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Original scientific paper

Enhanced Performance of Hybrid Dielectric Resonator Antenna with Hexagonal Ring Patch and Ground Slot for Multiband Operation in 5G Wireless Communication

M. MANIKANDAN*, S. PRASAD JONES CHRISTYDAS, R. SARAVANAKUMAR, S. ALAMELU ALIAS RAJASREE

Abstract: The article introduces a novel design for a Dual-Resonant Antenna (DRA), amalgamating a microstrip-fed Dielectric Resonator (DR) with a hexagonal ring patch. This innovative approach facilitates operation across seven distinct frequency bands by integrating a hexagonal slot into the ground structure, thereby enhancing performance metrics. The incorporation of the slot notably augments the antenna's impedance bandwidth, a crucial factor in achieving efficient wireless communication. Within the frequency spectrum of 5.09 GHz to 9.12 GHz, resonances are effectively detected, underscoring the versatility of this antenna design. With a gain exceeding 1.9 dBi, the antenna exhibits notable signal amplification capabilities. Additionally, boasting a directivity of over 4, the antenna showcases its efficacy in focusing transmitted signals towards specific directions, thereby enhancing communication reliability and range. The enhanced impedance bandwidth and multi-band operation make this antenna design suitable for a myriad of wireless communication applications. Its adaptability and dependability are underscored by the ability to operate across various frequency bands, catering to diverse communication needs. Whether utilized in Wi-Fi networks, satellite communication systems, or other wireless applications, this antenna design offers a reliable solution for achieving robust and efficient communication links. Furthermore, its compact form factor and integrated design make it conducive for integration into various devices, ranging from smartphones to IoT devices, further expanding its potential utility in modern communication ecosystems.

Keywords: 5G wireless communication; hybrid dielectric resonator antenna (DRA); impedance bandwidth; millimeter-wave communication; spectrum scarcity

1 INTRODUCTION

In the current environment of wireless communication, there is a growing mandate for antennas that deliver a mixture of highgain, radiation competence, low cost with profile. This demand is expected to continue to grow. The dielectric resonator antenna (DRA) stands out as a leading contender among these several possibilities since it possesses the properties that are highly sought for. It is possible to purchase these antennas in a variety of forms and sizes from the commercial sector; nevertheless, the cylindrical configuration is particularly preferred for two convincing reasons. The first benefit is that it offers two degrees of freedom, which makes it possible to exercise exact control over the quality factor. Optimising the performance of the antenna requires this control to be optimised. The second advantage of the cylindrical DRA is that it is capable of supporting three various modes: the transverse electric (TE), the transverse magnetic (TM), and the hybrid electric magnetic (HEM) modes. These modes allow for the formation of a wide variety of far-field radiation patterns, which in turn offers diversity in terms of implementation [1, 2]. Because of its adaptability and robust performance, the cylindrical DRA is an excellent option for meeting the requirements of contemporary wireless communication. Particularly noteworthy is the fact that S. A. Long and his investigation team were forerunners in the investigation of the essential radiating mode in Cylindrical Dielectric Resonator Antenna. Their contributions cleared the door for a more in-depth understanding of the electromagnetic properties of DRAs, which in turn led to the development of antenna designs that were more efficient and dependable. The relevance of continual research and innovation in the advancement of antenna technology is highlighted by this historical context. This is necessary in order to meet the ever-changing requirements for wireless communication systems. In the current state of antenna engineering, there is a significant emphasis placed on the provision of antennas with the capacity to operate in both multiband and dual-polarized configurations. The shift in question is the result of three key motivations. In the first place, the incorporation of above characteristics in a solo antenna significantly increases its versatility transversely an extensive range of radio settings, hence catering to a variety of communication requirements [3]. In the second place, antennas that are endowed with such qualities have a reduced sensitivity to orientation, which enhances their adaptability and user-friendliness in a variety of deployment settings. Thirdly, these features allow for the vindication of multipath declining, which is a persistent difficulty in radiocommunication situations. As a result, signal reliability and performance are improved. For the purpose of accomplishing these goals, the discipline of antenna engineering has witnessed an increase in the number of different research endeavours. The operation of rectangular-shaped DRA through rifling and frill operations, which optimise their performance across different frequency bands, is one example of the new approaches that are included in these efforts [4]. In addition, researchers have investigated the possibility of developing hybrid cylindrical variations that combine the benefits of various antenna layouts. The objective of these hybrid variants is to achieve improved performance in terms of radiation characteristics and bandwidth [5]. Furthermore, the research of probe-coupled half-elliptical ring-shaped arrangements has shown encouraging findings in terms of attaining dual-polarized operation with better efficiency and reduced complexity [6-8]. A concerted effort is being made to fulfil the ever-changing requirements of modern wireless communication systems, and this continuing research and development in the field of antenna engineering reflects that collective endeavour. By addressing the requirement for antennas that are capable of multiband and dual-polarized operation, researchers want to improve the performance, adaptability, and reliability of wireless communication networks. This will pave the way for communication technologies that are more efficient and robust in a variety of applications.

2 LITERATURE REVIEW

Given the requirements of modern communication demands, 5G wireless networks have emerged as very desirable due to their extraordinary characteristics, which include fast data speeds, reduced latency, and higher capacity [1]. This is a reaction to the requirements of contemporary communication needs. The vast amount of material that is now available on the topic [2, 3] is proof that a significant amount of research efforts have been devoted to the creation of antennas that are specifically designed for 5G communication. Dielectric Resonator Antennas (DRAs) have garnered a great amount of interest from researchers due to the unique characteristics that they possess. These characteristics include their adaptive radiation features, negligible metal losses, wider bandwidth competencies, and customisable designs [4-9]. Fundamental geometries such as rectangular, cylindrical, and hemispherical configurations have gained priority among the numerous forms that are utilised in DRAs. This is due to the fact that these configurations are more cost-effective and simplify the fabrication processes. In particular, the rectangular DRA stands out due to its capacity to provide two degrees of freedom, which has a direct influence on the resonance frequency and radiation quality factor [10]. At the moment, antennas that are characterised by circular polarisation are preferred over their counterparts that are linearly polarised [11-20]. In light of the ever-expanding environment of wireless communications, it has become of the utmost importance to provide solid signal connectivity in order to cultivate communication networks that are reliable. This makes circularly polarised antennas very suitable for a wide variety of wireless applications [3, 20]. Circularly polarised antennas offer a number of benefits, including enhanced signal quality, protection from Faraday rotation in the ionosphere, and flexibility in source and receiver alignment. However, in order to fulfil the requirements of contemporary wireless communication, it is necessary to achieve wideband circular polarisation (CP). This presents a substantial difficulty when utilising basic Dielectric Resonator (DR) geometries and single feeding methods. Extensive research efforts have been directed to the enhancement of CP bandwidth in DRAs. Some of the tactics that have been used include alterations to basic forms, multi-layer dielectric topologies, and the incorporation of extra structures such as metallic walls [21-27]. In [21], for instance, a rectangular DRA that was supplied by a microstrip linked cross-slot was able to attain a CP bandwidth of 49.5% by utilising four parasitic walls. On the other hand, [22] reported a CP bandwidth of 3.8% by incorporating inclined slits into the diagonal and sidewalls of the resonator. On the other hand, these methods frequently involve intricate production processes, which contribute to an increase in the complexity, weight, and size of the antenna. There is also the possibility that researchers have investigated the utilisation of parasitic patches as a method to improve CP bandwidth. Their objective is to achieve wideband CP while simultaneously minimising the complexity and expense of production. The realisation of wideband CP antennas that strike a compromise between performance, complexity, and cost-effectiveness continues to be a problem, notwithstanding the gains that have been made towards this goal. In order to overcome these obstacles and realise the full potential of wideband CP antennas for contemporary wireless communication applications, additional research is required. A dual-band dual-polarized hybrid dielectric resonator antenna (HDRA) is the subject of this article, which digs into its various aspects. Specifically, it demonstrates a flawed ground structure that incorporates a stub in order to stimulate the DRA. This design has distinctive qualities, since it functions not only as a radiator but also as an exciter for two radiating hybrid modes that are included within the DRA. Additionally, the antenna exhibits a combination of circular and linear polarisations at a frequency of 5.0 GHz, in addition to exhibiting linear polarisation inside the 2.1 GHz frequency region. The fact that this innovative arrangement is able to accommodate a wide range of applications, including WLAN (5.0 GHz) and 2G and 3G (2.1 GHz), it highlights the significance of this configuration in wireless communication systems. The radiating structure that has been proposed is described in Section 2 of the article, along with an analysis of the structure, which provides a thorough comprehension of its design. A comprehensive presentation of the results can be found in Section 3, which provides an understanding of the antenna's performance. In sections 4 and 5, respectively, concluding thoughts and final results are presented. These sections shed insight on the prospective applications of the suggested DRA design as well as the relevance of the design. In general, this antenna design holds the potential to bring about breakthroughs in dual-band dual-polarized hybrid dielectric resonator technology. These advancements will make it possible for wireless communication systems to achieve improved performance and versatility across a variety of frequency bands. The literature review effectively connects the research to the broader context of 5G wireless communication networks by providing a comprehensive overview of existing studies, theories, and developments in the field. It highlights the relevance of the research within the context of 5G by discussing key concepts, challenges, and advancements related to millimeter-wave communication, antenna design, and spectrum utilization. The review identifies gaps or limitations in current research and discusses how the proposed study addresses these issues, contributing to the advancement of 5G technology. It also synthesizes findings from various sources to build a strong theoretical foundation for the research, demonstrating a clear understanding of the broader context and significance of the study.

3 MATERIAL AND METHODS

The substrate is made up of FR4 that is developed for the construction of the dual-band Slotted Dielectric Resonator Antenna (SDRA) that is proposed in this work. The design process is broken down into two steps, the first of which began with the creation of a fundamental seed antenna that operates at a frequency of 5 GHz. Modifications that have been made since then concentrate on the feed structure that has a full ground plane. The physical dimensions of the proposed antenna are indicated to be fifty millimetres by fifty millimetres by 1.6 millimetres. Additionally, the dielectric resonator (DRA) that is utilised has dimensions of twenty-six millimetres by twenty-six millimetres by thirteen megameters. The utilisation of this two-stage design technique makes it possible to optimise the performance of the antenna across the frequency ranges that are needed, while also taking into consideration practical constraints such as the characteristics of the substrate material and the overall size of the antenna. In order to ensure that the antenna has electromagnetic characteristics that are adequate for its operation, the selection of FR4 substrate, with its particular dielectric constant and loss tangent, is essential. Through careful engineering of the feed structure and dimensions of the antenna, the proposed SDRA is able to accomplish dual-band operation with better performance characteristics. This makes it appropriate for a variety of wireless communication applications that require antenna systems that are dependable and efficient.

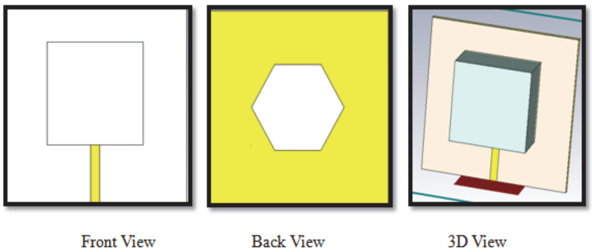

Figure 1 Hexa-slotted hybrid rectangular DRA

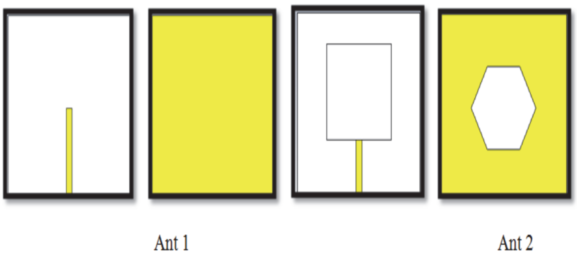

Figure 2 Hexa-slotted hybrid rectangular DRA evolution stages

Ant 1 and Ant 2 are the names given to the two stages of development that the Slotted Dielectric Resonator Antenna (SDRA) that has been suggested goes through. In the beginning, Ant 1 is made up of a modest monopole with I-shape having microstrip feed that has a full ground plane. However, these components do not have impedance matching, which results in non-resonance. Following this, the final design contains modifications to the underlying construction and introduces a Dielectric Resonator Antenna (DRA) that is structured like a square. As a result of the fact that this antenna resonates throughout seven bands, especially at frequency of 5.09, 6.29, 6.99, 7.79, 8.29, 8.69, and 9.11 GHz, it is appropriate for use in applications that are associated with C band and X Band technology. A visual representation of the suggested antenna's forward-facing view, backward facing view, and standpoint view is presented in Fig. 1, which elucidates the design of the antenna. In the meantime, Fig. 2 illustrates the progression of the antenna from Ant 1 to the final design, demonstrating the gradual adjustments that were done in order to achieve resonance. Additionally, the parameters of the proposed hybrid DRA are accessible in Fig. 3, which delivers a complete overview of the several critical specifications of the hybrid DRA. Overall, the iterative design process and the incorporation of new aspects result in an antenna solution that is capable of working across numerous frequency bands. This solution is able to meet the unique requirements of communication systems in a variety of technological areas.

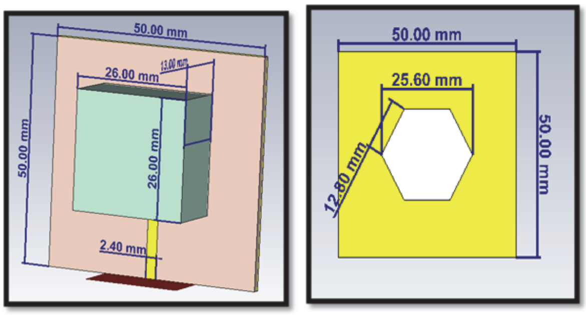

Figure 3 Hexa-slotted hybrid rectangular DRA parameter values

The designs of the microstrip array antenna at 28 GHz and the Substrate Integrated Waveguide (SIW) array antenna at 38 GHz are well-detailed, incorporating a thorough rationale for frequency selection and considerations for optimal performance. For the microstrip array antenna at 28 GHz, the selection of this frequency is likely based on several factors:

Available Spectrum: 28 GHz falls within the millimeter-wave frequency range, which is increasingly being explored for its potential in 5G and beyond-5G wireless communication systems. This frequency band offers ample available spectrum for high data rate transmission, making it attractive for next-generation wireless networks.

Propagation Characteristics: Millimeter-wave frequencies, including 28 GHz, exhibit unique propagation characteristics such as higher atmospheric attenuation and susceptibility to blockage by obstacles. However, these frequencies also offer shorter wavelengths, enabling the implementation of highly directional antennas and supporting high-capacity, short-range communication links.

The detailed designs of the microstrip array antenna at 28 GHz and the SIW array antenna at 38 GHz likely incorporate careful considerations of antenna geometry, feeding techniques, substrate materials, and manufacturing processes to achieve optimal performance within their respective frequency bands. These designs may leverage advanced simulation tools, such as electromagnetic modeling software, to fine-tune antenna parameters and ensure compliance with performance requirements and specifications. Additionally, factors such as antenna size, radiation pattern, polarization, and beam steering capabilities may also influence the design process to meet specific application needs and performance objectives.

4 RESULTS AND DISCUSSION

An illustration of Ant 2's operation spanning 7 bands with resonances at 5.09, 6.29, 6.99, 7.79, 8.29, 8.69, and 9.11 GHz is presented in Fig. 4, which depicts the return loss plot of Ant 2. The Voltage Standing Wave Ratio (VSWR) of the proposed antenna is illustrated in Fig. 5. This figure shows that the VSWR values are below 3 over the whole resonating frequency of operating bands. The microstrip feed that has a hexangular ring is subjected to a thorough analysis, and the feed length is optimised using iterative design techniques in order to couple electromagnetic (EM) energy into the Dielectric Resonator Antenna (DRA) in an effective manner. In addition, the implementation of the hexagonal slot results in an increase in the impedance bandwidth of the resonating bands. This is because the slot has been optimised to fit all seven operational bands. An assessment plot between the two evolution stages is shown in Fig. 6. This plot highlights the impact that the DRA and hexagonal slot have on the performance of the antenna throughout a variety of frequency bands. By comparing Ant 1 with Ant 2, this comparison highlights the critical impact that the DRA and slot configuration play in enabling the antenna to operate across several bands. It also indicates the improvement that was made in terms of resonance characteristics and bandwidth utilisation.

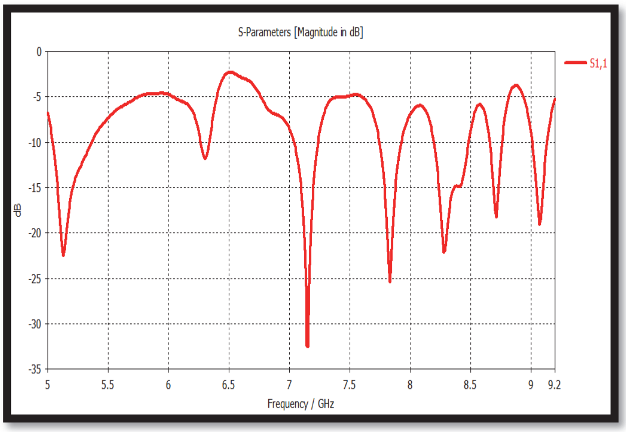

Figure 4 Hexa-slotted hybrid rectangular dra return loss plot

Fig. 4 displays the return loss plot of Ant 2, illustrating its operation across seven bands with resonances at 5.1GHz, 6.3 GHz, 7.1 GHz, 7.8 GHz, 8.3 GHz, 8.7 GHz, and 9.07 GHz. In Fig. 5, the Voltage Standing Wave Ratio (VSWR) of the proposed antenna is depicted, indicating VSWR values below 3 throughout the resonating band.

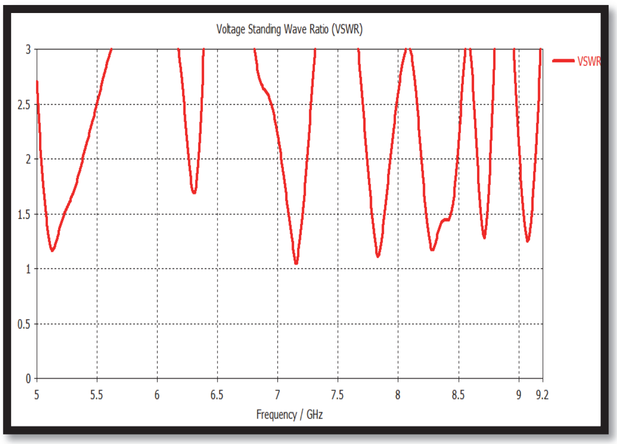

Figure 5 Hexa-slotted hybrid rectangular dra vswr plot

The microstrip feed with a hexagonal ring undergoes rigorous analysis, with the feed length optimized via iterative design procedures to efficiently couple electromagnetic (EM) energy into the Dielectric Resonator Antenna (DRA). Additionally, the introduction of the hexagonal slot enhances the impedance bandwidth of the resonating bands, with the slot optimized to accommodate the seven operating bands. Fig. 6 presents a comparison plot between Ant 1 and Ant 2, highlighting the impact of the DRA and hexagonal slot on the antenna's performance across different frequency bands. This comparison underscores the significant role played by the DRA and slot configuration in enabling the antenna's multi-band operation and illustrates the improvement achieved in terms of resonance characteristics and bandwidth utilization from Ant 1 to Ant 2.

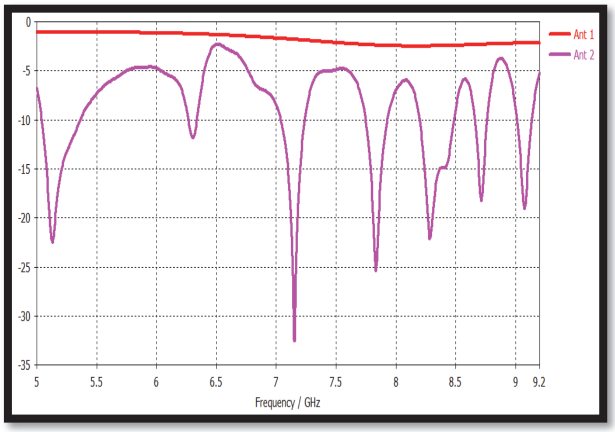

Figure 6 Return loss comparison plot of two evolution stages

A representation of the surface current distribution across a range of resonant frequencies can be found in Fig. 7. Specifically, it demonstrates that the surface current is primarily centred on the rectangular patch, which makes it easier for electromagnetic energy to be coupled into the Dielectric Resonator Antenna (DRA). Inductance and capacitance are produced, respectively, by the existence of the hexangular slot and the hexangular ring at the bottommost and upperpart of the substrate, respectively.

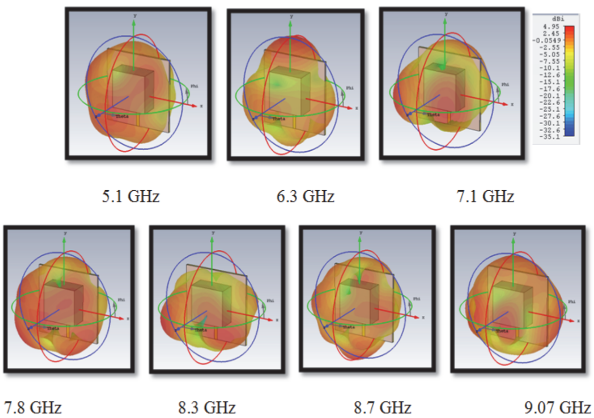

Figure 7 Hexa-slotted hybrid rectangular DRA radiation pattern (in GHz)

Within the structure of the antenna, these components are responsible for the production of novel resonance phenomena thanks to their contributions. This visual representation of the surface current distribution sheds light on the mechanisms that are responsible for the operation of the antenna and draws attention to the role that particular geometric features play in determining the electromagnetic characteristics of the antenna. Fig. 7 illustrates the radiation pattern of the proposed Dielectric Resonator Antenna (DRA) across different resonating frequencies, exhibiting an omnidirectional pattern essential for various wireless communication scenarios.

Fig. 8 showcases the gain performance of the DRA, demonstrating gains exceeding 2 dBi across all resonating bands. Additionally, Fig. 9 presents the directivity plotted against the frequency of operation, revealing that the directivity remains consistently above 4.5 across all resonating bands. These figures collectively underscore the antenna's favorable radiation characteristics, high gain, and robust directivity, highlighting its suitability for a wide range of wireless communication applications.

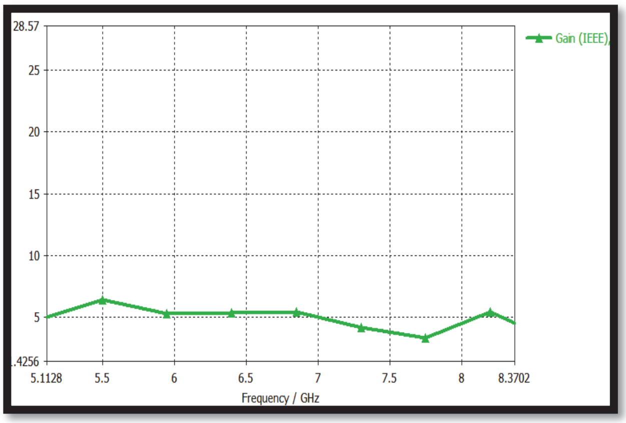

Figure 8 Hexa-slotted hybrid rectangular DRA ground gain

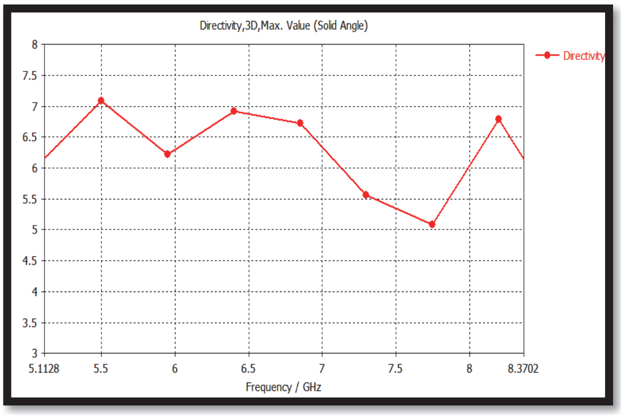

Figure 9 Hexa-slotted hybrid rectangular DRA directivity

The simulation results for the proposed microstrip patch antenna and the SIW antenna are compared here for the first time. Tab. 1 shows this contrast. It presents the results of an examination and comparison between the suggested SIW antenna design and the aforementioned research articles and reference document.

Table 1 Microstrip patch antenna versus proposed antenna comparison

Parameter	Single element		Antenna array	
	Patch	SW	Patch	SW
Frequency / GHz	28, 38	28, 38	28, 38	28, 38
Returnloss / dB	–17.61, –14.62	–18.841, –20.159	–22.32, –15.59	–13.70, –30.129
Bandwidth / %	2.43, 3.30	3.2, 1.3	3.22, 3.33	1.8, 2.06
Efficiency / %	76.96, 89.86	94.90, 89.14	82.41, 81.94	90.48, 83.78

5 CONCLUSIONS

The purpose of this paper is to provide a novel hybrid Dielectric Resonator Antenna (DRA) design that incorporates a DR that is fed by a ring patch over a microstrip feed method. Incorporating a hexagonal slot alteration into the ground construction is another feature. While the slot improves impedance bandwidth, the combination of the hexagonal ring and the DR makes it possible to operate across seven different bands. 5.09, 6.29, 6.99, 7.79, 8.29, 8.69, and 9.11 GHz are the frequencies at which resonances can be found. The suggested antenna displays promising performance for a variety of wireless communication applications, as it has gains that are greater than 1.9 dBi and directivity that remains greater than 4 across the seven operating frequency bands.

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Contact information:

M. MANIKANDAN, Assistant Professor
(Corresponding Author)
Department of Electronics and Communication Engineering,
SSM Institute of Engineering and Technology,
Dindigul-624002, Tamilnadu, India
E-mail: manisece910@gmail.com

S. PRASAD JONES CHRISTYDASS, Assistant Professor,
Department of ECE,
SRM Institute of Science and Technology,
Kattankulathur, Chennai, Tamilnadu-603203, India
Email: prasadjc@srmist.edu.in

R. SARAVANAKUMAR, Associate Professor
Department of ECE Saveetha School of Engineering,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University Chennai India 602105
E-mail: saravanakumarr.sse@saveetha.com

S. ALAMELU ALIAS RAJASREE, Assistant Professor
Department of Electronics and Communication Engineering,
Sri Ramakrishna Engineering College,
Coimbatore 641021, Tamilnadu, India
E-mail: alamelurajasree.s@srec.ac.in