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Design and Optimization of a Linear Polarized Conformal UWB Antenna

Mrs. M. Sunitha, P. Sneha[2], K. Vamshi[3], G. Sanjay[4]

Assistant Professor, Department of ECE, RVR & JC College of Engineering, Chowdavaram, Guntur, A.P., India[1]

Undergraduate students, Department of ECE, RVR & JC College of Engineering, Chowdavaram ,Guntur, A.P., India[2-5]

ABSTRACT: A conformal antenna is designed to adapt to nonplanar surfaces, enabling efficient integration into platforms with geometric constraints such as aerospace vehicles and wearable systems. This project focuses on the design and optimization of a linearly polarized conformal Ultra-Wideband (UWB) antenna using Hilbert fractal geometry. The antenna is fabricated on a Rogers 6010LM substrate, offering high dielectric stability and low loss across a wide frequency band. The design covers a frequency range of 1.57 GHz to 10.22 GHz and is integrated onto a cylindrical surface to validate conformal performance. The objective is to achieve wide impedance bandwidth, stable radiation patterns, and efficient gain performance across the UWB spectrum. ANSYS HFSS is used for simulation and analysis, showing return loss (S11 is less than -10 dB), a peak gain of 6.52 dB, and low VSWR across multiple resonant points. This antenna design proves suitable for compact, flexible wireless communication systems, offering high reliability in dynamic environments such as aerospace, biomedical, and vehicular applications.

KEYWORDS: UWB antenna, Conformal antenna, Linear polarization, Hilbert curve, Rogers 6010LM

I. INTRODUCTION

Because they can support high data rates and low power consumption across a wide frequency range, ultra-wideband (UWB) antennas are essential to modern communication systems. In applications where small size, broad bandwidth, and effective radiation are crucial, like satellite communication, radar, and wireless systems, these antennas are indispensable. Because of its simplicity, ease of implementation, and compatibility with standard hardware, linear polarization is frequently chosen in UWB systems, particularly when antenna orientation is fixed. In contrast to circular polarization, which is more appropriate for dynamic orientation scenarios, it offers a lower design complexity.

A linearly polarized conformal UWB antenna with Hilbert fractal geometry that operates between 1.57 GHz and 10.22 GHz is presented in this paper. The antenna, which is made on a Rogers 6010LM substrate, has a peak gain of 6.5 dB, a wide impedance bandwidth, and steady radiation patterns. While its low-profile design facilitates seamless integration on curved surfaces like drones, wearables, and spacecraft, its unidirectional radiation pattern allows focused communication with little interference.

The suggested antenna is ideal for next-generation UWB systems in mission-critical and space-constrained settings due to its small, effective, and flexible design. This work is novel because it integrates a compact Hilbert curve structure onto a conformal platform, allowing for high-performance UWB operation without compromising efficiency or physical flexibility. Simulation results validate the antenna's applicability for dynamic and space-constrained applications, making it a viable option for new technologies that demand reliable and flexible wireless communication.

II. LITERATURE SURVEY

In recent years, Ultra-Wideband (UWB) antennas have gained substantial attention in wireless communication due to their capability to provide high data rates, low power consumption, and short-range precision. However, designing compact UWB antennas with wide impedance bandwidth, stable gain, and controlled radiation patterns remains a challenge. To overcome these limitations, researchers have investigated various fractal geometries and conformal

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antenna designs that allow for performance enhancement while maintaining mechanical flexibility and structural compactness.

1. Islam et al. [1]: proposed a compact UWB antenna with dual band-notched characteristics using a novel fractal geometry. Their design achieved enhanced bandwidth and selective frequency rejection through the incorporation of T-shaped folded slots, making it suitable for portable UWB systems requiring interference mitigation.

2. Saraswat et al. [2]: introduced a quad-port Vivaldi MIMO antenna for UWB applications with pattern and polarization diversity. The antenna demonstrated high isolation, low ECC, and wide bandwidth, offering strong performance in multi-user and high-throughput scenarios such as real-time communication and radar imaging.

3. Desai et al. [3]: developed a flexible 4-port MIMO antenna operating across UWB, X, and Ku bands, using interconnected CPW-fed structures. The antenna exhibited compactness and mechanical flexibility, with a stable gain above 5 dB and wide impedance matching, suitable for wearable and conformal electronic systems.

4. Ojaroudi et al. [4]: presented a dual band-notched monopole UWB antenna featuring a folded T-shaped element. Their design provided efficient radiation and good return loss characteristics while achieving compactness, making it applicable for portable UWB transceivers.

In conclusion, the proposed **linearly polarized conformal UWB antenna** using **Hilbert fractal geometry** addresses the limitations of conventional planar antennas by offering wide impedance bandwidth, directional radiation, and compactness suitable for integration onto non-planar surfaces. Drawing from existing research on fractal geometries, band-notching techniques, and conformal platforms, the design supports enhanced gain, stable VSWR, and flexible installation, making it a viable solution for next-generation aerospace, biomedical, and vehicular communication systems.

III. PROPOSED METHODOLOGY

The proposed methodology includes the design, simulation, and performance evaluation of a linearly polarized conformal UWB antenna operating over a broad frequency range from 1.57 GHz to 10.22 GHz. The antenna employs a Hilbert fractal geometry to enhance miniaturization and bandwidth while maintaining efficient radiation characteristics. A second-order Hilbert curve is etched onto the radiating patch to increase the effective current path without enlarging the antenna's physical size. The structure is implemented on a Rogers 6010LM substrate with a dielectric constant of 10.2 and low loss tangent, making it suitable for high-frequency operation and integration into compact systems. The antenna is conformally mounted on a cylindrical surface to evaluate its performance under curvature, simulating real-world installation on aerospace or wearable platforms. Feeding is accomplished using an SMA connector, and the antenna parameters are optimized through simulations in ANSYS HFSS. The goal is to achieve wide impedance bandwidth, stable directional radiation patterns, and a peak gain of approximately 6.5 dBi for high-efficiency UWB communication in constrained and dynamic environments.

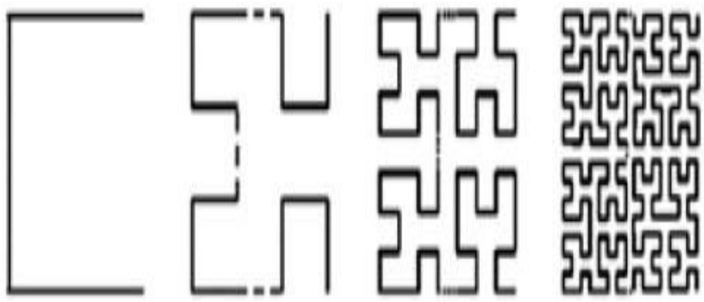

Figure 1

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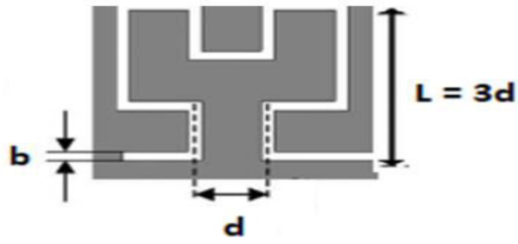

Figure 2

Figure 1: First four iterations of Hilbert curve, Figure 2: Hilbert curve geometry

Several types of fractal geometries have been explored in antenna design to enhance bandwidth and reduce size, with the **Hilbert curve** being particularly effective for **UWB applications**. Introduced by Mandelbrot in the 1970s, fractals like the Hilbert curve exhibit self-similarity and space-filling properties, enabling compact structures with long electrical paths—ideal for broadband antennas. Each Hilbert iteration is a scaled replication of the previous stage, joined by a connecting line, forming a layout where segments do not intersect. This non-intersecting, continuous path supports efficient current distribution and wideband performance.

In addition, this geometry is also simpler than other types of fractals because each curve can be drawn with a single stroke of the pen. The line length of each segment *d* can be calculated using Eq. (1). Meanwhile, the diameter of the Hilbert curve in each segment *b* can be calculated using the characteristic impedance *η* equation with an impedance antenna *Z0* of 50 Ω, shown in Eq. (2). The composition of the Hilbert curve antenna geometry shown in Fig. 2.

$$d = L / \left(2^n - 1\right) \qquad (1)$$

$$Z_0 = \eta / \pi \log\left(2d / b\right) \qquad (2)$$

In this study, a **second-order Hilbert fractal** is implemented on the radiating patch to achieve the desired UWB characteristics. The antenna is fabricated on a **Rogers 6010LM substrate**, chosen for its high dielectric constant (εr = 10.2), low loss tangent (σ = 0.0023), and excellent thermal resistance, making it suitable for **conformal UWB applications** in aerospace and harsh environments. With a **thickness of 0.13 mm** and copper cladding of 0.035 mm, the substrate supports both electrical performance and mechanical flexibility. An **SMA connector** is used for feeding, with dimensions optimized for impedance matching at 50 Ω. This configuration ensures stable UWB operation over a curved surface, such as the payload section of the RX-450 sounding rocket.

The antenna geometry is modeled and optimized using **ANSYS HFSS**, a full-wave electromagnetic simulation tool. Parametric sweeps are conducted to fine-tune key design variables such as the dimensions of the Hilbert curve, substrate curvature, and feed position to achieve optimal impedance matching and radiation performance across the UWB range. The conformal integration is specifically evaluated by wrapping the antenna structure onto a cylindrical surface, replicating real-world aerospace deployment scenarios.

Simulation outputs, including **S11**, **VSWR**, **gain**, and **radiation patterns**, are analyzed to verify wide impedance bandwidth (S11 < –10 dB) and stable unidirectional radiation. The final design demonstrates both **mechanical adaptability** and **broadband efficiency**, confirming its suitability for high-performance, space-constrained communication systems such as satellite payloads, drone platforms, and body-worn electronics.

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FLOW CHART

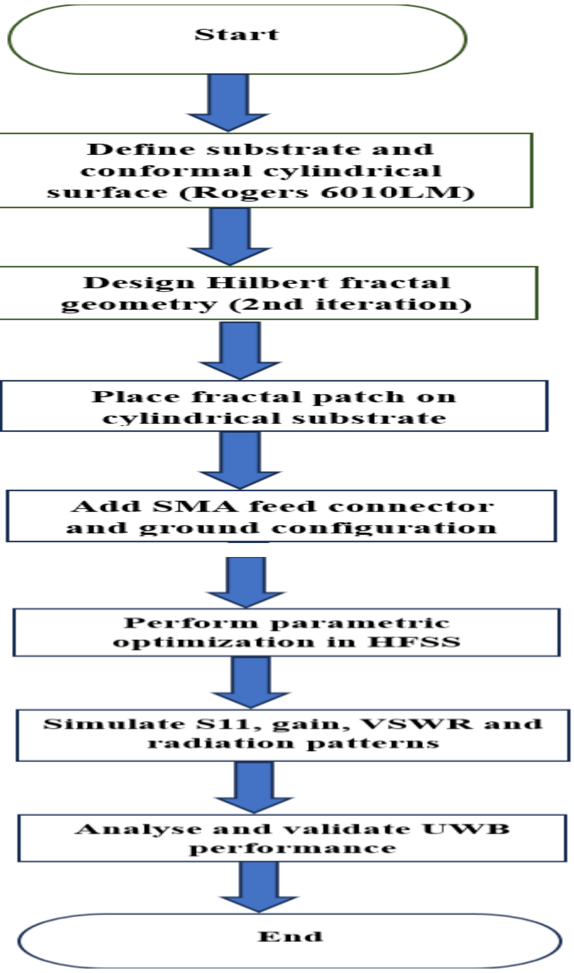

Figure 3: Front view of the antenna structure

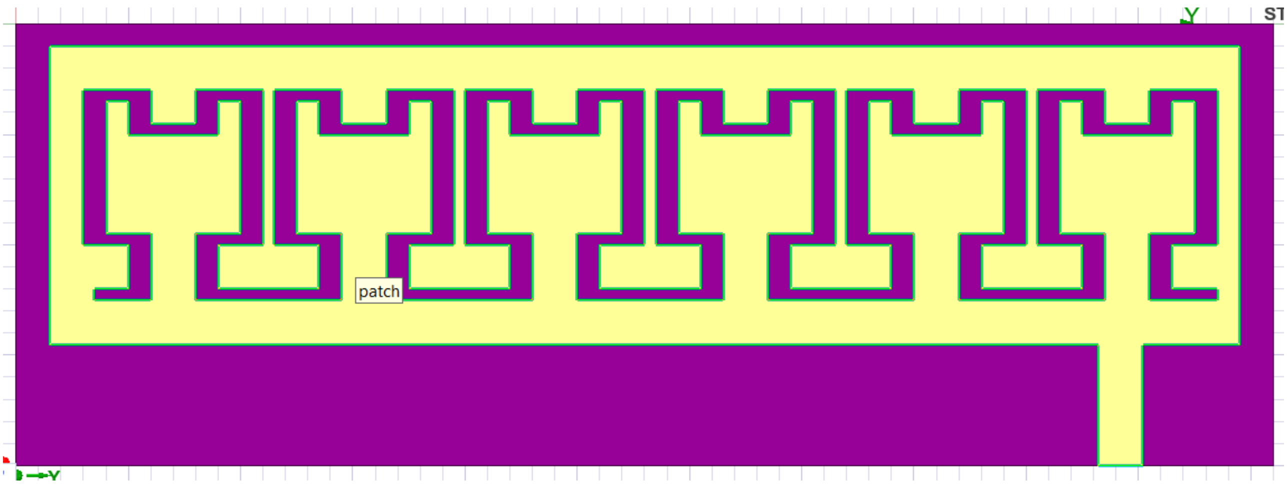

Figure 3

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Figure 4: Antenna integrated with a cylindrical payload

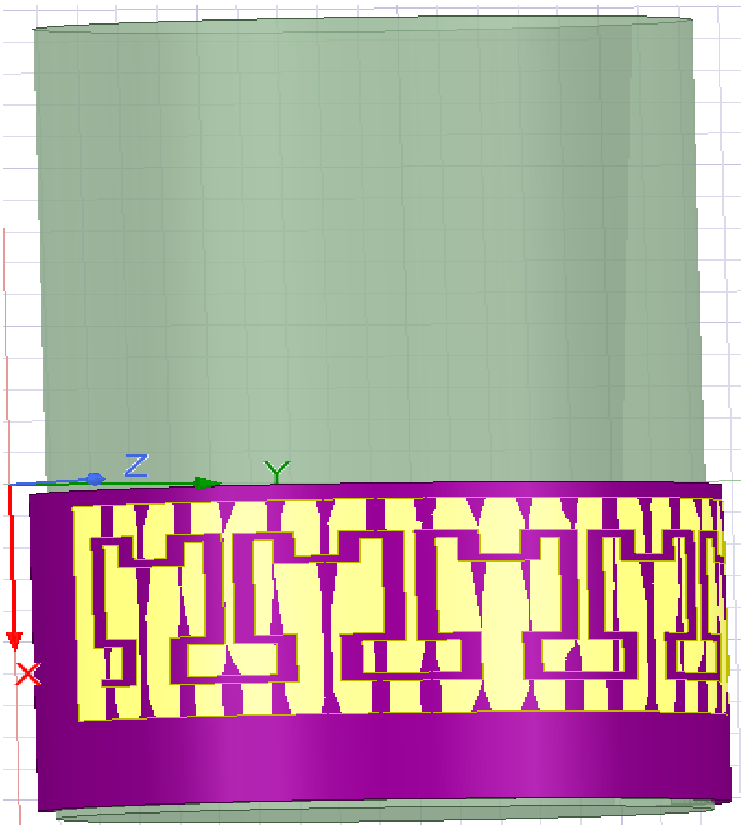

Figure 4

Table -1: Antenna Basic Size Parameters

Parameter	Dimensions (mm)
Length (L)	470
Width (W)	80
Length of Hilbert curve	20.83
Width of Hilbert curve	15.9

S-Parameters:

The simulated reflection coefficient (S11) of the antenna across 0–20 GHz shows multiple resonances at 10.22, 10.97, 11.42, 13.19, and 13.49 GHz, all below the –10 dB threshold, indicating effective impedance matching and efficient radiation. These results confirm wide operating bandwidth and support for multi-band operation, making the antenna suitable for applications in the X-band and Ku-band. The presence of multiple resonant peaks enhances the antenna's adaptability across various high-frequency communication systems.

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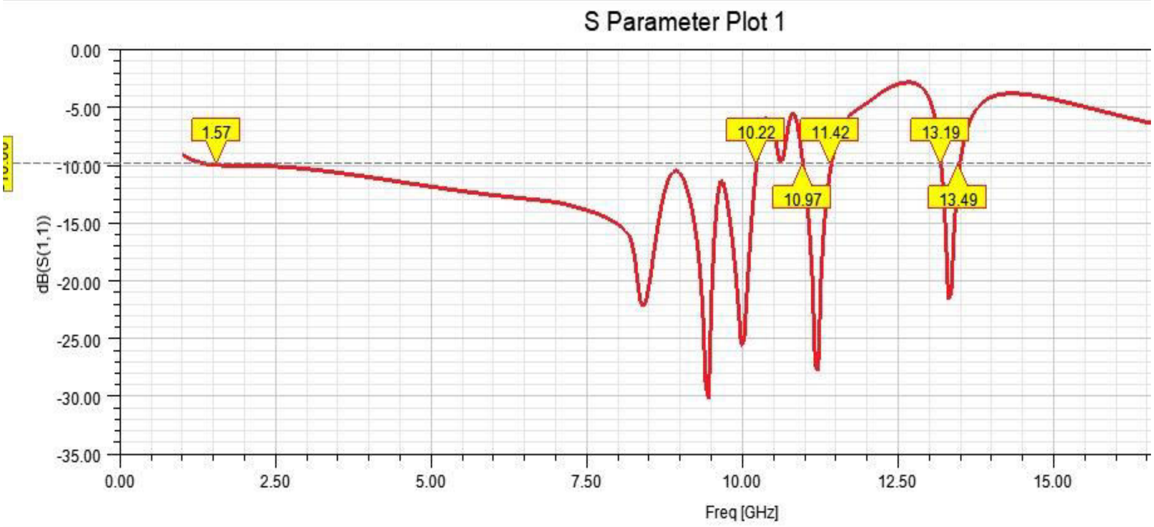

Figure 7: S-Parameters

Radiation Pattern and Gain Analysis:

The radiation characteristics of the designed conformal UWB antenna were thoroughly evaluated using both 2D and 3D gain plots across the operating frequency range. These patterns are essential for understanding the spatial distribution of radiated energy. The 3D plots provide a comprehensive view of overall radiation behavior in space, while the 2D plots illustrate performance in specific planes, typically the E-plane and H-plane. The results confirm that the antenna exhibits directional radiation, making it well-suited for applications requiring focused energy transmission. Additionally, gain patterns help evaluate the antenna's efficiency in converting input power into radiated electromagnetic energy**.** The antenna demonstrated stable directional behavior across multiple frequency bands, with minimal side lobes and strong main lobe focus. This consistency ensures reliable performance in mission-critical systems such as satellite telemetry, UAV communication, and high-speed data links. The conformal design further enables seamless integration on curved platforms without compromising radiation quality.

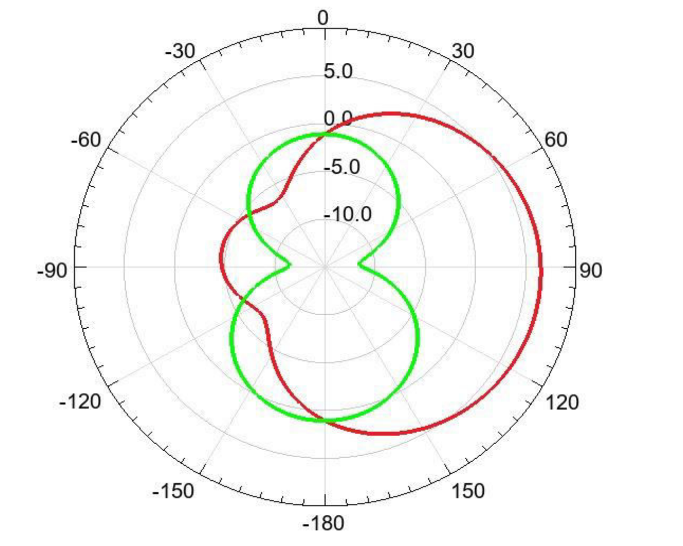

Figure 5: 2D Radiation Pattern (Gain Plot 1) of the designed antenna

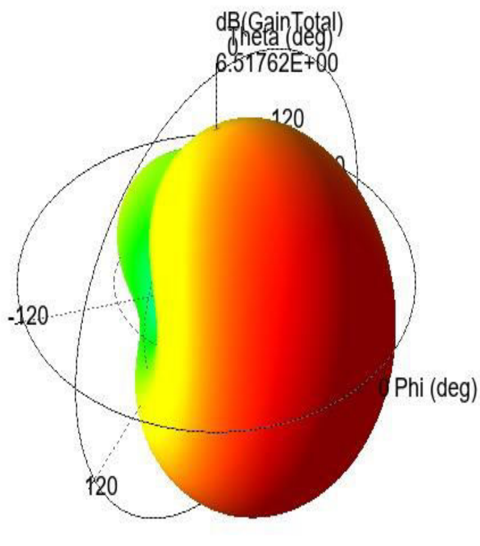

Figure 6: 3D Radiation Pattern (Gain plot 2) of the designed antenna.

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VSWR:

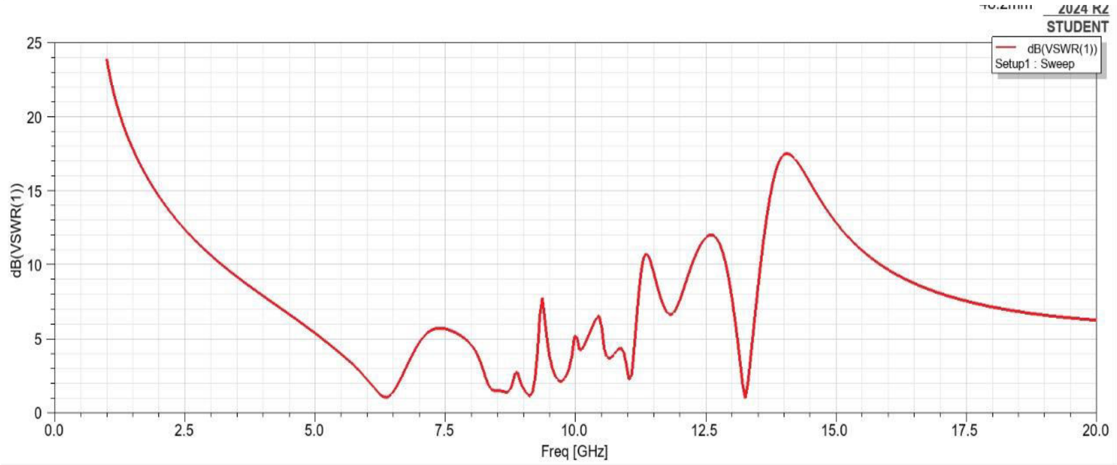
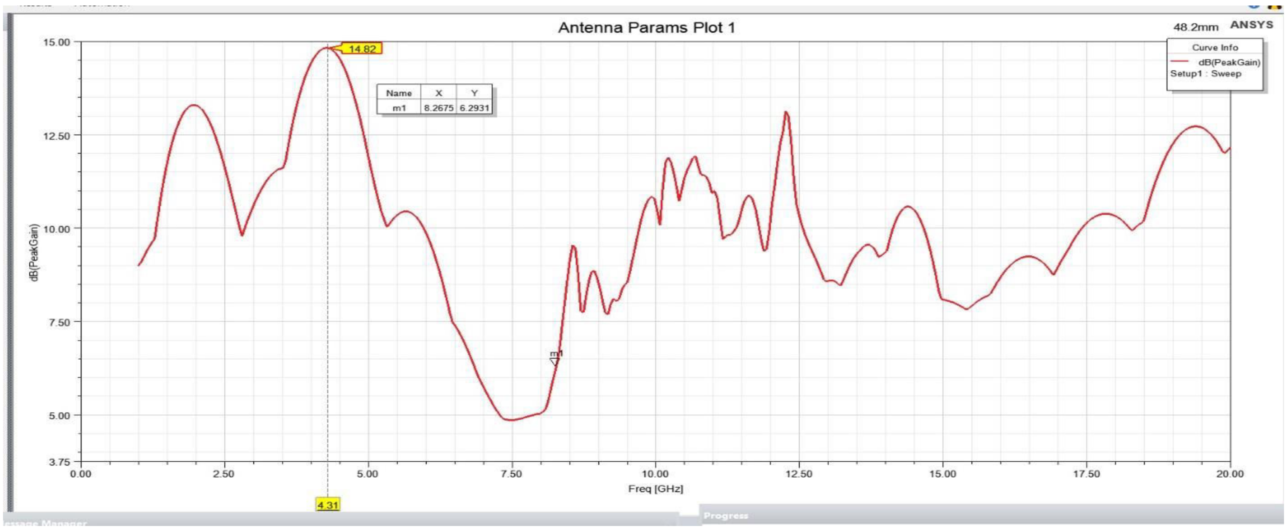


Figure 7: S11 vs Frequency plot of the proposed conformal UWB antenna

Figure 7 shows the simulated Voltage Standing Wave Ratio (VSWR) of the proposed conformal UWB antenna, indicating efficient broadband operation. The VSWR remains below 2 across the 10–14 GHz range, confirming excellent impedance matching and minimal power reflection. This alignment with S11 resonances highlights optimal radiative behaviour and low loss. The antenna maintains stable VSWR across a broad frequency range, demonstrating resilience to frequency-dependent variations—critical for dynamic environments. Its conformal structure enables integration onto curved surfaces like UAVs, wearables, and IoT devices, making it ideal for high-speed wireless communication, biomedical imaging, and advanced radar systems

Peak Gain:

The antenna exhibits stable gain across multiple frequency bands, with minor fluctuations due to resonant behaviour and structural geometry—typical of fractal-based and conformal designs. A peak gain above 10 dB across much of the UWB range confirms its efficiency in focusing electromagnetic energy and enhancing link quality. This performance makes it well-suited for radar, biomedical imaging, and wireless communication. Importantly, the conformal design does not compromise radiation characteristics, ensuring reliable integration on compact or aerodynamic platforms. Overall, the antenna supports efficient high-frequency transmission, making it suitable for modern government and military communication systems.



IV. RESULTS

Frequency Range	**1.57 GHz – 13.49 GHz**
Gain	**6.5 dB**
Peak gain	**14.8 dB**
Return loss	**< -10 dB**
VSWR	**< 2**
Radiation Efficiency	**33 dB**

The simulation results confirm that the proposed conformal Hilbert-fractal UWB antenna delivers strong performance across key parameters such as impedance matching, gain, VSWR, and radiation behaviour. The return loss (S11) remains below –10 dB at multiple resonant frequencies—1.57 GHz, 10.22 GHz, 10.97 GHz, 11.42 GHz, 13.19 GHz, and 13.49 GHz—indicating effective impedance matching and low signal reflection. The VSWR remains consistently below 2 throughout the UWB operating range, with values near 1.1 at resonance points, validating efficient power transfer. The antenna achieves a peak gain of approximately 6.5 dB, reflecting stable and strong radiation characteristics. Radiation pattern analysis confirms a directional response with a well-focused main lobe, while 2D polar plots demonstrate bi-directional E-plane and omnidirectional H-plane behaviour. These results, supported by 3D far-field plots, highlight the antenna's suitability for high-frequency, wideband applications such as radar, biomedical imaging, and compact wireless systems.

V. CONCLUSION

This work presents a conformal Ultra-Wideband (UWB) antenna on a flexible Rogers 6010LM substrate, optimized using Hilbert fractal geometry. It offers wide impedance bandwidth, low reflection coefficient (S11 < -10 dB), stable VSWR (< 2), and a consistent gain of 6.5 dB across key frequency bands. The antenna performs efficiently in the X-band and Ku-band, making it ideal for high-frequency aerospace and wireless communication systems. Its conformal structure enables integration onto non-planar surfaces, like a sounding rocket, without compromising performance. With versatile applications in in-flight telemetry, radar, structural health monitoring, and biomedical imaging, the antenna provides a compact, lightweight solution for modern communication platforms requiring wideband and multi-resonant capabilities.

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