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A Novel Radial Corrugated Vivaldi Antenna for UWB Applications and Enhanced Gain

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Abstract

The increasing demand for high-speed wireless communication has intensified the need for compact and efficient planar antennas that can be seamlessly integrated into modern electronic systems. This study presents a novel microstrip-fed profiled planar antenna, which enhances the conventional Vivaldi antenna design by introducing radial corrugations. These structural modifications significantly improve antenna performance by suppressing surface waves, enhancing radiation directivity, and increasing gain. Full-wave electromagnetic simulations were conducted using a professional solver, and the design was validated through physical fabrication and testing. The antenna, constructed on a 1.6 mm thick FR4 substrate and measuring 89.35 × 52.46 mm^2, was evaluated in an anechoic chamber. Results demonstrate a broad operating bandwidth from 3 GHz to 11 GHz and a peak gain of 12.03 dBi. Our study also highlights the importance of radial spacing and the symmetric placement of 24 corrugations, which contribute to gain enhancement by improving current uniformity and minimizing edge diffractions. Comparative analysis between simulated and measured return loss (S11) and gain values shows strong agreement, validating the accuracy of the design process. Furthermore, performance was consistently assessed at each UWB frequency point (from 3 to 11 GHz in 1 GHz steps), confirming stable high-gain behavior across the entire UWB range. This antenna design holds strong potential for advanced UWB communication systems requiring high efficiency and wideband performance.

Keywords: Antenna Design, Miniaturization, Tapered Slot Antenna Vivaldi, Ultra-wideband (UWB), Wireless Communication.

Introduction

The demand for high-performance, broadband, and high-gain antennas has significantly increased in both civilian and military sectors. Applications such as high-speed wireless communication, satellite systems, radio astronomy, and microwave imaging require antennas that are compact, reliable, and capable of operating across wide frequency ranges. Among various types, printed antennas, especially Tapered Slot Antennas (TSAs), have gained popularity due to their flat structure, easy fabrication, low cost, and excellent bandwidth performance. TSAs are particularly useful in Ultra-Wideband (UWB) systems. They are known for their simple structure, directional radiation, and wide impedance bandwidth. At lower frequencies, TSAs behave as resonant antennas, while at higher frequencies, they operate as traveling-wave antennas. The tapered slot helps in guiding the wave smoothly, allowing efficient radiation. However, traditional TSA designs—such as the widely used Vivaldi antenna (a type of Exponentially Tapered Slot Antenna or ETSA)—face certain performance issues at high frequencies. These include reduced gain due to surface wave excitation, flare-induced current spreading, and uneven field distribution in the aperture. To address these issues, this paper proposes a radial corrugated Vivaldi antenna. The design uses parametric optimization in HFSS to minimize surface wave propagation and to improve radiation directivity. The proposed method aims to enhance performance, especially at higher frequencies where traditional designs fall short.

TSAs were originally introduced for mobile communication and radar due to their compact size and low cost (1). Over time, several TSA

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variants have been developed to overcome limitations and improve bandwidth and radiation properties. The common types include: (A) Linearly Tapered Slot Antenna (LTSA), (B) Constant Width Slot Antenna (CWSA), (C) Exponentially Tapered Slot Antenna (ETSA), also called Vivaldi TSA (VTSA) (2). So many VTSA design improvement techniques in available in literature (3). While the exponential taper in VTSA theoretically supports an extremely wide bandwidth, real-world performance depends on antenna size and how well the feed is matched (4). A common method to reduce unwanted radiation and simplify connector attachment is to place the feed line along the antenna's center (X-axis) (5).

In addition to LTSA, CWSA, and ETSA, many other profiles have been created to meet specific needs. Some notable variations include: Double Exponentially Tapered Slot Antenna (DETSA), Dual Polarized TSA (DPTSA)Logarithmic Tapered Slot Antenna (logTSA), Asymmetrical TSA (Asym-TSA), Chebyshev-profile TSA, Spidron Fractal TSA (SFTSA)(6-19). Each of these designs offers a different way of improving bandwidth, gain, or structural efficiency. Especially in wireless applications, antenna performance must be optimized for specific frequency bands (20). The VTSA remains a strong candidate for UWB systems, and many researchers are trying to make it more compact while keeping performance high. One of the major challenges is to combine small size with wide bandwidth and high gain (21-23).

In this work, we reviewed existing TSA variants like LTSA, CWSA, and ETSA—each with its own advantages in terms of radiation and bandwidth. What makes our approach unique is the combination of axial and radial corrugations, which has not been explored together in this way before. These structural modifications help suppress surface waves and improve the uniformity of radiation.

Figure 1 shows the three basic TSA profiles, and Figure 2 illustrates the transition from the traditional TSA to the newly proposed radial corrugated structure.

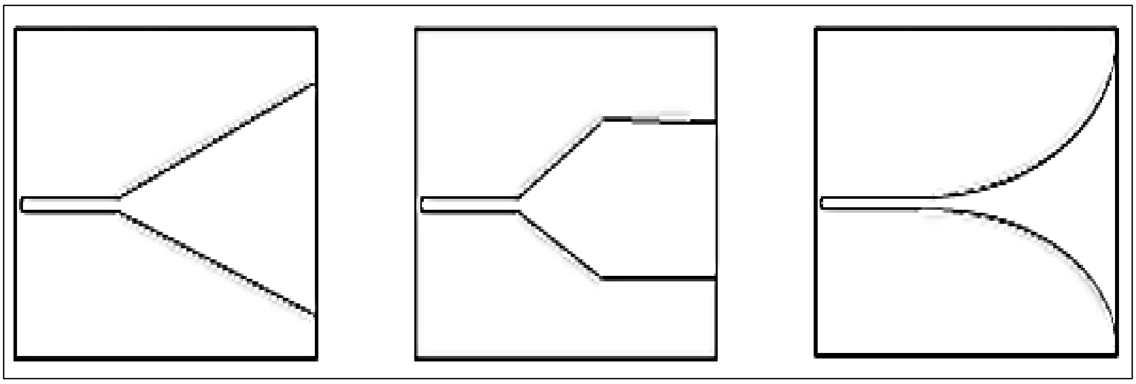

Figure 1: Tapered Slot Antenna TSA (A)LTSA, (B) CWSA, and (C) ETSA

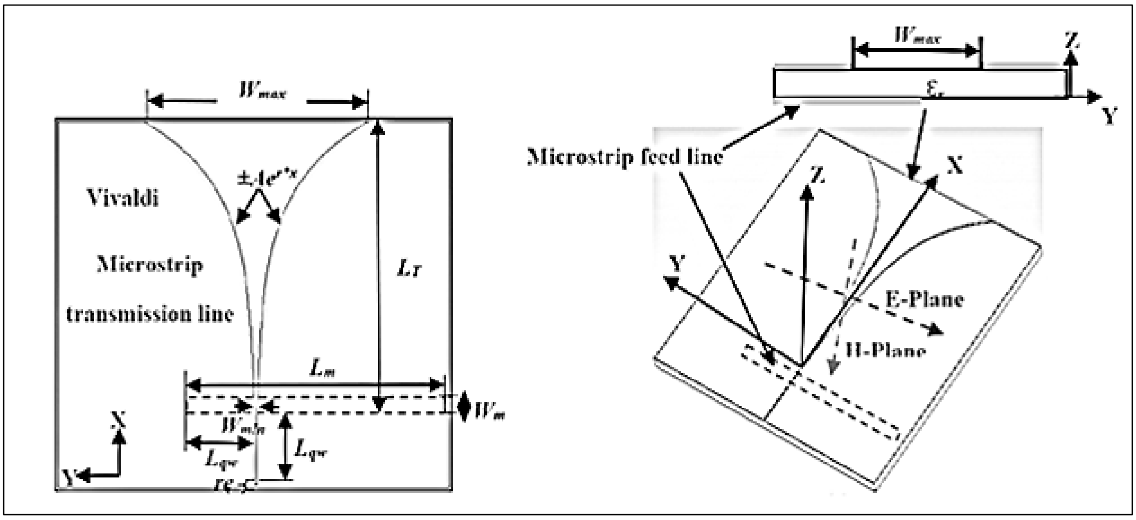

Figure 2: (A) Two Dimensional Geometry of TSA, (B) Three Dimensional Geometry of TSA

Methodology

Antenna Design

This section presents the detailed design process of a novel planar antenna intended for ultra-wideband (UWB) applications with improved gain and radiation characteristics. To meet these goals, a radial corrugated Vivaldi antenna was developed using High-Frequency Structure Simulator (HFSS) software.

The process began with the design of a conventional Vivaldi antenna in HFSS, as shown in Figure 3. While this initial model offered a wide impedance bandwidth, it did not meet the desired gain levels. Therefore, to enhance performance, the design was modified to include radial corrugations and additional structural features.

The proposed antenna was designed using parametric sweeps in HFSS. Key geometric parameters—such as slot length, corrugation gap, and cavity diameter—were iteratively optimized to achieve maximum performance across the UWB frequency band. Each parameter shown in Table 1, was varied systematically to observe its effect on antenna characteristics, enabling a fine-tuned balance between bandwidth and gain.

Based on insights from field simulations, a total of twenty-four symmetrically placed radial corrugations were introduced along the flare section of the antenna. These corrugations play a critical role in suppressing surface wave propagation, minimizing edge diffractions, and enhancing directional radiation.

In addition to geometrical optimization, surface current distribution plots and electric field simulations were employed to identify regions of maximum radiation. These electromagnetic field analyses were crucial in fine-tuning the antenna profile, ensuring that structural modifications resulted in meaningful performance improvements. To further optimize radiation characteristics, two circular slots were added near the mouth of the flare section, which helped refine the impedance matching and contributed to consistent gain across the operational bandwidth.

The finalized antenna geometry is presented in Figure 3, and the fabricated prototype is shown in Figure 4(A) (top view) and Figure 4(B) (bottom view). These Figures illustrate the structural layout, including the integration of corrugations and circular cavities that distinguish the proposed design from traditional Vivaldi antennas.

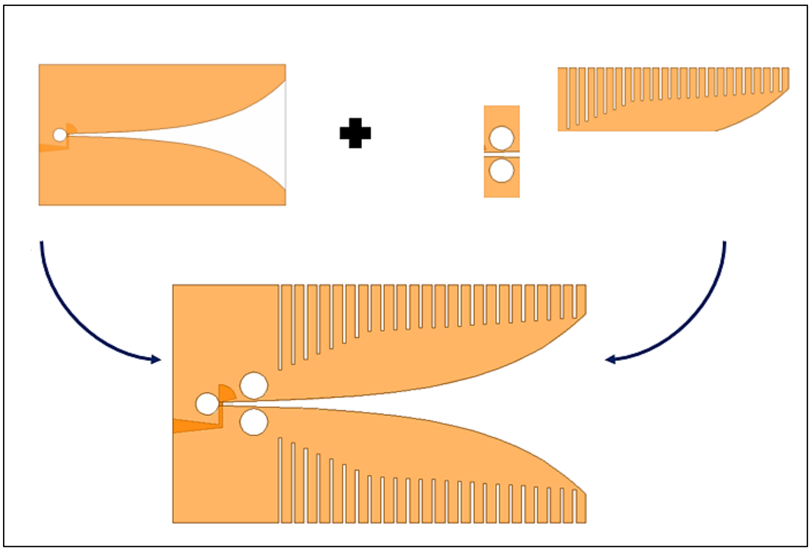

Figure 3: Evolution of the Proposed Radial Corrugated Profile Planar Antenna

Table 1: Parameters Used for the Proposed Invention

Sr. No	Description	Value
1	Width of the Flare at neck	0.8 mm
2	Substrate Length	89.35mm
3	Substrate Width	52.46 mm
4	Flare length	78.7mm
5	Length of aperture	41.02 mm
6	Cavity diameter	4.9mm

7	Distance from edge to first corrugation	22.75mm
8	Length of the tapered microstrip line	10.27 mm
9	Tapered microstrip line at port width	3 mm
10	Length of the tapered microstrip coupler	5.8 mm
11	Coupler Width	0.8mm
12	Radius of the microstrip stub	3mm
13	Stub Angle	80 deg
14	Corrugation Gap	2.75 mm
15	Substrate height	1.575mm
16	Dielectric constant of the substrate	4.4

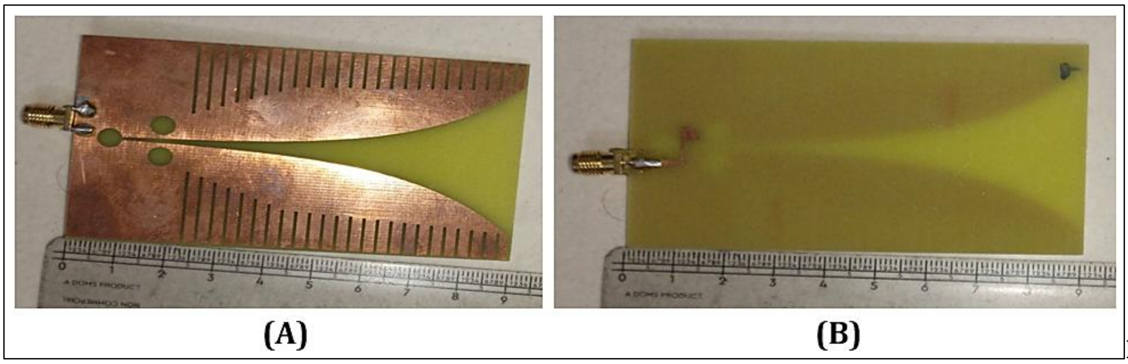

Figure 4: (A) Top View of Fabricated Axial and Radial Corrugated Profile Planner Antenna, (B) Bottom View of Fabricated Axial and Radial Corrugated Profile Planner Antenna

Fabrication and Experimental Setup

The proposed antenna was fabricated using an FR4 substrate, which has a dielectric constant of εr = 4.4 and a thickness of 1.6 mm. The overall antenna dimensions are 89.35 × 52.46 mm². The manufacturing process was carried out using standard PCB etching techniques to ensure accurate realization of the design, including its fine corrugation features. After fabrication, the antenna was tested in a professional anechoic chamber to evaluate its electromagnetic performance. A Vector Network Analyzer (VNA) was employed to measure the return loss (S11), and a rotating platform equipped with standard horn antennas was used to assess the radiation patterns and gain characteristics, as shown in Figure5 (A) and (B).

To ensure the repeatability and reliability of the measurements, three independent tests were conducted under identical conditions. The results across all trials exhibited high consistency, with a standard deviation in gain measurements of less than 0.25 dB, indicating excellent repeatability and fabrication precision.

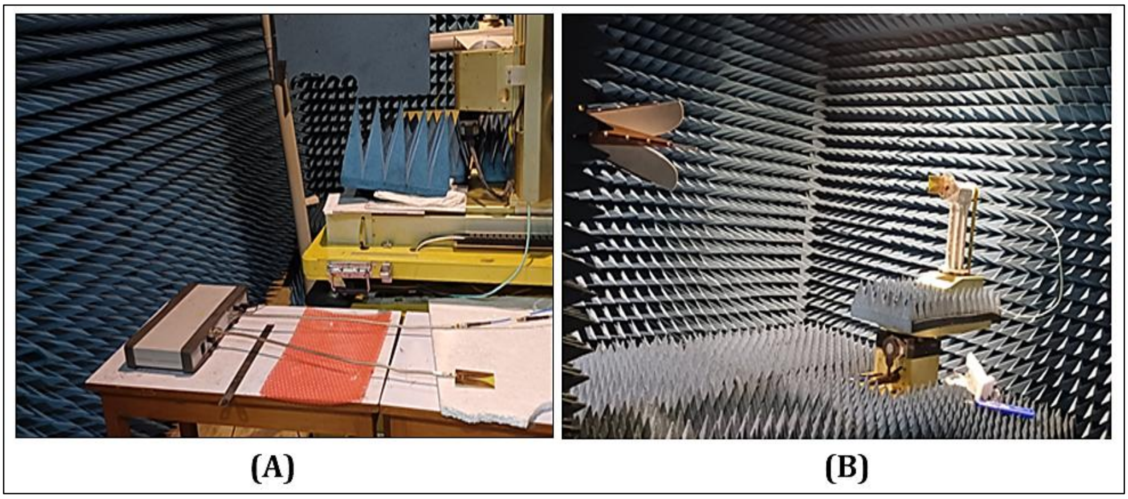

Figure 5: (A) Return Loss S_{11} Measurement Setup, (B) Gain and Radiation Pattern Measurement Setup

Results and Discussion

A comprehensive set of measurements and simulations was conducted to evaluate the performance of the proposed antenna. This section presents results related to return loss, radiation patterns, gain, surface current distribution, time-domain response, and cross-polarization behavior.

Return Loss Analysis

Figure 6 compares the simulated S11 of a conventional Vivaldi antenna and the proposed radial corrugated design. The conventional antenna shows effective bandwidth from 6 to 10 GHz, whereas the proposed design significantly extends this range to 3–11 GHz, demonstrating the impact of axial and radial corrugations in enhancing bandwidth. As the real time measurement is always required to analyze the performance of the antenna the proposed antenna is tested on VNA for return loss measurement and in anechoic chamber for radiation pattern and gain measurement. Figure 5(A) shows the VNA-based return loss measurement setup. The comparison between simulated and measured results is illustrated in Figure 7, where excellent agreement validates the simulation methodology.

Radiation Pattern Evaluation

Radiation patterns were measured at 1 GHz intervals from 3 GHz to 10 GHz, using the setup shown in Figure 5(B). Simulated patterns are shown in Figure 8(A) – 15(B), and their corresponding measured patterns appear in Figure 8(A), 15(B). The antenna demonstrates directional radiation patterns across the entire UWB range. The microstrip patch antenna always required directional radiation pattern. The proposed antenna gives directional radiation pattern for all frequency for both simulated and measured results. The gain remains consistent and stable, making it suitable for long-range and point-to-point communication applications.

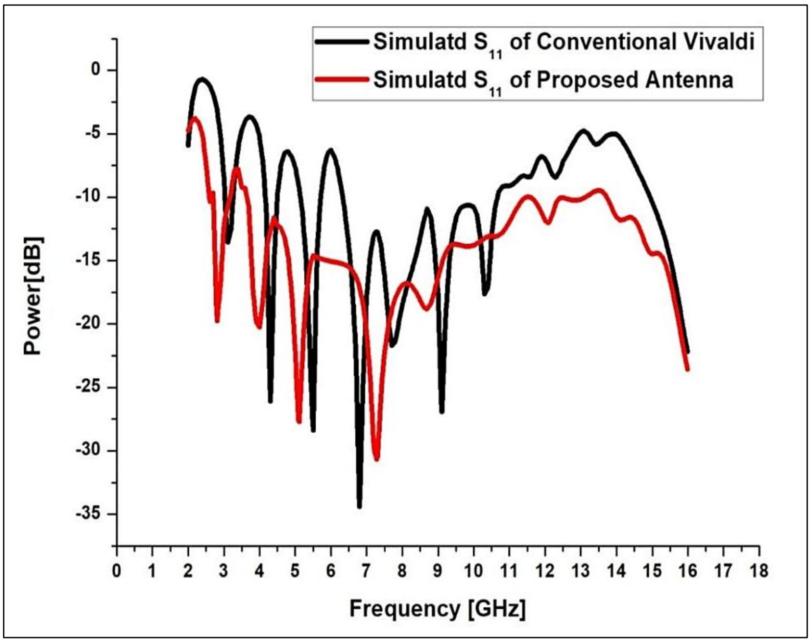

Figure 6: Simulated S11 Comparison of Conventional Vivaldi Antenna and Proposed Radial Corrugated Planar Antenna

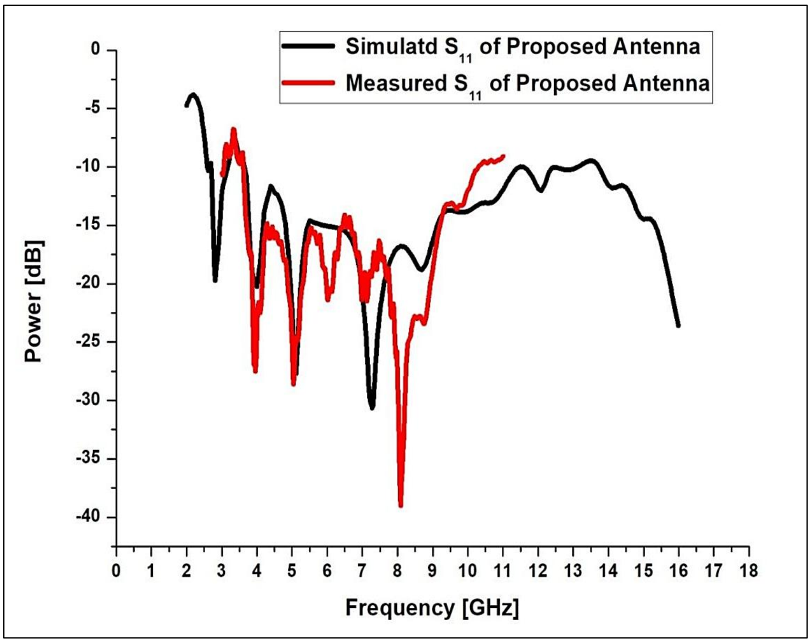

Figure 7: Comparison of Simulated and Measured S11 of Conventional Vivaldi Antenna and Proposed Radial Corrugated Planar Antenna

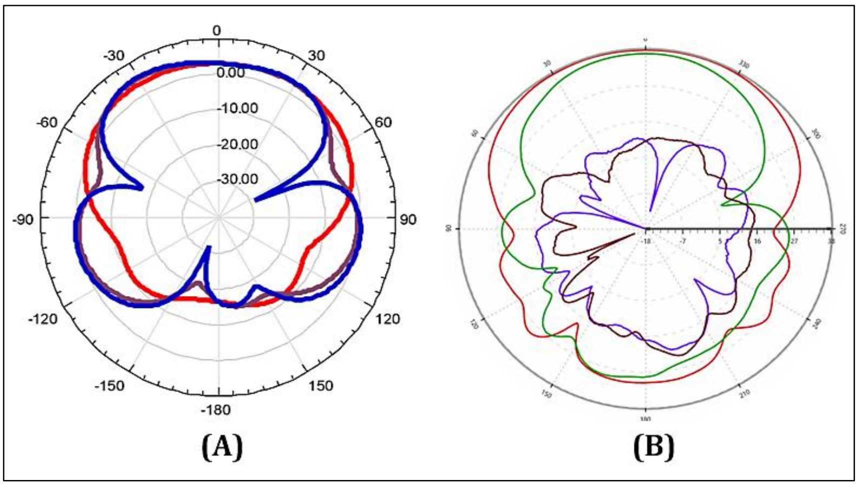

Figure 8: Radiation Patterns at 3 GHz: (A) Simulated, (B) Measured

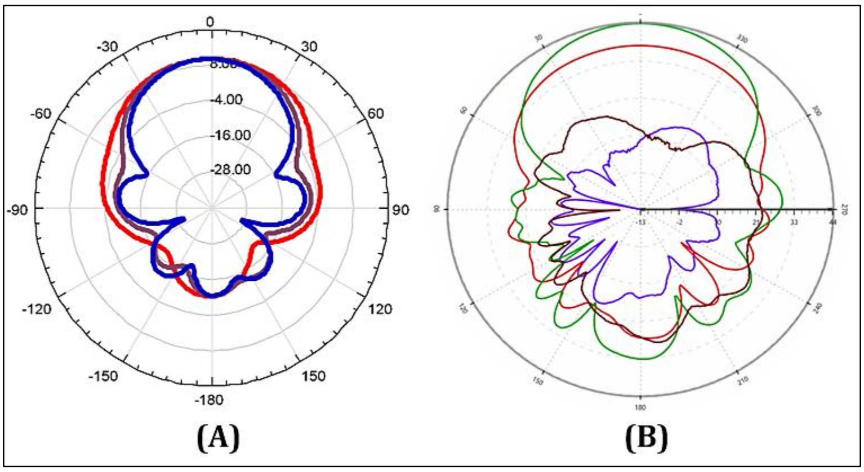

Figure 9: Radiation Patterns at 4 GHz: (A) Simulated, (B) Measured

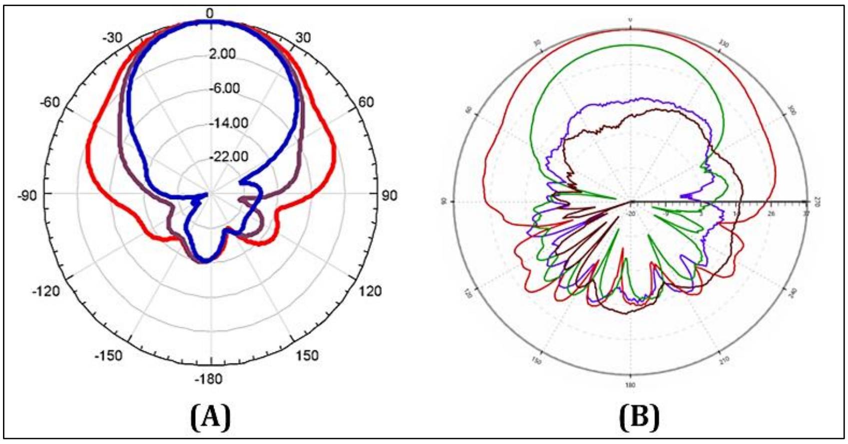

Figure 10: Radiation Patterns at 5 GHz: (A) Simulated, (B) Measured

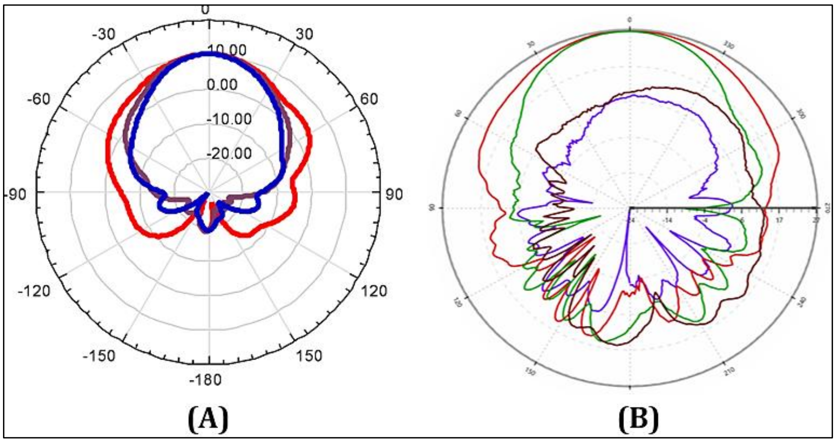

Figure 11: Radiation Patterns at 6 GHz: (a) Simulated, (b) Measured

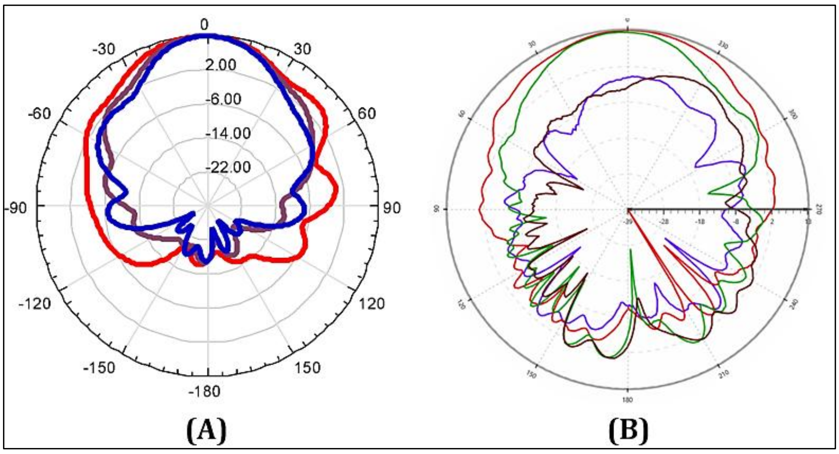

Figure12: Radiation Patterns at 7 GHz: (a) Simulated, (b) Measured

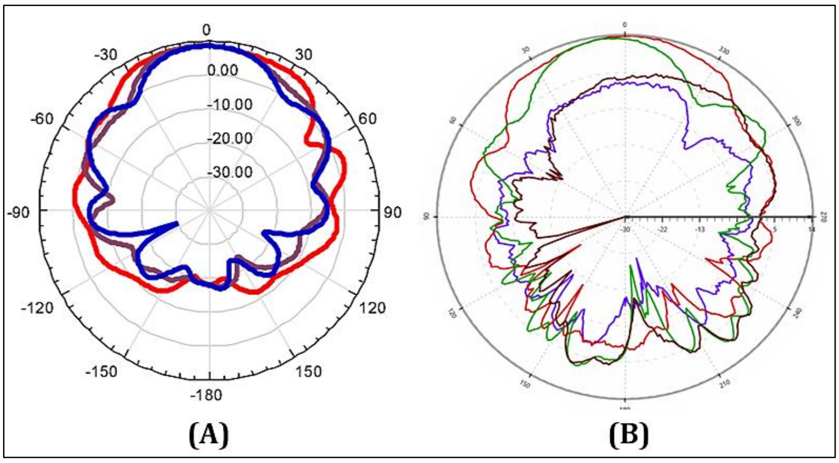

Figure 13: Radiation Patterns at 8 GHz: (A) Simulated, (B) Measured

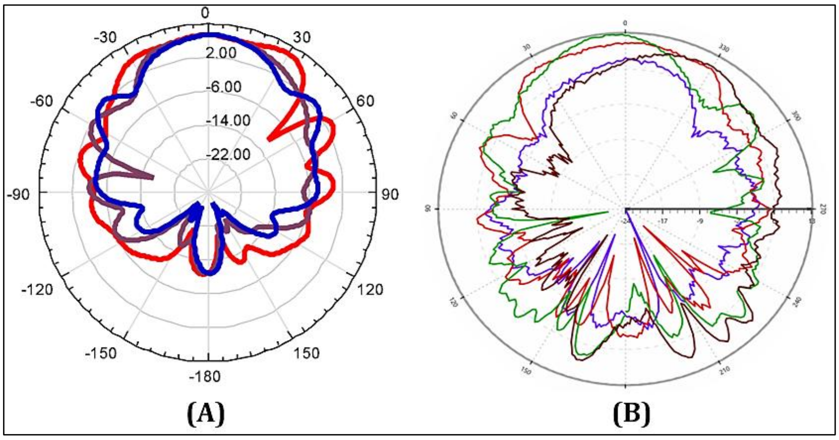

Figure 14: Radiation Patterns at 9 GHz: (A) Simulated, (B) Measured

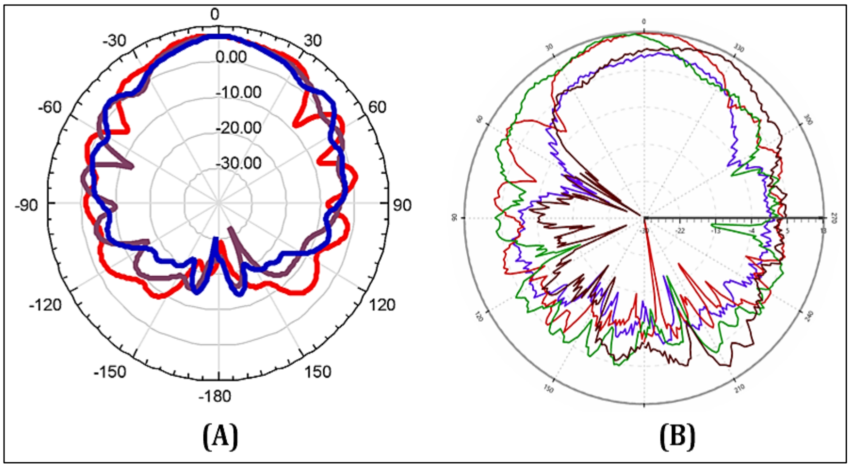

Figure 15: Radiation Patterns at 10 GHz: (A) Simulated, (B) Measured

Gain of Antenna at Different Radiating Frequency

Gain is a critical parameter for assessing antenna performance, as it directly influences the antenna's ability to transmit signals over long distances. For effective operation, an antenna must maintain sufficient gain across its operating frequency range. Figure 16 illustrates the gain performance across the UWB band. The antenna achieves a peak gain of 12.03 dBi and consistently maintains gain values above 7 dBi from 3 GHz to 11 GHz, making it highly suitable for wideband applications requiring strong signal strength.

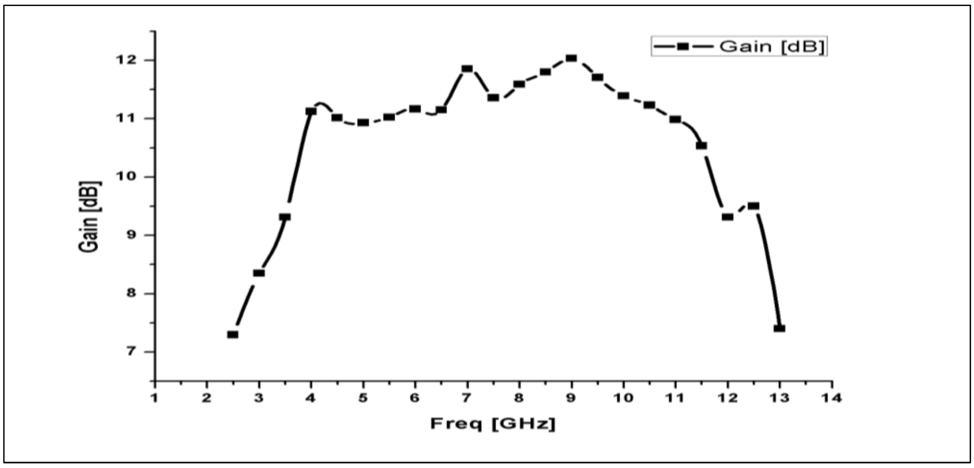

Figure 16: Simulated Gain vs. Frequency Plot of Proposed Antenna

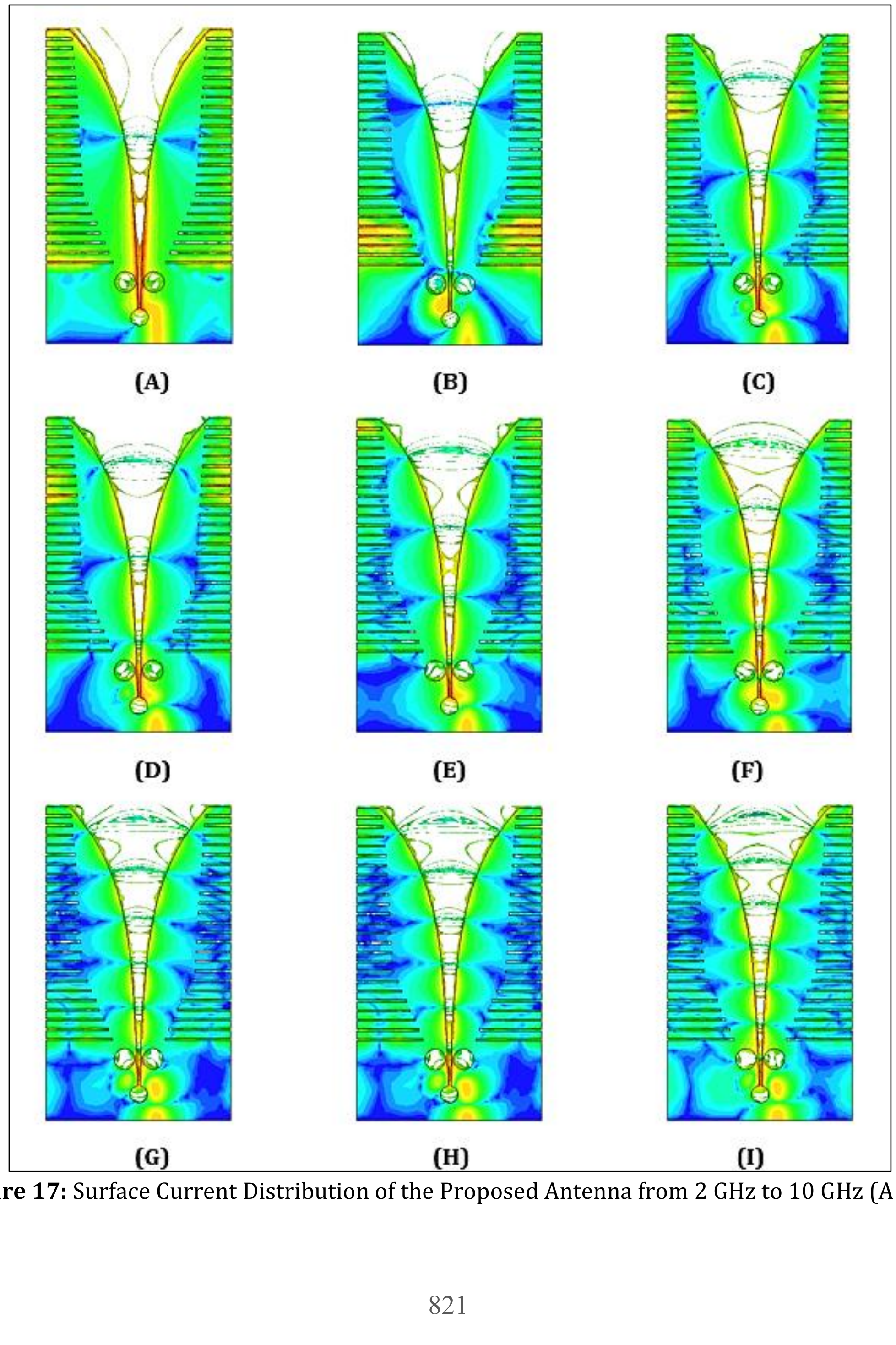

Figure 17: Surface Current Distribution of the Proposed Antenna from 2 GHz to 10 GHz (A to I)

Electromagnetic Field Analysis

To further understand the gain improvement mechanism, Figure 17 (A to I) presents the surface current distribution at a selected frequency. Surface current distribution analysis of the proposed antenna from 2 GHz to 10 GHz reveals efficient radiation behavior across the UWB range. At lower frequencies (2–3 GHz), current is concentrated near the feed and gradually spreads along the flare. From 4 GHz onward, the axial and radial corrugations guide surface currents symmetrically toward the aperture, enhancing forward radiation and reducing edge diffraction. At higher frequencies (7–10 GHz), strong, focused currents confirm effective gain enhancement and impedance matching. The results validate that the corrugated design supports wideband operation with uniform current flow, improved directivity, and stable electromagnetic behavior throughout the spectrum.

Cross-Polarization Performance

To evaluate the antenna's polarization behavior, cross-polarization levels were analyzed at each operating frequency. Figure 18 shows cross-polar radiation level at different frequency. The antenna maintains high polarization purity, with cross-polar levels well below -17 dB from 3 GHz to 11 GHz, confirming excellent linear polarization characteristics.

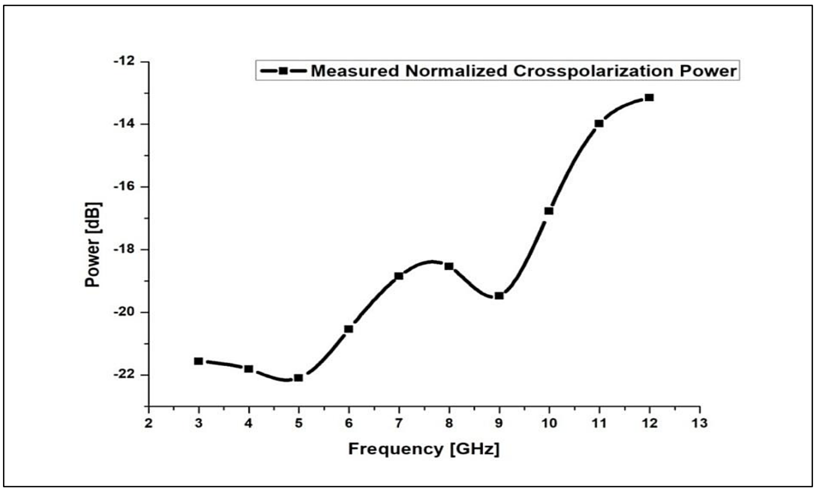

Figure 18: Peak Cross Polarization Level at Various Frequencies

Comparative Performance with Literature

This section provides a comparative analysis of the proposed antenna against existing designs reported in the literature. Table 2 summarizes the key parameters of several antennas, including substrate material, dielectric constant, dimensions, method used, return loss (S_{11}), gain, and bandwidth coverage. The proposed antenna demonstrates superior gain (12.03 dBi), wider bandwidth (3–11 GHz), and excellent S11 performance (-38 dB), outperforming other designs in terms of compactness, efficiency, and bandwidth coverage.

Table 2: Comparison of Existing Antennas with Proposed Antenna

Reference	Substrate Material	Dielectric Constant	Dimensions (mm)	Method Used	S11 (dB)	Gain (dB/dBi)	Band Coverage (GHz)
(20)	FR4	4.4	119x70x1.5	Antipodal Vivaldi Antenna	-23	9.2	1.85 to 9.2
(21)	FR4	2.2	280x155x1	Halved-Type Vivaldi Antenna	-40	7.2	0.52-1.83
(22)	FR4	4.4	33x34x1.6	Slots	-	3.6-4.6	1.4-11.3
(23)	Roger	3.3	Meta Surface-	Meta-surface	-20	5	3.0-6.0

	3003		50x50, antenna element-50x16.3	reflector used for Directivity enhancement			
Proposed antenna	FR4	4.4	89.35×52.46×1.6	Axial and radial corrugation in Vivaldi	-38	12.03	3-11

In summary, the designed antenna not only enhances gain and broadens bandwidth coverage but also demonstrates improved efficiency over existing technologies, positioning it as a viable option for applications requiring robust wideband performance.

Conclusion

In this paper, we presented a novel compact Vivaldi antenna featuring radial corrugations, specifically designed for ultra-wideband (UWB) applications. Our antenna effectively operates across a broad frequency range of 3 GHz to 11 GHz. With dimensions of just 89.35 mm in length, 52.46 mm in width, and a height of only 1.6 mm, this design is optimized for various applications where space is a constraint.

Comprehensive testing in an anechoic chamber demonstrated that our antenna achieves an impressive peak gain of 12.03 dBi throughout the UWB range. Importantly, the measured results align closely with our simulated data, particularly concerning gain and return loss (S_{11}), which validates the reliability and effectiveness of the design. Testing at 1 GHz intervals revealed robust gain performance across the entire frequency spectrum from 3 GHz to 11 GHz. These encouraging results underscore the potential of our antenna for deployment in UWB communication systems. The compact and high-performance characteristics of our Vivaldi antenna make it a promising choice for a wide range of wireless applications. Future optimizations and tests in varied environments could further enhance its real-world applicability. This study lays the groundwork for continued advancements in antenna design, paving the way for future innovations that may lead to even broader bandwidths and improved performance metrics in wireless communication.

Abbreviations

ALTSA: Asymmetrical Linear Tapered Slot Antenna, Asym TSA: Asymmetric Tapered Slot Antenna, BW: Bandwidth, CWSA: Constant Width Slot Antenna, DETSA: Doubly Exponentially Tapered Slot Antenna, DPTSA: Dual-Parabola Tapered-Slot Antenna, ETSA: Exponentially Tapered Slot Antenna, HFSS: High-Frequency Structure Simulator, LTSA: Linear Tapered Slot Antenna, logTSA: Logarithmically Tapered Slot Profile Antenna, MIMO: Multiple-Input Multiple-Output, SFTSA: Spidron Fractal Tapered Slot Antenna, TSA: Tapered Slot Antenna, UWB: Ultra-Wideband, VTSA: Vivaldi Tapered Slot Antenna.

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Author Contributions

Shahidmohammed S Modasiya: Fabrication of the antenna, conducted the experiments in the anechoic chamber, data interpretation, review, manuscript preparation, development of the manuscript, approved the final version of the manuscript, Balvant J Makwana: conceptualized the overall study, designed the antenna layout, performed the simulations, analyzed the results, research, development of the manuscript.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethics Approval

This research did not involve human participants or animal subjects; therefore, ethical approval was not required for this study. All experimental procedures adhered to establish guidelines for research integrity and ethical standards within the field.

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