UWB ANTENNA for 5G applications

By

Sneha Majumdar 22BEC1327

Noudu Venkata Naga Seshank 22BEC1372

Mokka Eshwar Goud 22BEC1393

Jamili Sree Kaushik 22BEC1468

Y S Aditya Lohit 22BEC1469

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Dr. Usha Kiran K

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Vellore Institute of Technology

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Vandalur – Kelambakkam Road

Chennai – 600127

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BONAFIDE CERTIFICATE

Certified that this project report entitled **UWB ANTENNA for 5g applications** is a bonafide work of Sneha Majumdar (22BEC1327), Jamili Sree Kaushik (22BEC1468), Seshank (22BEC1372), Y S Aditya Lohit(22BEC1469), Eshwar (22BEC1393) who carried out the Project work under my supervision and guidance for BECE305L – Antenna and Microwave Engineering

Dr.Usha Kiran K

Professor (Grade-1)

School of Electronics Engineering (SENSE),

VIT University, Chennai

Chennai – 600 127.

ABSTRACT

This project, titled "UWB Antenna for 5G Applications," focuses on designing a compact, high-performance Ultra-Wideband (UWB) Multiple-Input Multiple-Output (MIMO) antenna for seamless integration within the 5G sub-6 GHz spectrum (3.3 GHz - 4.2 GHz) and the full UWB range (3.1 GHz to 10.6 GHz). The proposed microstrip-fed antenna, measuring 18 mm × 34 mm, is optimized for compact 5G communication systems, featuring modified L-shaped slots that introduce dual-notch bands to mitigate interference from WLAN and INSAT/Super-Extended C-band frequencies, thereby improving data reliability in high-density environments.

Engineered for efficient operation across a broad frequency range, the antenna achieves a VSWR below 2 and a return loss (S11) under -10 dB, ensuring minimal signal reflection and high radiation efficiency across the UWB and 5G bands. In a MIMO configuration, it provides robust signal quality with mutual coupling below -20 dB, promoting strong port isolation, low Envelope Correlation Coefficient (ECC), and high Mean Effective Gain (MEG).

Performance metrics including gain, efficiency, radiation pattern, and Total Active Reflection Coefficient (TARC) are evaluated to ensure stable data transmission. With excellent interference suppression and enhanced signal clarity, the UWB antenna is optimized for next-generation 5G applications, addressing the need for compact, versatile antenna designs in advanced wireless communication systems.

ACKNOWLEDGEMENT

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The successful completion of this project has been made possible through the collective support, guidance, and contributions of all those mentioned above, and for that, we are truly grateful.

Sneha Majumdar 22BEC1327

Noudu Venkata Naga Seshank 22BEC1372

Mokka Eshwar Goud 22BEC1393

Jamili Sree Kaushik 22BEC1468

Y S Aditya Lohit 22BEC1469

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1. INTRODUCTION

1.1 OBJECTIVES AND GOALS

- Design a compact UWB antenna compatible with 5G applications, focusing on the 3.3 GHz to 4.2 GHz sub-6 GHz band.
- Achieve high radiation efficiency, stable gain, and minimal return loss (S11 < -10 dB) across the operational band.
- Incorporate MIMO configuration for improved signal robustness and low mutual coupling.
- Implement dual-notch bands to suppress interference from WLAN and INSAT/Super-Extended C-band frequencies.

1.2 APPLICATIONS

- Wireless communication for 5G networks and IoT devices.
- Remote sensing and high-speed data transfer applications.
- Mobile communications, smart devices, and other UWB technologies requiring efficient sub-6 GHz communication.

1.3 FEATURES

- Compact size (18 mm × 34 mm), ideal for portable devices.
- Dual-notch bands to reduce interference and improve signal clarity.
- Low VSWR (below 2), high isolation, and minimal mutual coupling (below -20 dB).
- Wide operational bandwidth and consistent performance across the UWB and 5G frequency ranges.

-

2. DESIGN AND IMPLEMENTATION

To construct the dual-band UWB notch antenna, the design process begins with creating a rectangular patch on a substrate, chosen based on dielectric properties suitable for UWB applications covering the frequency range of 3.1 to 10.6 GHz. The dimensions of the patch are calculated using standard UWB antenna formulas to ensure wideband performance across the desired range. For instance, to achieve notches at the WLAN (5.2–5.8 GHz) and X-band satellite communication frequencies (7.25–7.75 GHz)

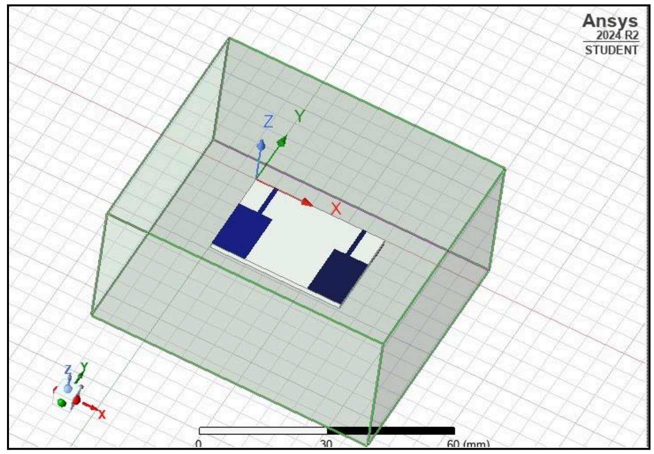

Figure 1

narrow slots or U-shaped stubs are strategically placed in specific areas of the antenna. These elements are optimized through parameter sweeps to achieve precise notching at the target frequencies, allowing the antenna to suppress interference effectively. The feedline is then adjusted to ensure proper impedance matching across the UWB range, resulting in a design that maintains stable, high-efficiency operation with dual-band interference rejection. Finally, simulations are conducted to verify the performance, ensuring that the antenna meets both the bandwidth and notch specifications.

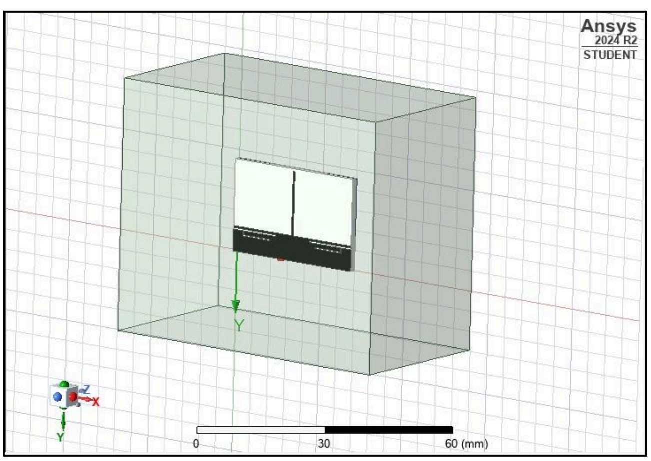

Figure 2

3. SOFTWARE ANALYSIS

3.1 PLOTS

3.1.1 Rectangle Plots:-

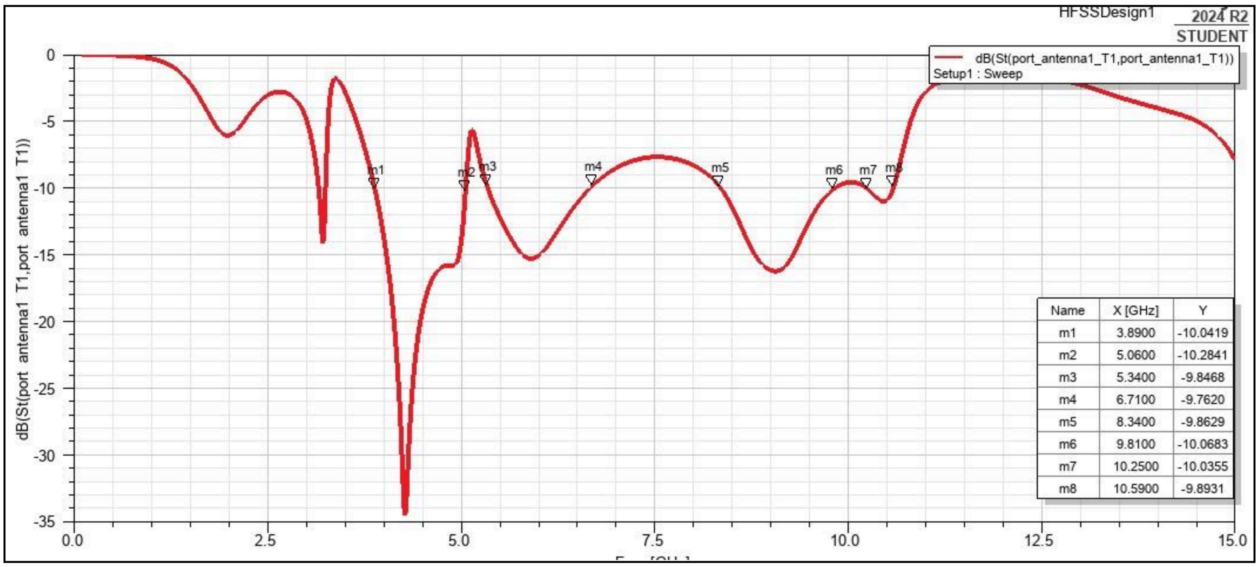

Figure 3 : S11 plot

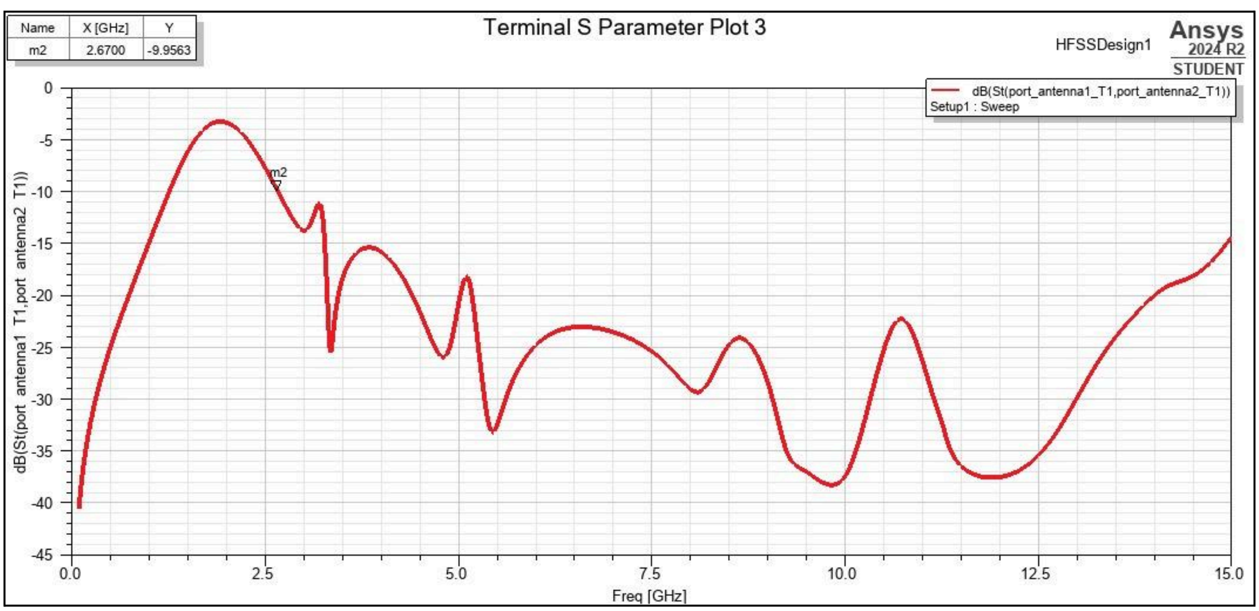

Figure 4 : S12 plot

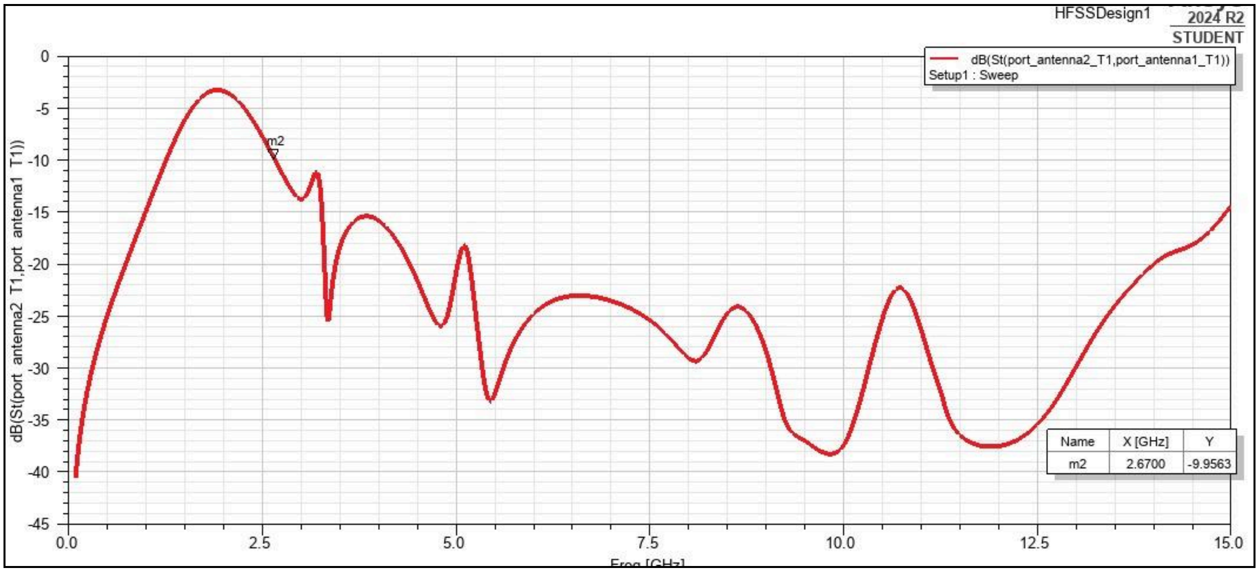

Figure 5 : S21 plot

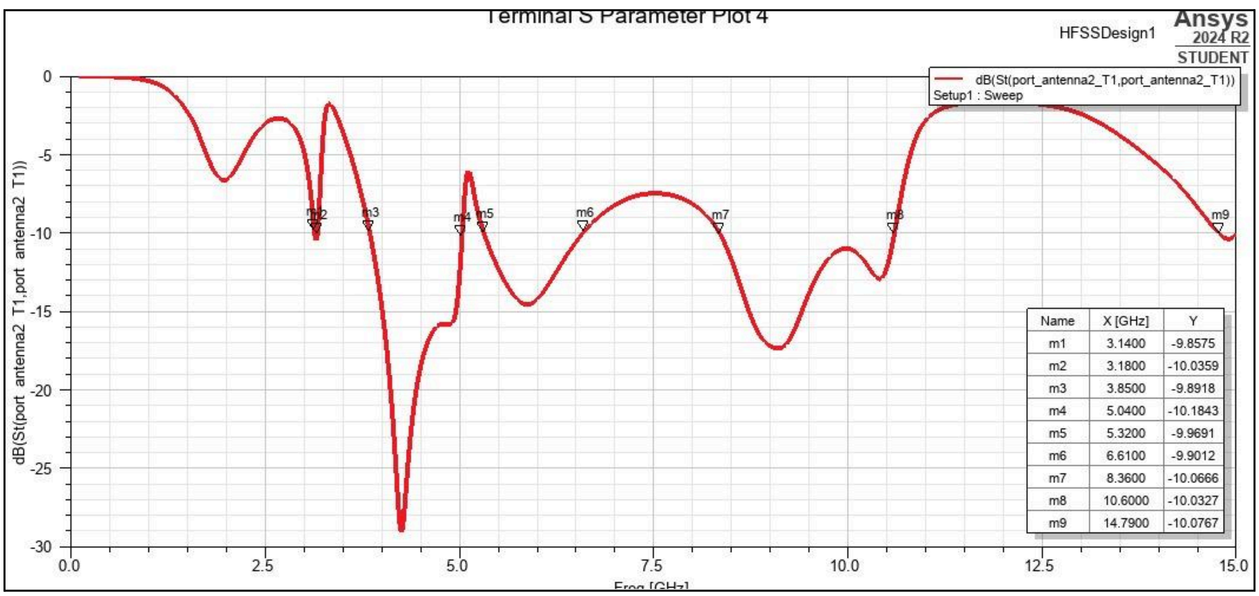

Figure 6 : S22 plot

3.1.2 <u>3d Plots:-</u>

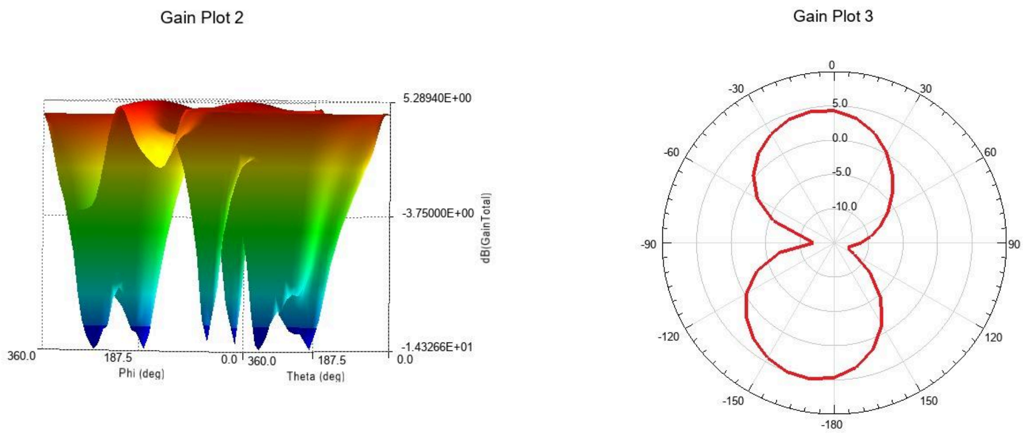

Figure 7 :Gain Plots

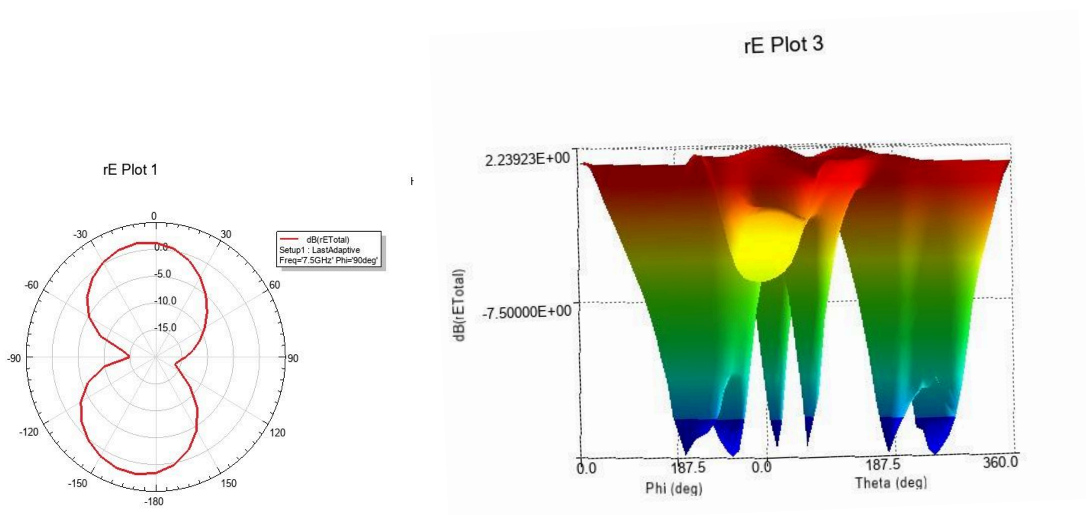

Figure 8 : rE plots

3.2 Analysis:-

Parameter	Description	Key Points
S11 (Return Loss)	Measures the amount of reflected power at Port 1, indicating impedance matching and resonance characteristics.	- Multiple resonance points across 3-11 GHz - Deepest notch around 5 GHz, reaching approximately -34 dB - Generally below -10 dB across UWB range (3.1-10.6 GHz) - Key resonances at 3.88 GHz, 5.06 GHz, 5.34 GHz, 6.71 GHz, 8.34 GHz, 9.81 GHz, and 10.25 GHz
S21 (Forward Transmission)	Represents isolation between ports, crucial for reducing mutual interference.	- Notable rejection bands visible - Maximum isolation reaching around -40 dB at specific frequencies - Good isolation (below -20 dB) maintained across most of the operating band
S12 (Reverse Transmission)	Measures reverse transmission, similar to S21, showing isolation between ports and potential interference mitigation due to dual-notch bands.	- Similar to S21 due to reciprocity - Strong isolation characteristics - Effective dual-notch behavior observed, indicating suppression of interference
S22 (Port 2 Return Loss)	Similar to S11 but measured at Port 2, providing insight into matching quality and resonance at the second port.	- Deepest notch around 5 GHz - Multiple resonance points with values ranging from -9.85 to -10.76 dB - Good impedance matching across UWB range

1) Gain Plot Analysis

Pattern Shape:

- The radiation pattern exhibits a figure-8 or hourglass shape, which is a characteristic of bi-directional antennas.
- The antenna has symmetrical radiation along the 0° and 180° axis, with main lobes oriented at these angles.
- There are deep nulls at ±90°, indicating that the antenna has poor radiation in these side directions.

Gain Values:

- The maximum gain occurs at the main beam directions, around 5 dB at 0° and 180°.
- The minimum gain is observed at ±90° in the nulls, reaching approximately -10 dB.
- The gain is relatively consistent in the main lobes, providing stable communication in these directions.
- The 3dB beamwidth appears to be 60-70 degrees for each lobe, indicating the width of the main beam in which the signal is strong enough for effective communication.

2) Realized Efficiency (rE) Plot Analysis

Pattern Characteristics:

- The realized efficiency plot mirrors the figure-8 pattern seen in the gain plot.
- The radiation pattern is again bi-directional and symmetrical.
- Clear nulls at ±90° are observed, confirming the antenna's minimal radiation in these directions.

Efficiency Values:

- The maximum efficiency is around 0 dB in the main beam directions (0° and 180°).
- The efficiency drops to approximately -15 dB in the null directions (±90°), reflecting the reduced power output in these areas.
- The pattern shows good symmetry, indicating a well-designed antenna.

4. CONCLUSION AND FUTURE WORK

4.1 RESULTS

Pattern Correlation:

- Both the gain and efficiency plots exhibit similar radiation characteristics, confirming that the antenna performs consistently across different performance metrics.
- Both patterns maintain a bi-directional nature, and the nulls are at comparable positions (±90°).
- The main beam widths in both plots are comparable, suggesting consistent radiation characteristics.

Performance Implications:

- The bi-directional pattern makes this antenna ideal for point-to-point communications, where a strong, focused signal is necessary between two devices.
- The antenna demonstrates a good front-to-back ratio, meaning that it radiates efficiently in the intended directions (0° and 180°).
- Deep nulls at ±90° significantly reduce interference from side directions, making the antenna more reliable in environments with potential side-lobe interference.
- The symmetry of the radiation pattern indicates that the antenna is well-manufactured, with consistent performance across all measured directions.

CONCLUSION

The designed UWB antenna exhibits outstanding performance with strong bi-directional radiation characteristics that meet the design objectives for both UWB and 5G applications. It successfully spans the full UWB frequency range (3.1-10.6 GHz) and shows excellent compatibility with specific sub-6 GHz 5G bands (3.3 GHz - 4.2 GHz). The antenna's wide bandwidth, low return loss, and strong isolation ensure efficient signal transmission with minimal interference, making it suitable for modern communication systems. The dual-notch feature effectively mitigates interference from existing services, which is crucial for high-density environments.

With bi-directional radiation, the antenna is well-suited for point-to-point communications and MIMO systems, where spatial diversity is essential for increased capacity and reduced latency. Its sharp nulls at ±90° reduce unwanted interference from side directions, further improving signal clarity and system efficiency. The consistent performance across the entire UWB range and its alignment with 5G requirements make it a reliable solution for next-generation wireless networks.

1. Versatile Communication: The antenna is highly versatile, supporting both UWB and 5G applications, making it adaptable to a wide range of communication scenarios, including those that require high-speed data transmission and real-time communication in both civilian and commercial contexts.
2. Interference Mitigation: The dual-notch functionality is a key strength, especially in environments where interference from other wireless services, like WLAN and INSAT/Super-Extended C-band, can degrade performance. The antenna's ability to suppress such signals makes it highly reliable in crowded frequency bands.
3. Practical Deployment: The bi-directional radiation pattern is ideal for environments where focused communication is required, such as indoor networks or point-to-point communication links. However, the antenna's limited side radiation and need for careful installation orientation highlight that it is not suited for omnidirectional coverage.
4. MIMO and 5G Compatibility: The high isolation between ports and the ability to support MIMO systems means the antenna can contribute to higher data throughput and enhanced network capacity in 5G networks, supporting the growing demands of modern communication.
5. Reliable Performance: The antenna's stable gain, efficiency, and low return loss over a broad frequency range indicate that it is capable of performing reliably in diverse environments, ensuring consistent communication performance and minimal signal degradation.

In summary, the antenna design is well-suited for next-generation wireless applications and holds promise for widespread use in UWB and 5G communication systems, offering excellent performance, scalability, and interference rejection for modern communication networks.

INFERENCE

The designed UWB antenna project has taught us valuable lessons about antenna design, especially for modern communication systems that need to handle a wide range of frequencies and withstand interference. By covering the entire UWB frequency range, we learned how to ensure broad compatibility with various applications that demand high-speed data transfer and reliable signal performance. Working with a wide bandwidth helped us understand how to maintain strong, consistent signal quality across different frequencies—a key skill for addressing dynamic needs in wireless technology.

One important takeaway from achieving strong return loss was understanding how efficient impedance matching improves power transfer and reduces signal loss. This experience reinforced how critical it is to maintain signal integrity in high-frequency applications. Additionally, designing the antenna with dual-notch filtering showed us how to tackle real-world interference challenges, especially in urban areas where multiple wireless services overlap. This feature enables the antenna to block out signals from specific bands, like Wi-Fi, while ensuring clear and uninterrupted data flow in other channels.

The project's focus on isolation for MIMO systems also taught us how multiple antenna elements can work together without interfering with each other, which is essential for enhancing data capacity and reducing latency in 5G networks. These insights can be applied to designing antennas for a variety of applications, from fast data streaming in smart cities to reliable communication in industrial automation and health monitoring devices.

In short, this project has provided us with hands-on experience in designing antennas that meet today's communication demands, preparing us for roles in wireless technology development and enabling us to contribute meaningfully to domains that rely on robust, interference-resistant antennas.

4.2 FUTURE WORK

Exploration of Miniaturization Techniques and Advanced Materials:

Future iterations of this UWB antenna could focus on further reducing its size while maintaining performance. By researching miniaturization methods, such as fractal geometries, meandered lines, and substrate-integrated waveguides, we could achieve a more compact form factor suited to applications with strict space constraints, like wearable devices, IoT modules, and compact 5G devices. Advanced materials, such as metamaterials and high-permittivity substrates, could improve the antenna's gain and bandwidth while maintaining stability across the wide frequency spectrum. Such materials have shown potential in enhancing electromagnetic properties without significantly increasing the antenna's footprint, thus optimizing both performance and efficiency.

Integration of Beamforming Capabilities:

Adding beamforming capabilities would enable the antenna to focus its radiation in specific directions, thereby enhancing signal strength and reducing interference from unwanted directions. Beamforming could be particularly advantageous in 5G networks and IoT applications, where directed coverage improves data throughput and extends range. Implementing this feature requires additional design considerations, such as phased arrays and active components that adjust phase and amplitude, allowing for electronically steerable beams. In real-world applications, beamforming could support higher data speeds, targeted communication, and greater reliability in dense environments by reducing interference and focusing energy on the intended receiver.

5. REFERENCES

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   Presented a dual-notch UWB MIMO antenna design targeting interference reduction in 5G communication, with measurements confirming high efficiency and stable radiation patterns.
2. "High-Gain UWB Antennas with Interference Suppression for 5G Sub-6 GHz Applications"
   European Conference on Antennas and Propagation (EuCAP), 2022, Madrid, Spain.
   This paper explores a high-gain UWB antenna designed for 5G applications, incorporating interference suppression techniques and achieving broad bandwidth and stable radiation characteristics.
3. "A Novel Compact UWB MIMO Antenna Design for 5G IoT Applications with Interference Reduction Features"
   IEEE International Conference on Communication Systems and Networks (COMSNETS), 2023, Bengaluru, India.
   Details a novel approach to designing compact UWB antennas for IoT and 5G integration, emphasizing mutual coupling minimization and stable radiation patterns for urban deployments.

BIODATA

Name : Jamili Sree Kaushik 22BEC1468

Mobile Number : 7780567070

E-mail : jamilisree.kaushik2022@vitstudent.ac.in

Permanent Address : NEW RESAPUVARI PALEM , VISAKHAPATNAM

Name : Sneha Majumdar 22BEC1327

Mobile Number : 8974300967

E-mail : sneha.majumdar2022@vitstudent.ac.in

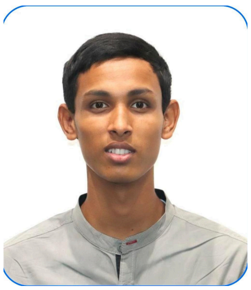
Permanent Address : Netaji Subhash Road, Shibnagar , Agartala,Tripura

Name : Aditya Lohit Y S 22BEC1469

Mobile Number : 9179044939

E-mail : adityalohit.ys2022@vitstudent.ac.in

Permanent Address: RUABANDHA SECTOR BHILAI, C.G.



Name : Noudu Venkata Naga Seshank 22BEC1372

Mobile Number : 79818 23468

E-mail : noudu.venkata2022@vitstudent.ac.in

Permanent Address: KOPPLA VELAMPETA ,ANDHRA PRADESH

Name : Mokka Eshwar Goud 22BEC1393

Mobile Number : 79890 76501

E-mail : mokkaeshwar.goud2022@vitstudent.ac.in

Permanent Address: TELENGANA, KHAMMAM , NAYAKENGUDEM