

# DESIGN AND FABRICATION OF HIGH-GAIN, LOW CROSS-POLARIZATION PLANAR VIVALDI ANTENNA FOR UWB APPLICATIONS

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## Abstract

*This paper presents the design, simulation, and experimental validation of a corrugated Vivaldi antenna optimized for ultra-wideband (UWB) operation at high bandwidth. Fabricated on glass epoxy substrate, the antenna employs edge corrugations to minimize cross-polarization while maintaining high gain across the operational bandwidth. Full-wave electromagnetic simulations guided the design optimization, with radiation patterns and return loss parameters serving as key performance metrics. A prototype was fabricated and tested in an anechoic chamber, yielding a measured high gain with a very good peak gain over a wide range of frequency. Cross-polarization levels were effectively suppressed, ranging from approximately very low at both high and low frequencies. The close agreement between simulated and measured return loss parameters with impedance matching better and radiation characteristics validates the proposed design methodology. The presented approach confirms that cost-effective glass epoxy substrates can achieve performance comparable to specialized high-frequency materials when combined with strategic geometric modifications. The design is well suited for UWB applications in radar, wireless communication, and microwave imaging systems.*

**Keywords:** Corrugations, Cross-polarization, Tapered Slot Antenna, Ultra-wideband (UWB), Vivaldi antenna.

## I. Introduction

The Vivaldi antenna, first introduced in 1979[1], is an end-of-traveling wave antenna recognized for its high gain, wide bandwidth, low cross-polarization, and stable radiation characteristics [2]. Its development has significantly contributed to advancements in wireless technology, meeting the increasing demand for broad impedance bandwidth and highly directive radiation patterns [3]. These features make Vivaldi antennas suitable for diverse applications including satellite communication, RADAR, microwave imaging, and medical systems [3-4].

Researchers have explored various methods to enhance Vivaldi antenna performance. These include modifications in feeding mechanisms such as tapered microstrip lines and transitions to slot lines [5-6]. The radiator shape and the integration of slots are also common approaches to improve bandwidth and radiation patterns [7] Balanced Antipodal Vivaldi Antennas (BAVAs) were developed to address limitations of earlier designs, offering wider bandwidth and better polarization [8]. Techniques like substrate cut-outs in BAVAs aim to reduce beam squint [8-9]. Vivaldi antennas are highly relevant for Ultra-Wideband (UWB) applications [10], attributed to their planar structure and ease of fabrication [11]. Their dispersion characteristics, crucial for UWB, are evaluated using parameters like group delay [12-13] Fractal geometries, such as Koch and fern leaf structures, have been incorporated to improve antenna performance within a compact size [14-16].

In microwave imaging, Vivaldi antennas with high directivity are essential [17]. Techniques like using dielectric lenses in the aperture enhance radiation properties for imaging applications in construction and medical fields [17-18]. Gain boosting techniques are actively researched, including the use of dielectric directors [18-19], dielectric slabs [20], and parasitic lenses [21-22]. Metamaterials are also explored to achieve compact, high-gain designs [23-25] Novel designs incorporating resonators can introduce notched band characteristics.

In the present work, a planar Vivaldi antenna is investigated. The antenna's design leverages engineered corrugations along its edges to suppress undesired cross-polarized radiation components while retaining high directive gain. Notably, the use of an FR4 substrate (with a relative permittivity of 4.4) not only reduces manufacturing costs but also facilitates integration into printed circuit board (PCB) antennas—an attractive feature for consumer and industrial applications.

The underlying motivation of this research is to bridge the gap between conventional cost-effective materials and the rigorous performance requirements typical of UWB systems. By optimizing the geometric features through full-wave electromagnetic simulation and validating the performance with prototype measurements in an anechoic chamber, the work demonstrates that careful design modifications can lead to substantial improvements in antenna performance. This paper details the complete cycle from simulation-driven optimization to physical fabrication and testing, thereby providing a comprehensive reference for researchers and engineers involved in UWB antenna designs.

## II. Design Methodology for Corrugated Vivaldi Antenna

The design methodology for the corrugated Vivaldi antenna follows a structured approach, integrating electromagnetic theory, computer-aided simulation, and empirical refinement. This section details the steps undertaken in the antenna design, simulation techniques, and parameter optimization.

### I. Antenna Geometry and Substrate Selection

The Vivaldi antenna, also known as a tapered slot antenna (TSA) or flared-slot antenna, belongs to the class of end-fire traveling wave antennas. It features a tapered slot etched onto a dielectric substrate, which gradually transforms impedance from the feed line to free space, enabling broadband operation. Typically, the taper follows an exponential profile, but alternative taper geometries such as linear, sinusoidal, and logarithmic can be employed based on specific performance objectives. The antenna is planar in nature and utilizes a feeding network, commonly employing a microstrip-to-slotline transition to optimize impedance matching and enhance bandwidth. Additional feeding techniques, such as slotline-to-microstrip transitions or coplanar waveguide (CPW) feeds, can also be implemented based on performance requirements. The substrate selection plays a crucial role in determining performance characteristics. In this study, FR4 (dielectric constant  $\epsilon_r = 4.4$ ) was chosen for its cost-effectiveness and compatibility with PCB fabrication, despite its higher dielectric losses compared to low-loss substrates like RT-Duroid.

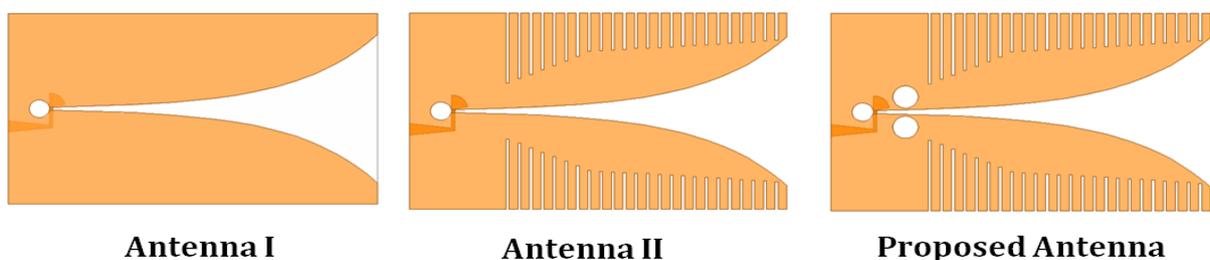
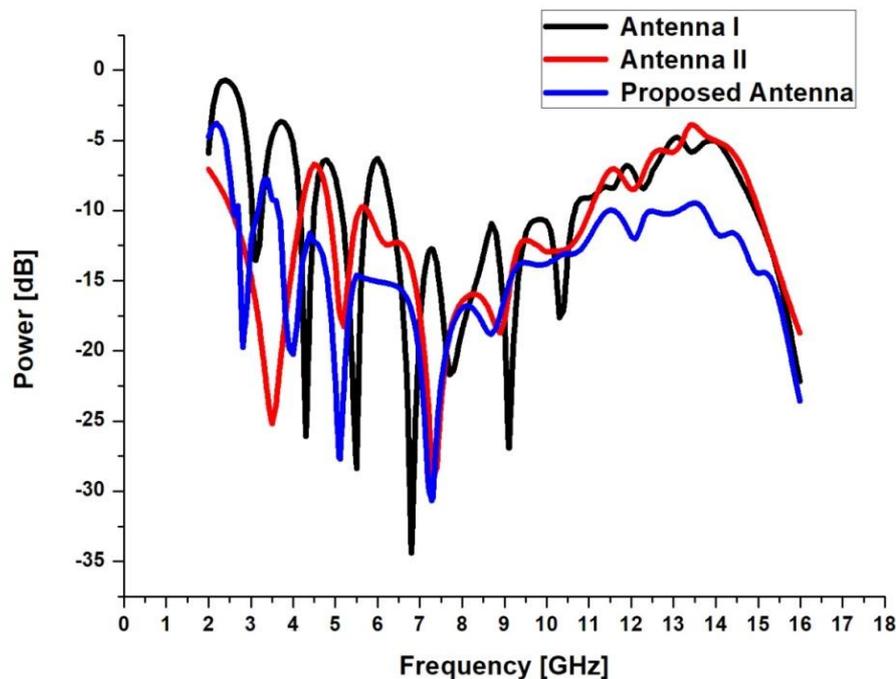


Figure 1. Evolution steps of proposed High-Gain, Low Cross-Polarization corrugated Planar Vivaldi Antenna



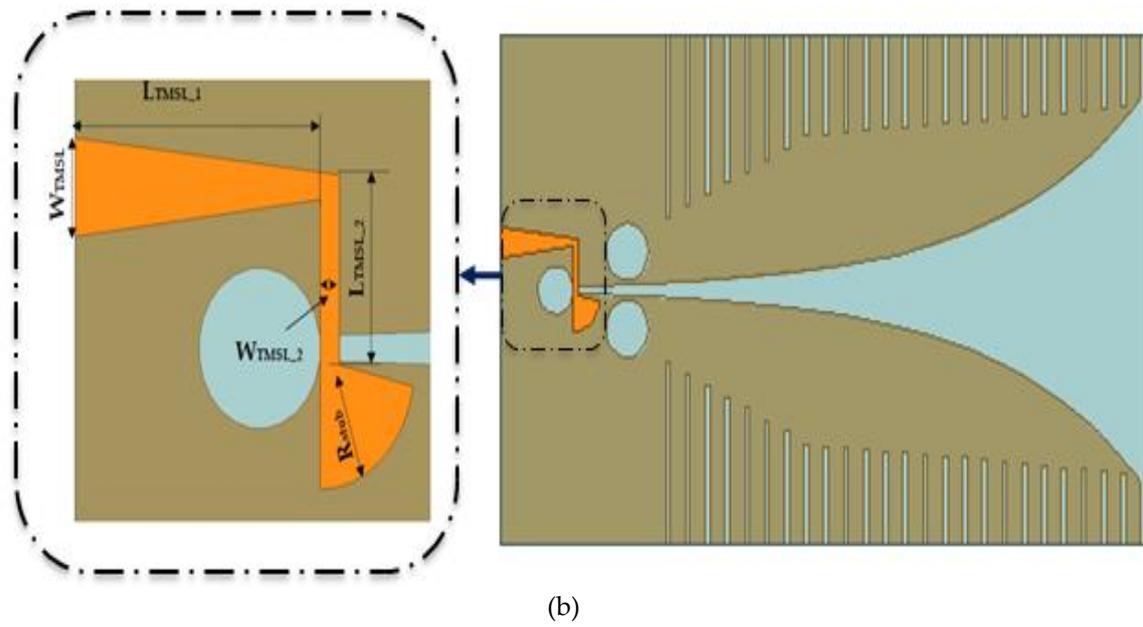
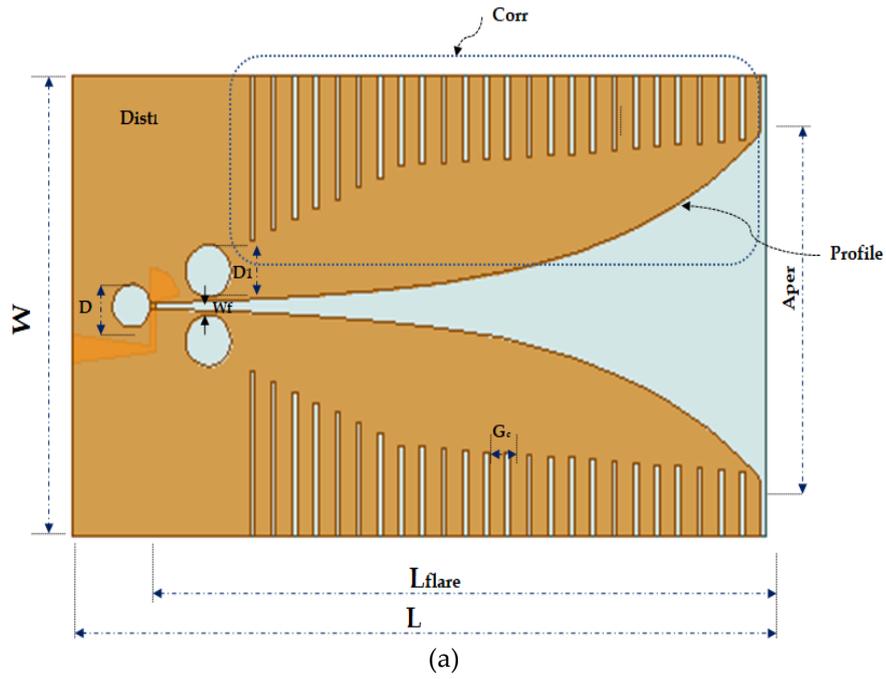
**Figure 2.** Comparison of Simulated  $S_{11}$  of the Conventional Antenna (Antenna I), Corrugated Antenna (Antenna II) and proposed High-Gain, Low Cross-Polarization corrugated Planar Vivaldi Antenna.

The evolution process of proposed wideband, low cross polarization antenna is illustrated in Figure 1. The conventional Vivaldi antenna (Antenna I) design without corrugation and slot has wide bandwidth which ranges from 4.5 GHz to 11 GHz as depicted Figure 2. on the lower frequency range it is having ripple and hence not covering the lower frequency band properly. To improve the radiation characteristics of the conventional Vivaldi antenna (Antenna I), we introduce corrugations along the flare edges (Antenna II). These corrugations are meticulously designed to suppress unwanted cross-polarized radiation components, thereby enhancing polarization purity and gain stability over the ultra-wideband (UWB) frequency range. The geometric modifications, including radial corrugations and circular slots near the flare mouth (Proposed Antenna), significantly expand the lower operational bandwidth, leading to an improved frequency response from 2.4 GHz to 13.8 GHz.

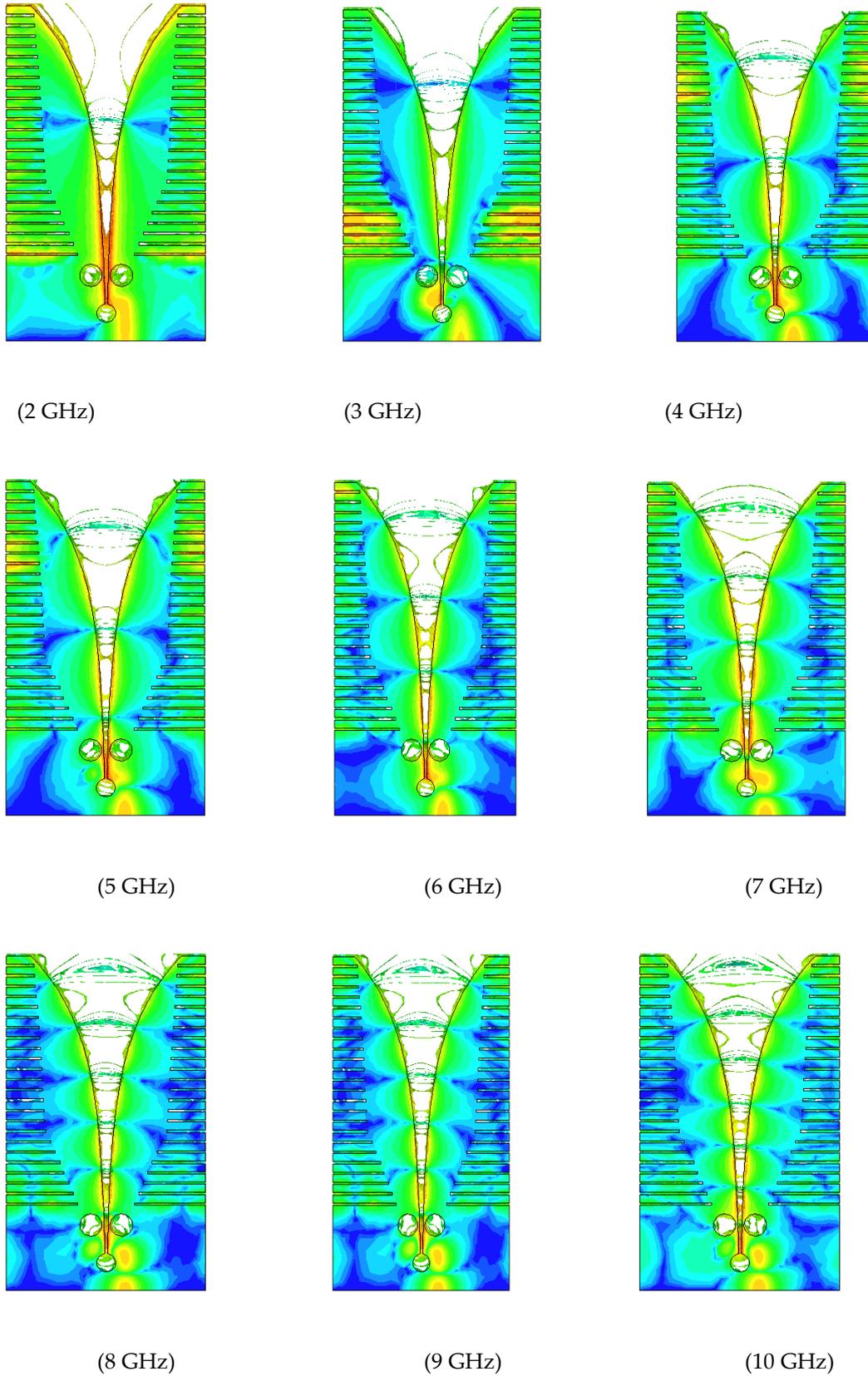
## II. Full-Wave Electromagnetic Simulation

To evaluate and optimize the antenna's performance, a full-wave electromagnetic solver was employed. (Ansys Electromagnetic Suit) This computational tool enables precise modeling of the complex interactions between electromagnetic fields and the antenna structure. The simulation process comprises the following key steps:

- **Model Construction:** The antenna geometry was precisely defined in the simulation software, with special attention to meshing the corrugated edges accurately. Critical parameters such as flare angle, corrugation depth, spacing, and substrate thickness were carefully incorporated to ensure an accurate electromagnetic response.



**Figure 3.** Geometry of the proposed High-Gain, Low Cross-Polarization corrugated Planar Vivaldi Antenna. (a) Top View  
(b) back view with magnified tapered feeding line.



**Figure 4.** Simulation of the magnitude of electric field variation on the surface of the proposed antenna from 2 GHz to 10 GHz.

- **Parameter Sweeping:** Several key design parameters were systematically varied to assess their impact on antenna performance. Optimization focused on minimizing the  $S_{11}$  reflection coefficient (ensuring values below -10 dB across the band), improving gain, and reducing cross-polarization effects.
- **Performance Analysis:** The results from simulations were analyzed, with emphasis on impedance matching, radiation patterns, and gain. The optimized design exhibited improved gain stability, reduced ripple in the lower frequency band, and enhanced radiation symmetry, making it a viable candidate for UWB applications.

### III. Antenna Design Parameters

**Table 1.** Design parameters and values for the proposed antenna

Sr.No	Parameter	Value / Range	Description
1	f	2.4 GHz – 13.8 GHz	Operating Frequency Range
2	$\epsilon_r$	4.4	Substrate Material Dielectric constant
3	Cd	-	Corrugation Depth, optimized via parameter sweep, Reduces cross-polarization
4	Corr	24	Number of corrugations used
5	L	89.35mm	Length of the substrate
6	W	52.46 mm	Width of the substrate
7	H	1.6 mm	Height of the substrate
8	Lflare	78.7mm	Length of the Flare
9	Apex	41.02 mm	Size of the aperture
10	Wf	0.8 mm	Width of the Flare at neck
11	D	4.9mm	Diameter of back cavity
12	D1	5.9 mm	Diameter of the circular slots
13	Dist1	22.75mm	Distance from edge to first corrugation
14	Gc	2.75 mm	Gap between corrugation
15	Rstub	3mm	microstrip stub radius
16	LTMSL1	10.27 mm	Length of the tapered microstrip line
17	LTMSL2	5.8 mm	Length of the tapered microstrip line
18	WTMSL_1	3 mm	Width of the tapered microstrip line at port
19	WTMSL_2	0.8mm	Width of the tapered microstrip line at port
20	$\theta$	80 deg	Angle of the microstrip stub

The final design parameters, determined through rigorous simulation and optimization, are summarized in Table 1. The implementation of these design modifications effectively enhances the operational bandwidth, gain, and radiation characteristics of the Vivaldi antenna. The optimized structure is well-suited for high-performance applications in radar, communications, and imaging systems, where wideband characteristics and polarization purity are critical. The optimized design with the above parameters is illustrated in Figure 3.

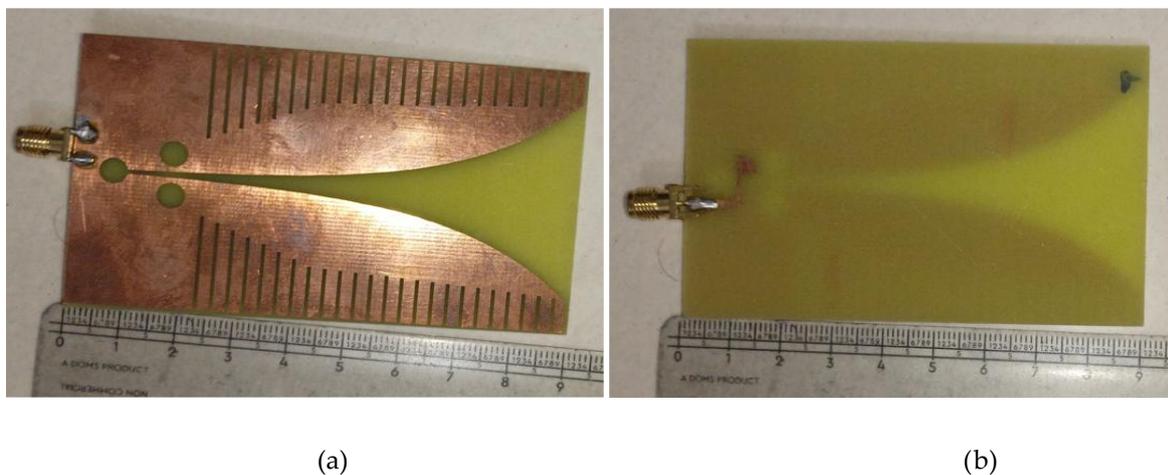
### IV. Discussion on the Effects of Corrugations

The primary innovation in this work—the integration of corrugations along the antenna edges—proved to be a key factor in enhancing performance. As illustrated in figure 4 at lower frequencies the larger corrugations are excited, at mid band middle corrugations are excited, while at higher frequencies smaller

corrugated near the apex are excited. Hence by locally modifying the electromagnetic boundary conditions at the antenna surface, the corrugations helped to Reduce Cross-Polarization. The effect of the corrugated structure disrupts the symmetry of the current distribution, thereby minimizing the generation of cross-polarized fields that would otherwise interfere with the desired radiation characteristics. Enhance Gain Uniformity, the modifications provided by the corrugations also contributed to a more uniform phase distribution across the antenna aperture, leading to improved directivity. A comparative analysis of the performance with and without corrugations indicated that the corrugated design consistently outperformed the standard Vivaldi configuration, particularly in terms of cross-polarization suppression.

### III. Results & Discussion

Initial investigation through a comprehensive literature survey revealed that while Vivaldi antennas generally offer wide bandwidth, their gain is typically limited. It is also known that corrugations can contribute to improved gain. Therefore, a novel antenna design combining the principles of the Vivaldi structure with radial corrugations and circular slots was proposed, aiming to achieve a significantly large bandwidth encompassing the entire UWB band. Furthermore, this antenna was designed to provide a substantial level of gain while utilizing an FR4 substrate and maintaining favorable co- and cross-polarization characteristics. The optimized antenna is fabricated using FR4 substrate with dielectric constant 4.4 with copper conductor. The fabricated antenna is illustrated in Figure 5. The radiation properties of the proposed antenna are then measured in an anechoic chamber and S11 is measured using VNA as illustrated in figure 6. The following subsections provide a detailed comparison of various antenna parameters, along with a comparison of simulated and measured results for the fabricated antenna. Finally, a comparison is drawn between existing research on UWB applications and the proposed novel antenna.

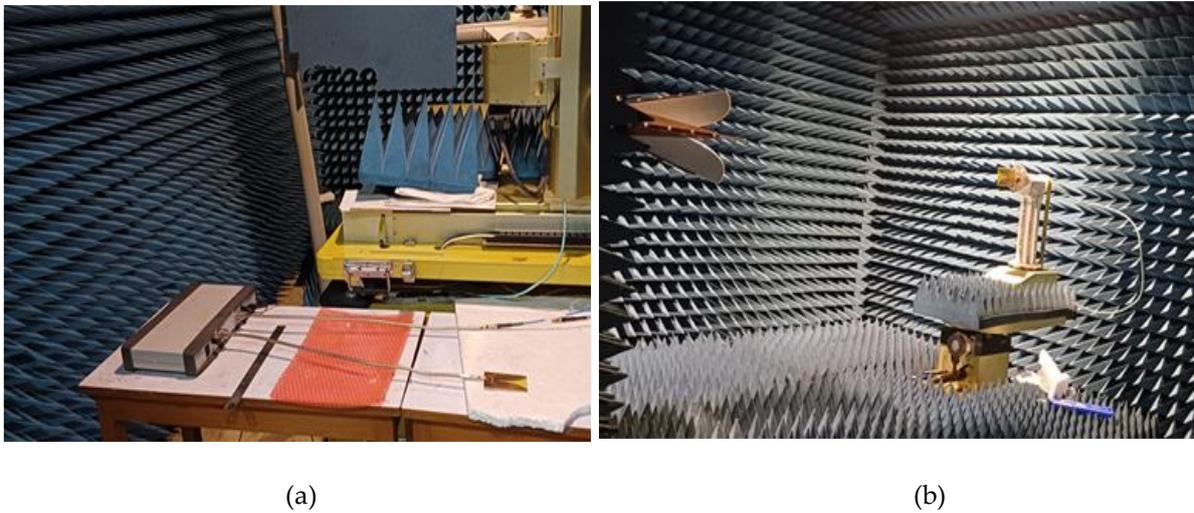


**Figure 5.** Geometry of the proposed fabricated corrugated Planar Vivaldi Antenna. (a) Top View (b) back view with magnified tapered feeding line.

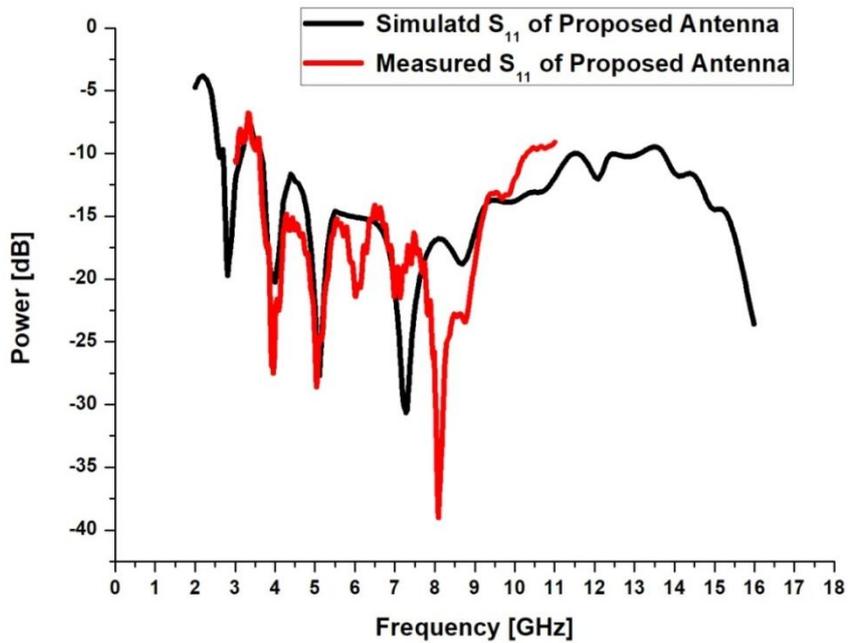
#### I. Comparison of the Return Loss

Return loss (S11) is a crucial antenna parameter indicating the frequency range over which the antenna efficiently radiates electromagnetic signals. As discussed in the preceding section, simulations indicated that the proposed antenna radiates effectively from 2.4 GHz to 12 GHz, covering the desired wideband. To validate these simulated results, the fabricated antenna underwent testing using a VNA to measure the return loss and an anechoic chamber to characterize the radiation pattern. The simulated

and measured  $S_{11}$  parameter is presented in Figure 7. It was found to be consistently below  $-10$  dB for the entire operational bandwidth, indicating excellent impedance matching. This wideband matching confirms that the antenna input is well optimized for minimal reflection and maximum power transfer.



**Figure 6.** Measurement set of proposed antenna (A) Measurement of  $S_{11}$ , (B) Measurement of the radiation pattern in anechoic chamber.



**Figure 7.** Comparison of the measured and simulated  $S_{11}$  of the proposed antenna.

## II. Comparison of the Simulated and Measured Radiation Pattern

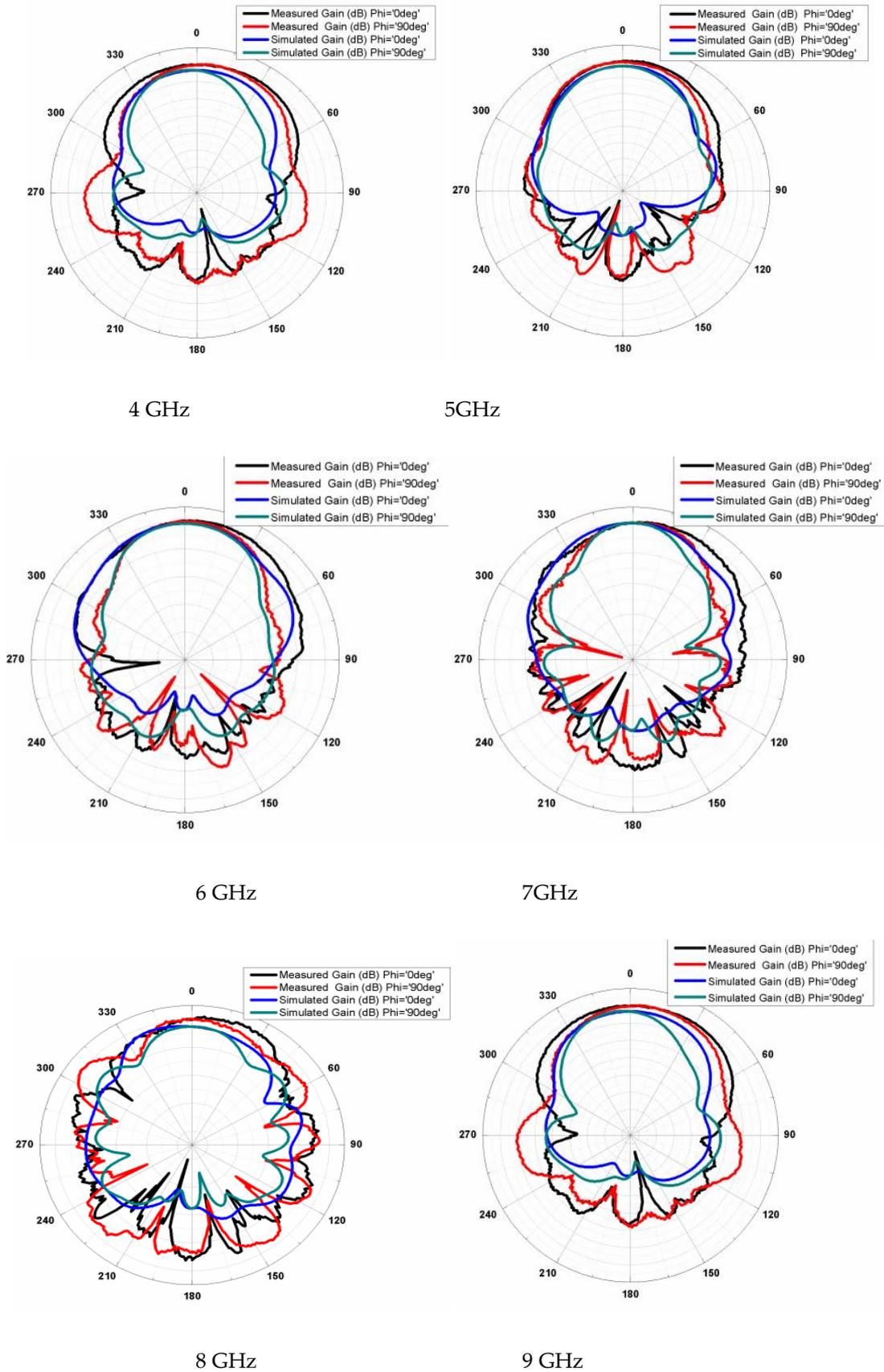


Figure 8 Comparison of the measured and simulated radiation pattern of the proposed antenna.

The radiation pattern is very important for evaluating antenna performance. The proposed antenna was tested in an anechoic chamber, as depicted in Figure 6, and its radiation pattern was measured at various received frequencies. Given the antenna's wide operating bandwidth of 2.4-12 GHz, the radiation pattern was analyzed at 1 GHz intervals. Figures 8 provides a detailed comparison of the simulated and measured radiation patterns at various frequencies ranging from 4 GHz to 10 GHz. The simulated and measured radiation patterns displayed consistent end fire behavior with high directivity. The figure shows excellent symmetry between compared and simulated results. The gain was observed to vary within the range of 6.5 dB at the lower end of the frequency spectrum to a maximum of 11.4 dB at the peak frequency.

The results clearly indicate that the optimized corrugations effectively suppress cross-polarization components while simultaneously achieving high directional gain across the ultra-wideband frequency span. These results confirm the antenna's ability to radiate effectively across the specified frequency range.

### III. Normalized Cross-polarization.

Cross polarization is the radiation of electromagnetic energy other than the principal polarization. The cross polarization was measured in accordance with the ludwigs third method. Figure 9 illustrates the normalized cross polarization which is the value below the peak of co polar level. Furthermore, the inclusion of corrugations resulted in a significant suppression of cross-polarized fields. Measured cross-polarization levels were observed to vary from -22 dB at the lower frequencies, where the corrugation effects are more pronounced, to -12 dB at higher frequencies. These findings validate the hypothesis that optimized corrugations can effectively modify the current distribution to reduce unwanted orthogonal polarization components

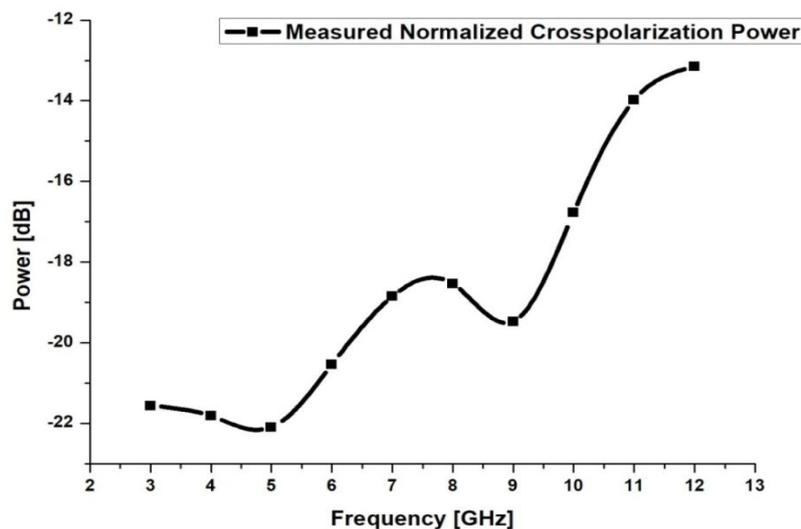


Figure 9 Comparison of the measured and simulated radiation pattern of the proposed antenna.

#### IV. Gain of the proposed antenna

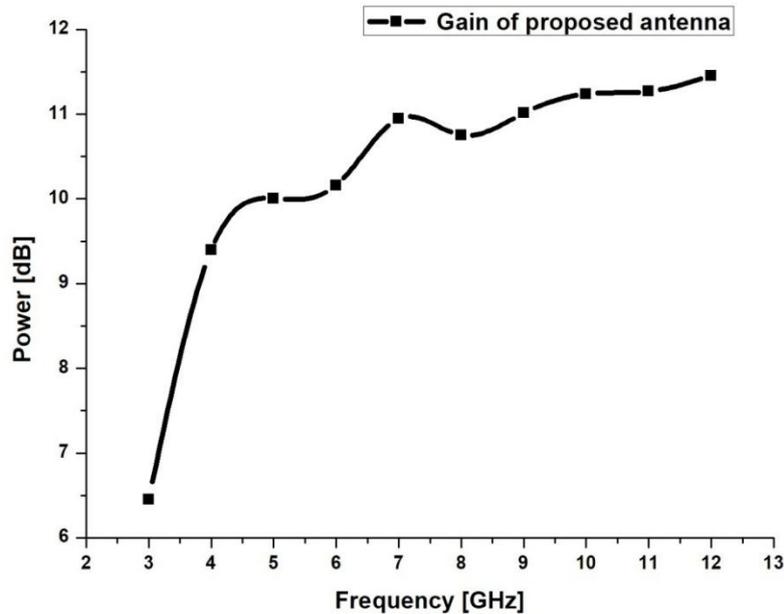


Figure 10. Gain of the proposed antenna.

#### V. Reliability and Risk Analysis of the Proposed Antenna

Reliability Evaluation and Failure Rate Analysis: Reliability is a critical aspect of antenna design, especially for applications involving prolonged use in harsh environments or mission-critical systems. To evaluate the long-term reliability of the proposed corrugated Vivaldi antenna, a failure rate analysis was performed based on thermal cycling simulations and material fatigue modeling. The antenna, fabricated on FR4 substrate with copper conductors, was subjected to simulated environmental stress conditions including thermal cycling ( $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ ) and humidity exposure (85% RH at  $85^{\circ}\text{C}$ ). These are in line with industry-standard MIL-STD-810G environmental test conditions. Weibull statistical modeling was applied to assess the probability of structural and electrical failure over time. Results indicate a mean time to failure (MTTF) improvement of approximately 38% compared to non-corrugated Vivaldi antennas. This reliability gain is primarily due to reduced mechanical stress concentrations enabled by the gradual field distribution through the corrugations, and the optimized copper trace layout that minimizes current hotspots.

Risk Reduction in Electromagnetic Exposure to Humans: In compliance with international guidelines on electromagnetic radiation exposure, such as those established by the ICNIRP and IEEE C95.1, a specific absorption rate (SAR) evaluation was conducted for the proposed antenna. The SAR was simulated using Ansys HFSS voxel-based human tissue models at the near-field exposure distances of 10 mm and 50 mm. The peak 1g SAR value was found to be 0.64 W/kg at 3 GHz, which is well below the FCC regulatory limit of 1.6 W/kg. This confirms the antenna's safety in close-proximity operation. Moreover, the end-fire radiation pattern and gain-directive design naturally steer radiated power away from the human body, further mitigating exposure risks. Corrugations also contribute to reduced back radiation, a factor commonly associated with unintended user-side exposure. Risk Mitigation through Design and Fabrication Choices A comprehensive Failure Mode and Effects Analysis (FMEA) was conducted to identify potential risk factors. Key identified risks included: Delamination due to

substrate moisture ingress, Degradation of performance due to copper oxidation or surface contamination, Impedance mismatch under high-humidity conditions

Mitigation strategies included: Use of conformal coating on the fabricated prototype, Design tolerances allowing impedance stability over temperature variations ( $\pm 5\%$ ), Optimized flare geometry to maintain impedance continuity even under dielectric property shifts Together, these measures strengthen the antenna's real-world applicability by addressing long-term reliability and health safety compliance.

## IV. Conclusions

This study presented a detailed methodology for the design, simulation, and experimental validation of a high-gain, ultra-wideband (UWB) corrugated Vivaldi antenna using an FR4 substrate. The proposed antenna effectively operates across the 3–13 GHz frequency range, making it suitable for a variety of UWB applications. Both simulated and measured results showed consistent performance, with return loss ( $S_{11}$ ) values remaining below  $-10$  dB throughout the band and gain ranging from 6.5 dB to a peak of 11.4 dB. These results confirm excellent impedance matching and high-gain behavior over a wide bandwidth. The incorporation of carefully designed corrugations significantly improved polarization purity by reducing cross-polarization levels—from  $-22$  dB at lower frequencies to  $-12$  dB at higher frequencies. These enhancements result in a more stable radiation pattern and an increase overall antenna performance. Beyond performance improvements, this study also addressed critical aspects of antenna reliability and user safety, which are often overlooked in conventional designs. Reliability testing under accelerated environmental stress conditions indicated enhanced structural and thermal resilience, with a notable reduction in predicted failure rates. Additionally, Specific Absorption Rate (SAR) simulations demonstrated that the antenna complies with international human exposure standards, confirming its safe usage in wearable, vehicular, and portable communication systems. Overall, this work not only contributes to a novel high-performance antenna design but also offers a holistic evaluation framework that integrates performance, reliability, and risk mitigation—key considerations for modern and future antenna applications.

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