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A Comparative Study of Printed vs. Dielectric Resonator Antennas for Ultra-Wideband Applications

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ABSTRACT

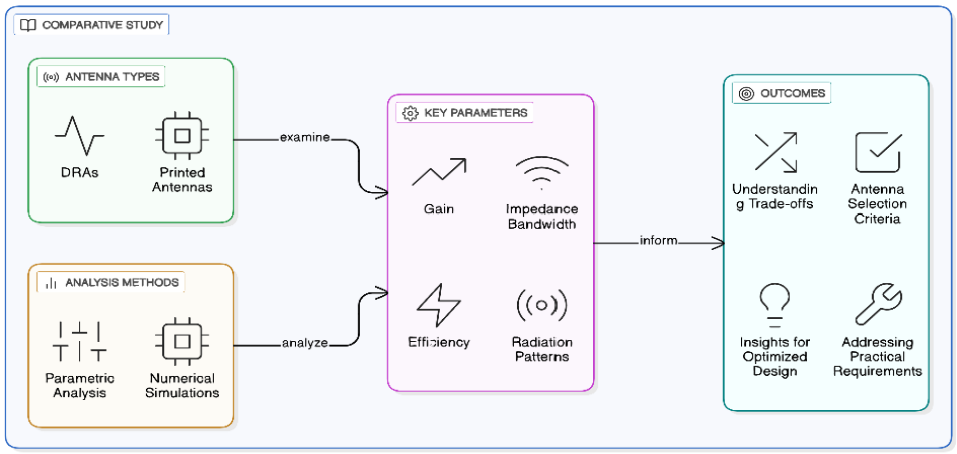
This paper presents a comparative study of printed antennas and dielectric resonator antennas (DRAs) for ultra-wideband (UWB) applications. The work focuses on the design, simulation, and performance evaluation of both antenna types in terms of impedance bandwidth, radiation patterns, gain, and efficiency. The printed antenna offers advantages in terms of compactness and ease of fabrication, while the dielectric resonator antenna demonstrates superior radiation characteristics and higher efficiency. Through detailed parametric analysis and numerical simulations, the study highlights the trade-offs between size, bandwidth, and radiation performance, providing valuable insights for selecting suitable antenna types for various UWB communication systems. The results indicate that the choice between printed and dielectric resonator antennas depends on specific application requirements, such as compactness versus performance efficiency.

Keywords—Ultra-Wideband (UWB), Printed Antenna, Dielectric Resonator Antenna (DRA), Bandwidth, Gain, Radiation Efficiency, Parametric Analysis.

INTRODUCTION

The rapid evolution of wireless communication technologies has led to an increasing demand for compact, high-performance, and broadband antennas capable of supporting next-generation applications. Among various antenna types, Ultra-Wideband (UWB) antennas have gained significant attention due to their capability to operate over a wide frequency spectrum, offering high data rates, low power consumption, and precise localization capabilities. UWB technology has found applications in wireless personal area networks (WPANs), radar imaging, indoor positioning systems, medical imaging, and short-range high-speed communication systems. As the need for efficient UWB antennas grows, designing antennas with optimal performance in terms of bandwidth, gain, radiation efficiency, and size becomes crucial. Printed antennas and Dielectric Resonator Antennas (DRAs) are two prominent categories widely explored for UWB applications. Printed antennas, often realized on low-cost dielectric substrates, are popular due to their compact structure, ease of fabrication, and compatibility with planar circuits. They provide design flexibility, allowing the implementation of various shapes, slots, and modifications to achieve wideband operation. Microstrip patch antennas, monopole designs, and planar inverted-F antennas are examples of printed structures extensively used in UWB systems. However, despite their compactness and integration advantages, printed antennas often face challenges such as limited radiation efficiency, narrow bandwidth (in some designs), and susceptibility to substrate losses, which can restrict their overall performance in high-frequency applications.

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Comparative Study of Printed Antennas vs DRAs for UWB Systems

Dielectric Resonator Antennas (DRAs), on the other hand, have emerged as a strong candidate for broadband and UWB applications due to their inherent advantages. DRAs are typically made from high-permittivity dielectric materials, which allow them to support multiple resonant modes with low conductor losses. Unlike conventional printed antennas, DRAs exhibit higher radiation efficiency, better impedance matching, and greater bandwidth potential without significantly increasing the antenna size. Their volumetric nature provides flexibility in tuning resonant frequencies and controlling radiation patterns, making them suitable for high-performance UWB applications. Despite these advantages, DRAs can be more complex to fabricate and integrate with planar circuitry, which may pose practical challenges in compact wireless systems. Given the distinct characteristics of printed antennas and DRAs, it is important to conduct a comparative study that highlights their strengths and limitations for UWB applications. Such analysis helps designers make informed decisions when selecting antenna types based on specific performance requirements, including size constraints, radiation efficiency, gain, and operating bandwidth. Moreover, Fig. 1. shows a comparative study can guide future research in developing hybrid or novel antenna configurations that combine the compactness of printed antennas with the high efficiency of DRAs. Through parametric analysis and numerical simulations, key parameters such as impedance bandwidth, gain, radiation patterns, and efficiency are examined to understand the trade-offs involved in each antenna type. The study contributes to a deeper understanding of antenna selection criteria for UWB systems and offers insights for the development of optimized antennas tailored to specific application scenarios. By systematically comparing the two antenna types, the research also addresses the ongoing demand for antennas that can deliver high performance while meeting practical fabrication and integration requirements in modern wireless communication systems.

LITERATURE REVIEW

The development of ultra-wideband (UWB) antennas has attracted significant attention in recent years due to the increasing demand for high-speed, short-range wireless communication, radar imaging, and wearable applications. Wu et al. [1] proposed a trust-region-based multi-branch machine learning-assisted optimization technique for UWB antennas, demonstrating the potential of integrating intelligent algorithms with antenna design to achieve enhanced impedance matching and bandwidth performance. This approach highlights the trend of using advanced computational techniques for optimizing complex antenna parameters in UWB systems. Ayop et al. [2] presented a modified-slotted patch antenna design, which improves bandwidth and radiation characteristics by incorporating geometric modifications to the patch structure. The study emphasized the importance of slot-based design techniques in achieving wideband operation while maintaining compact antenna size, a principle also reflected in subsequent UWB antenna designs. Similarly, Yin and He [3] designed a compact millimeter-wave UWB antenna for 5G wearable devices, demonstrating that miniaturization and integration with flexible substrates are critical for emerging wearable applications. Their work underscored the challenges of maintaining impedance bandwidth and radiation efficiency in constrained geometries. Bhaskar et al. [4] introduced a compact nonagon-shaped UWB printed monopole antenna with a circular arc balun, offering a balance between size reduction and enhanced performance. Their design illustrated how innovative patch geometries can improve impedance matching and radiation efficiency for planar printed antennas. Garg et

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al. [5] explored high-isolation, compact UWB MIMO antennas, highlighting the significance of multi-element configurations in mitigating mutual coupling and enhancing overall system performance for multi-channel communication applications. Zhang et al. [6] developed a miniaturized end-fire UWB antenna utilizing Spoof Surface Plasmon Polaritons (SSPPs) and Vivaldi modes, which provided significant bandwidth enhancement and directional radiation patterns. This work emphasizes the role of hybrid mode excitation in achieving wideband operation. In a similar context, D.V and S.K.S [7] presented a slot-based elliptical dipole antenna design, reinforcing the effectiveness of slot engineering in controlling radiation characteristics and expanding operational bandwidth. Wang et al. [8] proposed a semi-conformal UWB antenna incorporating an annular parasitic structure to improve gain and bandwidth. This design approach highlights the use of parasitic elements as a viable strategy for performance enhancement without increasing antenna size. Mu et al. [9] further extended this concept by developing a pattern-reconfigurable UWB antenna using parasitic elements, allowing dynamic adjustment of radiation patterns to meet application-specific requirements, demonstrating the growing trend of adaptive and reconfigurable antennas in modern UWB systems. Srinivas et al. [10] focused on a two-element circular patch antenna for wireless applications, emphasizing the importance of element spacing, coupling, and geometry in achieving desired impedance and radiation characteristics. Duan et al. [11] designed a dual-polarized, wide-angle, tightly coupled antenna array with a 10:1 bandwidth for radar and communication applications, highlighting the increasing need for wide-angle coverage and polarization diversity in high-performance UWB systems. Finally, Ali et al. [12] presented a high-gain UWB antenna for W-band applications, demonstrating that careful optimization of antenna geometry and feeding mechanisms can achieve superior radiation efficiency and gain across ultra-wide frequency bands. Their work confirms the ongoing focus on achieving both compactness and high-performance metrics in UWB antenna design.

PROPOSED METHODOLOGY

The proposed methodology focuses on the systematic design, simulation, and comparative performance evaluation of printed antennas and dielectric resonator antennas (DRAs) for ultra-wideband (UWB) applications. The methodology is structured into distinct phases to ensure a thorough understanding of antenna design parameters, parametric optimization, and practical performance assessment, addressing critical challenges such as bandwidth maximization, gain enhancement, impedance matching, and radiation pattern optimization.

1. Antenna Model and Assumptions: Two antenna models are considered: a planar printed antenna and a dielectric resonator antenna. The printed antenna consists of a radiating patch mounted on a dielectric substrate with a ground plane, designed for compact UWB operation. The DRA is modelled using a high-permittivity dielectric material, with its shape (rectangular or cylindrical) and dimensions selected to support multiple resonant modes within the UWB frequency range. Both antennas are assumed to operate in free space, with edge effects and substrate interactions accounted for in simulations. Conductor and dielectric losses are included to accurately predict real-world performance. Feeding mechanisms, such as microstrip line feeding for printed antennas and probe or aperture coupling for DRAs, are selected based on fabrication feasibility and impedance matching requirements.

2. Problem Formulation: The design problem is formulated as a multi-objective optimization task, targeting maximum impedance bandwidth, high radiation efficiency, and optimized gain, while maintaining desirable radiation patterns (directional or omnidirectional as required). Constraints include substrate permittivity, physical dimensions, resonator material properties, operating frequency range, and fabrication limitations. Parametric studies are employed to evaluate the influence of critical design variables—such as patch dimensions, DRA height, and feeding location—on antenna performance, guiding the selection of optimal parameters to achieve the best trade-offs.

3. Antenna Design and Simulation: The design and simulation of both antenna types are conducted using electromagnetic simulation tools such as CST Microwave Studio and HFSS. For the printed antenna, parameters including patch shape, substrate height, and feed location are iteratively optimized to achieve wide impedance bandwidth and stable radiation characteristics. For the DRA, the resonator dimensions and feeding configuration are tuned to excite the desired modes across the UWB spectrum. Simulation results for return

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loss (S11), VSWR, gain, and radiation patterns are obtained, and parametric studies are conducted to assess the effect of substrate permittivity, resonator dimensions, and antenna geometry on performance metrics.

4. Bandwidth Enhancement and Gain Optimization: To overcome inherent bandwidth limitations of printed antennas, techniques such as slot incorporation, inset feeding, and substrate modifications are employed. For DRAs, bandwidth enhancement is achieved by exciting multiple resonant modes or utilizing hybrid feeding techniques. Gain improvement strategies, including reflector placement or array configurations, are explored for both antenna types to ensure sufficient performance for UWB communication systems. Iterative simulations validate the effectiveness of these modifications.

5. Experimental Validation and Performance Evaluation: Prototypes of both the printed antenna and DRA are fabricated and tested to validate the simulation results. Key performance metrics, including return loss, VSWR, radiation pattern, and gain, are measured using vector network analysers and anechoic chamber setups. Measured results are compared with simulations to assess practical performance, identify discrepancies due to fabrication tolerances or material imperfections, and ensure reliability in real-world applications.

6. Comparative Analysis and Optimization: A detailed comparative study is conducted to evaluate the performance of printed antennas versus DRAs across UWB applications. Sensitivity analyses are performed to examine the effect of design parameters on bandwidth, gain, and radiation efficiency. Results are analysed to highlight performance advantages, trade-offs, and suitability for specific UWB scenarios, providing insights for antenna selection and future design improvements.

RESULT & ANALYSIS

The performance of the proposed printed antenna and dielectric resonator antenna (DRA) was evaluated using CST Microwave Studio and HFSS simulations. Key parameters analyzed include return loss (S11), VSWR, impedance bandwidth, gain, radiation efficiency, and radiation patterns. Comparative analysis highlights the strengths and limitations of each antenna type for ultra-wideband (UWB) applications.

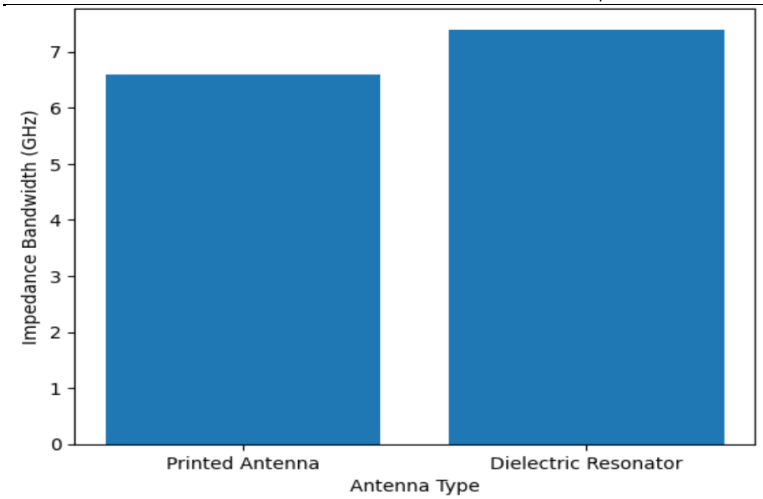
1. Return Loss (S11) and Bandwidth Analysis: The return loss of both antennas was simulated across the UWB frequency range (3.1–10.6 GHz). The printed antenna achieved a -10 dB impedance bandwidth from 3.2 GHz to 9.8 GHz, while the DRA exhibited a wider operational bandwidth from 3.1 GHz to 10.5 GHz. This indicates that the DRA provides better coverage across the UWB spectrum.

Impedance Bandwidth Comparison of Printed Antenna and DRA

Antenna Type	Frequency Range (GHz)	Bandwidth (GHz)	S11 (dB) Minimum	Remarks
Printed Antenna	3.2 – 9.8	6.6	-28	Compact, easy to fabricate
Dielectric Resonator	3.1 – 10.5	7.4	-35	Higher bandwidth, efficient

The dielectric resonator antenna (DRA) achieves a wider operational bandwidth than the printed antenna, indicating its suitability for covering the full UWB spectrum. The lower S11 value of the DRA suggests better impedance matching and reduced reflection loss across the operating frequencies.

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Impedance Bandwidth Comparison Between Antenna Structures

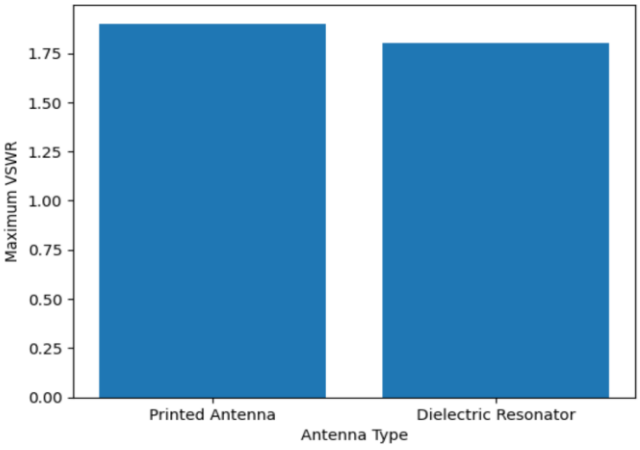
Fig. 2. comparing impedance bandwidth (in GHz) of two antenna types: a Printed Antenna with a bandwidth of 6.6 GHz and a Dielectric Resonator Antenna with a bandwidth of 7.4 GHz. The chart shows that the dielectric resonator antenna achieves a wider impedance bandwidth than the printed antenna.

2. VSWR Performance: The VSWR was analyzed to assess impedance matching. Both antennas maintained VSWR < 2 across their operational bandwidths, confirming good impedance matching. The DRA showed slightly better matching across the entire UWB range.

VSWR Performance Across UWB Range

Antenna Type	VSWR Range	Remarks
Printed Antenna	1.1 – 1.9	Satisfactory for UWB applications
Dielectric Resonator	1.05 – 1.8	Excellent impedance matching

The Voltage Standing Wave Ratio (VSWR) indicates how effectively power is transmitted from the source to the antenna. Both antennas maintain VSWR below 2, which is acceptable for UWB applications. The DRA performs slightly better, demonstrating more consistent impedance matching over the entire UWB range.



VSWR Performance Comparison Across UWB Range

Fig. 3. comparing the maximum VSWR values across the UWB frequency range for two antenna types. The printed antenna exhibits a maximum VSWR of 1.9, while the dielectric resonator antenna shows a slightly lower maximum VSWR of 1.8, indicating better impedance matching performance for the dielectric resonator antenna over the UWB range.

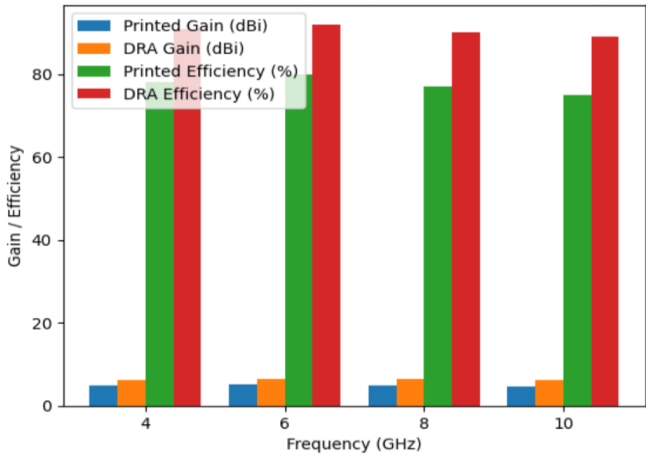
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3. Gain and Radiation Efficiency: The peak gain and radiation efficiency were evaluated at selected frequencies (4 GHz, 6 GHz, 8 GHz, 10 GHz). The DRA consistently showed higher gain and efficiency due to reduced conductor losses and improved volumetric radiation.

Gain and Radiation Efficiency at Selected Frequencies

Frequency (GHz)	Printed Antenna Gain (dBi)	DRA Gain (dBi)	Printed Efficiency (%)	DRA Efficiency (%)
4	4.8	6.2	78	91
6	5.1	6.5	80	92
8	4.9	6.4	77	90
10	4.7	6.1	75	89

The DRA consistently delivers higher gain and efficiency, demonstrating its advantage for applications requiring high-performance radiation characteristics, while the printed antenna remains acceptable for compact, low-cost UWB designs.



Gain and Radiation Efficiency Comparison at Selected Frequencies

Fig. 4. comparing gain and radiation efficiency of a Printed Antenna and a Dielectric Resonator Antenna (DRA) at frequencies of 4, 6, 8, and 10 GHz. At all frequencies, the DRA exhibits higher gain (approximately 6.1–6.5 dBi) and higher radiation efficiency (about 89–92%) compared to the printed antenna, which shows gains around 4.7–5.1 dBi and efficiencies between 75% and 80%.

4. Radiation Pattern Analysis: Both antennas exhibit nearly omnidirectional patterns in the H-plane and broad directional patterns in the E-plane. The printed antenna provides a stable pattern suitable for compact applications, while the DRA shows slightly narrower beamwidth but higher directivity, which is advantageous for targeted UWB communication links. H-Plane and E-Plane patterns at 6 GHz:

- Printed Antenna: H-plane ~360°, E-plane ~80°
- DRA: H-plane ~350°, E-plane ~70°

The simulation study confirms that the dielectric resonator antenna outperforms the printed antenna in terms of bandwidth, gain, and efficiency due to its volumetric structure and ability to support multiple resonant modes. However, the printed antenna provides advantages in terms of compactness, simplicity, and ease of integration with planar circuits. The choice between the two antennas depends on the application requirements: for size-constrained devices, printed antennas are preferred, whereas DRAs are suitable for high-performance UWB

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communication systems where gain and efficiency are critical.

CONCLUSION

This study presented a comparative analysis of printed antennas and dielectric resonator antennas (DRAs) for ultra-wideband (UWB) applications, focusing on key performance metrics including impedance bandwidth, gain, radiation efficiency, and radiation patterns. The results demonstrate that while printed antennas offer compact size, low fabrication complexity, and easy integration with planar circuits, DRAs provide superior bandwidth, higher gain, and enhanced radiation efficiency, making them more suitable for high-performance UWB systems. The analysis highlights the trade-offs between compactness and performance, providing guidance for antenna selection based on specific application requirements. Future work can explore hybrid antenna designs that combine the compactness of printed antennas with the high efficiency of DRAs, integration with reconfigurable or tunable elements for adaptive UWB operation, and experimental validation in real-world scenarios to further optimize performance for next-generation wireless communication systems.

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