, R. K. Mongia, A. Ittipiboon, and J. S. Wight, "Investigation of various feed structures for linear arrays of dielectric resonator antennas," *IEEE Antennas and Propagation Society International Symposium. 1995 Digest*, Newport Beach, CA, USA, vol. 4, pp. 1982-1985, 1995.
- [19] A. Gaya, M. H. Jamaluddin, M. R. Kamarudin, and I. Ali, "Design of Wideband Dielectric Resonator Antenna with Aperture Coupled technique for 5G Applications," *2018 IEEE International RF and Microwave Conference (RFM)*, Penang, Malaysia, pp. 254-257, 2018.
- [20] N. Mohd Nor, M. Haizal Jamaluddin, M. Ramlee Kamarudin, and S. Zareen Naqiyah Zool Ambia, "Design of Planar Dielectric Resonator Antenna Array at 28 GHz," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 5, no. 3, pp. 622-627, 2017.
- [21] Y. Liu, K. W. Leung, J. Ren, and Y. Sun, "Linearly and Circularly Polarized Filtering Dielectric Resonator Antennas," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 6, pp. 3629-3640, 2019.
- [22] A. Gaya, M. H. Jamaluddin, I. Ali, and M. R. Kamarudin, "A Wideband Dielectric Resonator Antenna with a C shaped Slot Aperture for 5G Applications," *2018 IEEE International RF and Microwave Conference (RFM)*, Penang, Malaysia, pp. 258-261, 2018.
- [23] M. B. Oliver, R. K. Mongia, and Y. M. M. Antar, "A new broadband circularly polarized dielectric resonator antenna," *IEEE Antennas and Propagation Society International Symposium. 1995 Digest*, Newport Beach, CA, USA, vol. 1, pp. 738-741, 1995.
- [24] D. M. Pozar, "A review of aperture coupled microstrip antennas: History, operation, development, and applications," *Univ. Massachusetts Amherst*, pp. 1-9, 1996.
- [25] R. K. Mongia, "Theoretical and experimental resonant frequencies of rectangular dielectric resonators," *IEE Proceedings H-Microwaves, Antennas and Propagation*, vol. 139, no. 1, pp. 98-104, 1992.

BIOGRAPHIES OF AUTHORS



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 Millimeter wave 5G Communications at WCC. He is also working towards Design of Phased Array Antenna system for 5G Base Stations. His research interest also includes channel measurements for 5G at Millimeter wave frequencies. He is a student member in IEEE. He received his Bachelors (B. Tech) and Masters (M. Tech) degree in Electronics and Communication Engineering from Berhampur University, Odisha, India.



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, 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.



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 dielectric resonator antennas, microstrip patch antennas, MIMO antennas, mutual coupling analysis. He has published more than 8 papers in reputed journals and conference proceedings.