Progress In Electromagnetics Research Letter, Vol. 114, 97-102, 2023

(Received 18 October 2023, Accepted 20 November 2023, Scheduled 3 December 2023)

3D Printed Wideband Ring Dielectric Resonator Antenna

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ABSTRACT: In this article we present a ring Dielectric Resonator Antenna (DRA) fabricated on three-dimensional (3D) printed Acrylonitrile Butadiene Styrene (ABS) filament. The 3D printer offers antenna easy to fabricate and the possibility to design new antennas shapes more complex. The simulation performed using CST software 2020 shows that the proposed ring DRA has two resonance frequencies 23.5 GHz and 26.4 GHz with an obtained great gain 9.5 dB and 10.5 dB, respectively. A wideband about 42.4% was measured.

1. INTRODUCTION

Dielectric Resonators now hold the attention of numerous researchers since they have been introduced in 1983 [1], and due to their attractive performance in terms of bandwidth [2], small size and low profile [3], and the very high radiation efficiency compared to microstrip antennas [4]. They can provide design flexibility in multi-frequency or further broadband operation [5]. Different shapes of DRAs such as cylindrical, hemispherical, elliptical, pyramidal, rectangular, and triangular have been presented in the literature [6–9]. The properties of the Dielectric Resonator Antenna (DRA) can be altered depending on the proper selection of the resonator's size and dielectric constant, and for the cylindrical DRA the radius, the height and the permittivity as well make it straightforward to regulate the resonant frequency [10]. In DRAs, we can use a wide range of dielectric constants ($\varepsilon_r = 2.1$–100), that allowing the designer to have control over the physical size of the DRA and its bandwidth.

Due to the time savings and design intricacy, 3D printing has recently attracted a lot of interest. With great precision, 3D printing has the potential to be able to print a variety of materials in three dimensions, which allows for complicated designs to be created quickly, used for 3D RF include antennas. recently, biodegradable antennas with several benefits were developed using PLA ceramic thanks to the 3D printer [11, 12], Moreover, [13] shows the proves that the ABS could be used as a substrate for a microstrip patch antenna. Francesco et al. in [14] present a study highlighted how various additive manufacturing methods might be appropriate for applications with varied restrictions by giving a quick analysis of the state-of-the-art in the field of 3D printed antennas, that they are very well suited for creating dielectric resonator antennas.

Novel designs for wideband circularly polarized (CP) dielectric resonator antennas were presented in Papers [17] and [18], both studies explored the integration of asymmetric-slot radiators to achieve bi-directional radiation characteristics. These designs utilized a rectangular-DR over an asymmetric-rectangular-slot radiator, producing two orthogonal modes for bi-directional CP radiation. The measured reflection coefficient bandwidth in both studies covered a wide frequency range. The antennas exhibited similar performance with average gains around 3.55 dBic.

In this study, our focus was on exploring the impact of varying the radius of the central hole of the ring dielectric resonator antenna (DRA) and on the benefits of using ABS. It is a type of plastic that can be produced using 3D printing technology and is renowned for its durable structure, high-temperature resistance, and low tangent loss of 0.0051. Its relative permittivity of 2.74 also allows for achieving a wide bandwidth, making it an attractive option for antenna fabrication. The main contributions of this paper can be summarized as follows. Firstly, we propose a cost-effective and time-efficient fabrication method for the proposed antenna design. Secondly, the compact size and wideband characteristics of the proposed design make it a promising candidate for use in 5G applications. The design can be easily integrated into 5G systems and can provide a reliable and efficient performance in various communication scenarios.

2. HOMOGENOUS CYLINDRICAL DRA DESIGN

2.1. Geometry and Configuration

The suggested cylindrical Dielectric Resonator Antenna is illustrated in Figure 1. The cylindrical form provides a significant amount of freedom of radius $R = 5\,\text{mm}$ and height of $h = 10\,\text{mm}$, using Acrylonitrile Butadiene Styrene (ABS) that has a tangent loss of 0.0051, and the relative permittivity is $\varepsilon_r = 2.74$. As a result, the coaxial probe feed of 50-Ω adjacent to a DRA delivers a high gain and offers a great coupling. An Aluminum ground plane size $34 \times 34 \times 2\,\text{mm}^3$ is considered. The studied geometry is then designed by using CST microwave studio software.

The working frequency of the cylindrical DRA is specified by the antenna's size. More specifically, the resonant frequency of the system may be altered by varying the radius or height of the dielectric resonator. The dielectric resonator antenna's ra-

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doi:10.2528/PIERL23101801 Published by THE ELECTROMAGNETIC ACADEMY

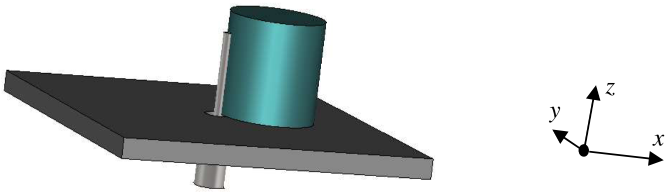


FIGURE 1. Cylindrical DRA design.

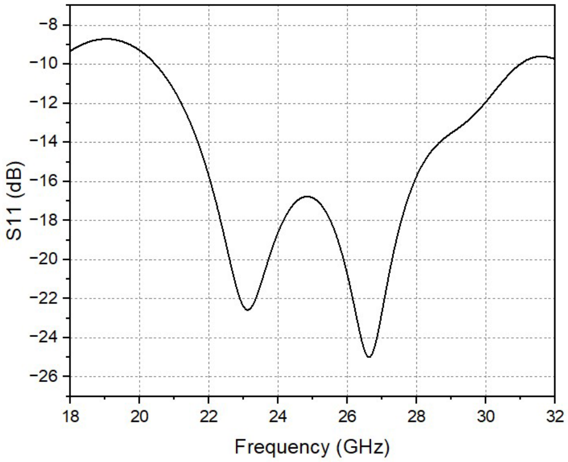


FIGURE 2. Simulated return loss vs frequency of the cylindrical DRA.

dius and height are determined using the following formulae (1) corresponding to the case of mode HM11 [2]:

$$f = \frac{c}{2\pi\sqrt{\varepsilon_r}}\left[m^2 + \left(\frac{n}{R}\right)^2 + \left(\frac{p}{h}\right)^2\right] \tag{1}$$

where ε_r is the permittivity, R the radius, h the height of the antenna, m the axial mode number, n the radial mode number, and p the angular mode number.

It is important to note that the dimensions are first determined using the following formulae, but they are afterwards optimized to improve impedance bandwidth.

2.2. Results and Discussion

Using the CST Microwave Studio simulation tool, Figure 2 displays the return loss characteristics of the CDRA as the function of frequency. The results indicate that the S_{11} parameter exhibits two distinct resonances at frequencies of 23.1 GHz and 26.8 GHz, with a maximum return loss of -21 dB and -25 dB, respectively. The bandwidth of the RDRA extends from 20.7 GHz to 31.3 GHz, and the gains of the two resonance frequencies are 9.5 dB and 11.3 dB, respectively. The resonances in the CDRA are a direct result of the dielectric resonator's geometry and its composition, which enable the antenna to effectively trap and reradiate electromagnetic energy within the desired frequency range. These results demonstrate the efficacity of the CDRA design for achieving high gain and broadband operation in the 20–30 GHz frequency range, which is relevant for a variety of modern wireless communication applications.

3. RING DRA DESIGN

3.1. Geometry and Results

Figure 3 depicts the new ring DRA, which has been developed to operate in the same bandwidth of about 25 GHz as the previous design, with the use of identical materials for the ground and dielectric resonator. The design process of the new antenna involved the introduction of a new parameter, the internal radius of the dielectric resonator (Rin). This additional degree of freedom in the design is crucial in achieving optimal performance and tuning the resonance frequency of the antenna. By varying the Rin, the antenna can be adjusted to resonate at the desired frequency, while also enabling the exploration of a wider range of design possibilities. This new parameter has been carefully considered and analyzed to ensure that the design goals of the antenna, such as high gain and wide bandwidth, are met while maintaining a simple and cost-effective manufacturing process.

To investigate the impact of the radius of the central hole of the ring DRA on the performance of the antenna. Varying Rin from 0 mm to 3 mm in increments of 1 mm, the reflection coefficient S_{11} was used to assess antenna performance. Results in Figure 4 indicated that the optimal bandwidth, ranging from 18.5 GHz to 31 GHz, was achieved at $Rin = 2$ mm. This sweep analysis served to highlight the correlation between the internal radius of the ring and the antenna's performance, specifically in relation to the bandwidth achieved. This bandwidth was accompanied by a gain between 9 dB and 10.5 dB, as presented in Figure 5(a). Furthermore, we observed in simulation that the use of a ring DRA resulted in a significant volume reduction of about 32% compared to a cylindrical antenna. Additionally, we achieved a band expansion of 1.3 GHz, which ultimately led to a wide bandwidth of 52.2%. The antenna exhibited a measured maximum gain in Figure 5(b) of 10.4 dB. The obtained values support and validate the simulated gains, confirming the efficacy of the proposed design in practical application. These results highlight the advantage of using a ring DRA over a cylindrical antenna in terms of size reduction and bandwidth enhancement. Meanwhile, the antenna measurements have yielded valuable insights into its performance characteristics. The bandwidth of the antenna spans from 21 GHz to 31.5 GHz, indicating its ability to cover a wide range of frequencies. Notably, the measurements have revealed multiple resonance points at approximately 21 GHz, 24 GHz, 26 GHz, and 27.1 GHz. The measurement shows a bandwidth of 42.4%, and the discrepancies between the simulated and measured re-

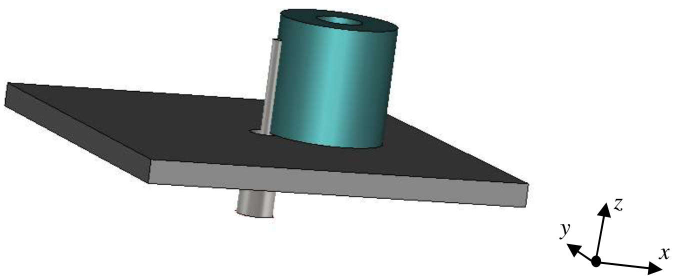


FIGURE 3. Design on CST of the ring DRA.

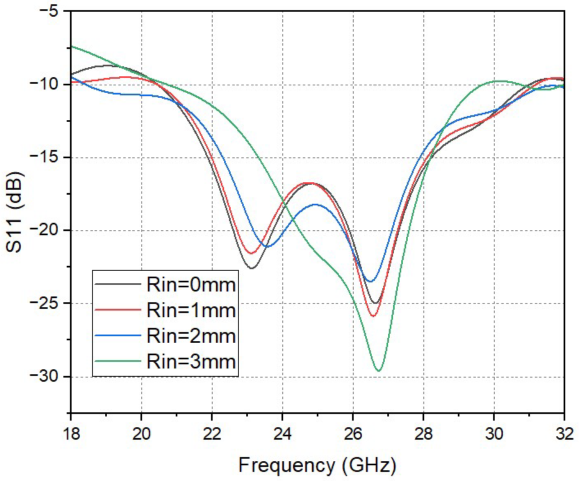


FIGURE 4. Parametrical sweep of Rin from 0 mm to 3 mm with a step of 1 mm of the reflection coefficient Vs frequency of the DRA.

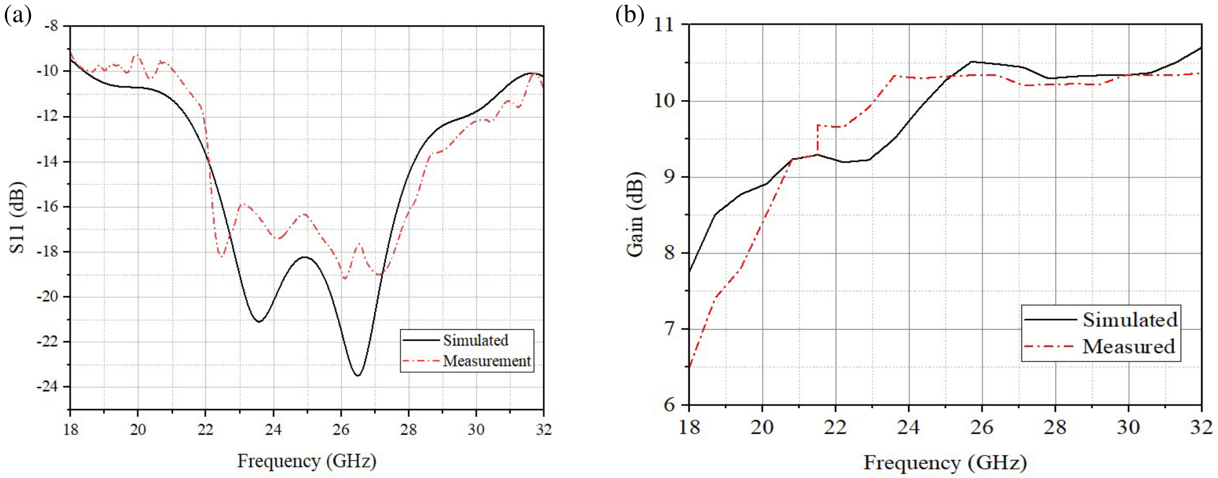


FIGURE 5. Performances of the ring DRA for $Rin = 2$ mm: (a) Simulated and measured S_{11}. (b) Simulated and measured gain Vs frequency.

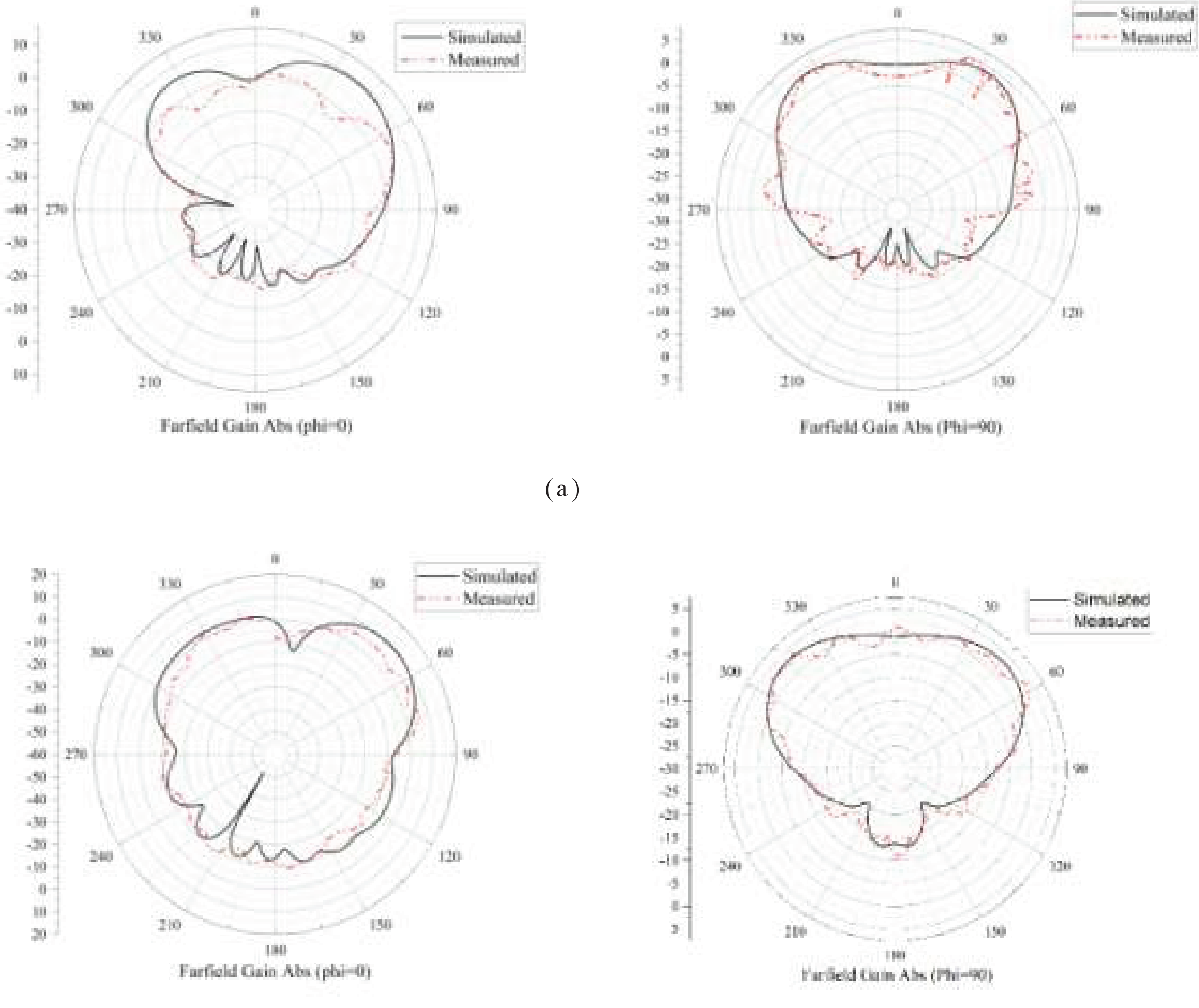
TABLE 1. Comparison of the proposed DRA with recent works on bandwidth enhancement performance.

Reference	Frequency range (GHz)	Bandwidth (%)	Gain (dBi)	Dielectric constant
[15]	23.8–28.3	17.3	9.3	10
[16]	24.25–27.5	15.38	6.5	-
This paper	21–31.5	42.4	9–10.4	2.74

sults exist due to fabrication imperfections, specifically related to bonding ABS to Aluminum.

Figure 6 showcases the simulated radiation patterns in the E-plane ($\varphi = 0°$) and H-plane ($\varphi = 90°$) for both frequencies. In the E-plane ($\varphi = 0°$), an almost omnidirectional pattern is observed for both frequencies. This indicates that the antenna radiates electromagnetic energy predominantly in the direction perpendicular to the antenna structure. In the H-plane ($\varphi = 90°$), at 23.5 GHz, the radiation pattern shows a larger beamwidth, indicating a broader coverage of radiation in different directions. On the other hand, at 26.4 GHz, significant radiation is observed in one specific direction and symmetrical broadside. This suggests that the antenna exhibits a directional radiation pattern in the $\varphi = 90°$ plane at this frequency.

This study has been conducted with the major aim of achieving a cost-effective and simple manufacturing process. In line with this objective, the previous sections have presented the design and analysis of a ring DRA with ABS material. To further explore the possibilities for cost-effectiveness and simplicity, this section investigates the use of Alumina as an alternative material. The Alumina material is known for its durability and high-temperature resistance, but it is generally more expensive than ABS. Drawing upon our prior experience working with the latter material as evidenced in [3], we encountered a hybrid an-



(a)

(b)

FIGURE 6. Simulated radiation patterns of the Ring DRA on H-plane (right) and E-plane (left): (a) 23.5 GHz. (b) 26.4 GHz.

tenna composed of approximately 80% Alumina and 20% ABS. This section aims to determine the feasibility of using Alumina in the ring DRA design by comparing its performance with the ABS design. The results obtained show that the Alumina-based ring DRA exhibits a lower bandwidth, gain, and frequency than the ABS-based design. Figure 7 shows the simulation results, where it can be seen that the alumina-based design has a resonance frequency of 8.24 GHz with a gain of 6 dB and a bandwidth about 14%. These results demonstrate the effect of material selection on the performance of the ring DRA design and emphasize the importance of considering various materials and their electrical properties in antenna design. Despite the lower performance of the alumina-based design, it is still a viable option for specific applications that require its unique properties, Alumina, as a ceramic material, exhibits hardness and resilience that make it challenging to machine using conventional methods. For cutting, specific laser machines are often required due to the precision and power needed to work through this durable material. In comparison, ABS also holds advantages in terms of 3D printing, making it a more accessible choice for a wide range of projects.

The Ring Resonator was manufactured using an Ultimaker 3 printer and a Cura software configuration for the correct deposition of ABS filament. An Agilent N5222A Performance Network Analyzer is being used to measure the result as shown in Figure 8, and (PNA) N5222A instrument can measure frequencies between 10 kHz and 43.5 GHz.

To evaluate the performances of our proposed design, with a comparative analysis presented in Table 1, our proposed ABS ring Dielectric Resonator Antenna (DRA) demonstrates a significantly superior bandwidth compared to similar works in the field at around 26 GHz. The comparison involved two notable designs, one by Ali et al. [15] and the other by Gaya et al. [16], and the achieved bandwidth of 42.4% in our ABS DRA surpasses both referenced designs, highlighting its competitiveness and superior performance in the given frequency range.

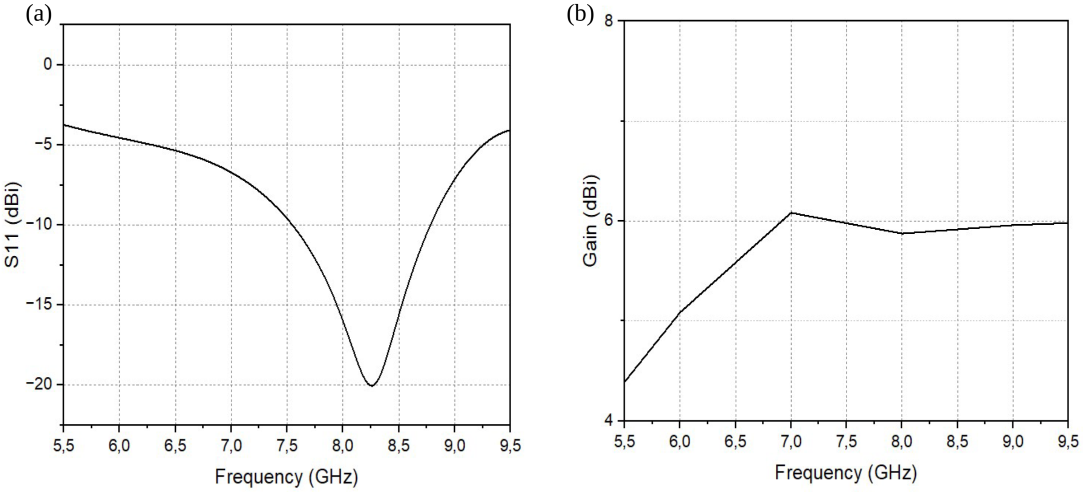


FIGURE 7. The Alumina Ring DRA: (a) Simulated return loss. (b) Simulated gain Vs frequency.

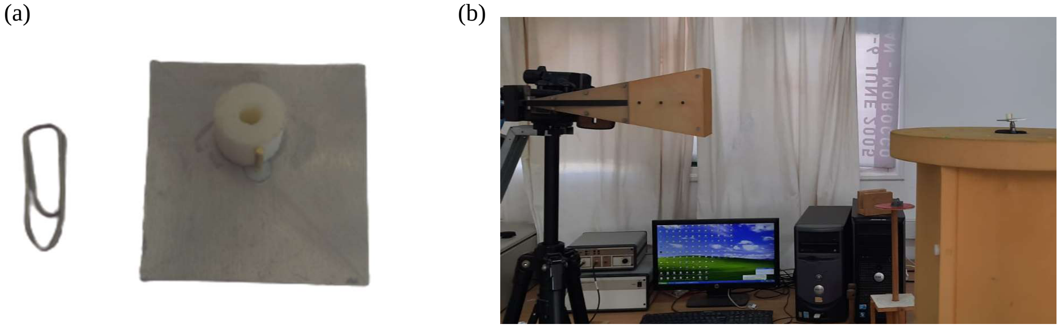


FIGURE 8. Ring DRA: (a) Three-dimensional view of antenna prototype. (b) Measurement bench for radiation patterns.

4. CONCLUSION

In this work, we present a Ring DRA with a wideband thanks to the low permittivity of ABS. We realized a comparative study with traditional Alumina Ring DRA performances, and the bandwidth, gain, ease of fabrication, and cost make the ABS much better. Our agreement between the measured and simulated results was fairly average. The antenna extends from 21 GHz to 31.5 GHz, showcasing a measured bandwidth of 42.4%. The proposed Ring design presents the reduction of volume. An important feature of this 3D printed antenna is its low cost and important bandwidth.

REFERENCES

[1] Long, S. A., M. W. McAllister, and L. C. Shen, "The resonant cylindrical dielectric cavity antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 31, No. 3, 406–412, 1983.

[2] Petosa, A., *Dielectric Resonator Antenna Handbook*, Artech House, Norwood, Ma, USA, 2007.

[3] Ben Yamoun, J., N. Aknin, and A. Jaoujal, "Low profile ultra wide band hybrid dielectric resonator antenna for emergent networks," in *2019 7th Mediterranean Congress of Telecommunications (CMT 2019)*, 1–5, Fez, Morocco, Oct. 2019.

[4] Lai, Q., G. Almpanis, C. Fumeaux, H. Benedickter, and R. Vahldieck, "Comparison of the radiation efficiency for the dielectric resonator antenna and the microstrip antenna at Ka band," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 11, 3589–3592, Nov. 2008.

[5] Thamae, L. Z. and Z. Wu, "Broadband bowtie dielectric resonator antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 11, 3707–3710, Nov. 2010.

[6] Maity, S. and B. Gupta, "Experimental investigations on wideband triangular dielectric resonator antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 64, No. 12, 5483–5486, Dec. 2016.

[7] Gaya, A., M. H. Jamaluddin, I. Ali, and A. A. Althuwayb, "Circular patch fed rectangular dielectric resonator antenna with high gain and high efficiency for millimeter wave 5G small cell applications," *Sensors*, Vol. 21, No. 8, 2694, Apr. 2021.

[8] Chauhan, M., A. K. Pandey, and B. Mukherjee, "A novel cylindrical dielectric resonator antenna based on Fibonacci series approach," *Microwave and Optical Technology Letters*, Vol. 61, No. 10, 2268–2274, Oct. 2019.

[9] Khattak, M. A., S. Saeed, M. A. Al-Husseini, A. Saeed, and S. Gull, "Design and analysis of millimeter wave dielectric resonator antenna for 5G wireless communication systems," *Progress In Electromagnetics Research C*, Vol. 98, 239–255, 2020.

[10] Kumar, J. and N. Gupta, "Performance analysis of dielectric resonator antennas," *Wireless Personal Communications*, Vol. 75, No. 2, 1029–1049, Mar. 2014.

[11] Kumar, P., S. Dwari, Utkarsh, S. Singh, and J. Kumar, "Investigation and development of 3D printed biodegradable PLA as

compact antenna for broadband applications," *IETE Journal of Research*, Vol. 66, No. 1, 53–64, Jan. 2020.

[12] Kumar, A., P. Kapoor, P. Kumar, J. Kumar, and A. Kumar, "Design and development of enhanced gain aperture coupled broadband biodegradable dielectric resonator antenna for WLAN applications," *Wireless Personal Communications*, Vol. 115, No. 2, 1525–1539, Nov. 2020.

[13] Malek, N. A., A. M. Ramly, A. Sidek, and S. Y. Mohamad, "Characterization of acrylonitrile butadiene styrene for 3D printed patch antenna," *Indonesian Journal of Electrical Engineering and Computer Science*, Vol. 6, No. 1, 116–116, 2017.

[14] Chietera, F. P., R. Colella, and L. Catarinucci, "Dielectric resonators antennas potential unleashed by 3D printing technology: A practical application in the IoT framework," *Electronics*, Vol. 11, No. 1, Jan. 2022.

[15] Ali, I., 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*, Vol. 8, No. 3, 2019.

[16] Gaya, A., M. H. Jamaluddin, M. R. Kamarudin, and I. Ali, "A wideband dielectric resonator antenna with a cross slot aperture for 5G communications," *TELKOMNIKA*, Vol. 17, No. 5, 2218–2225, 2019.

[17] Kumar, R., Nasimuddin, and R. K. Chaudhary, "Wideband circularly polarized hybrid dielectric resonator antenna with bi-directional radiation characteristics for various wireless applications," *International Journal of RF and Microwave Computer-aided Engineering*, Vol. 29, No. 9, e21826, Sep. 2019.

[18] Kumar, R., N. Nasimuddin, and R. K. Chaudhary, "A new dual C-shaped rectangular dielectric resonator based antenna for wideband circularly polarized radiation," *International Journal of RF and Microwave Computer-aided Engineering*, Vol. 29, No. 6, e21672, Jun. 2019.