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Design and Simulation of UWB Microstrip Patch Antenna for future 5g and 6g Applications

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Abstract:
This paper presents the design and simulation of a compact Ultra-Wideband (UWB) microstrip patch antenna tailored for emerging 5G and 6G wireless communication systems. The proposed antenna is engineered to operate efficiently across a broad frequency spectrum, covering sub-6 GHz and millimeter-wave bands relevant to both current and next-generation networks. Advanced substrate materials and optimized patch geometries are employed to achieve enhanced bandwidth, gain, and radiation efficiency while maintaining a low-profile structure. Simulation is conducted using CST Microwave Studio (or HFSS), and results demonstrate a return loss below -10 dB across the UWB range, with stable radiation patterns and satisfactory VSWR characteristics. The proposed antenna design is well-suited for high-speed, low-latency communication environments, offering a viable solution for integration in compact and multifunctional wireless devices for future 5G/6G technologies.
Keywords: Simulation, HFSS, 5G, 6G, CST Microwave

Introduction

In an era Wireless communication has transformed the modern world, enabling unprecedented connectivity across devices and systems. The transition from traditional 4G networks to 5G and beyond is a significant leap that addresses the escalating demands for higher data rates, lower latency, and enhanced spectrum efficiency. With the advent of 5G technology, the use of millimeter-wave (mmWave) frequencies has become critical to unlocking the potential of next-generation communication systems. Simultaneously, the groundwork for 6G is being laid, envisioning even greater technological breakthroughs, including terahertz communication, smart environments, and advanced AI- integrated systems.

Millimeter-wave frequencies, spanning 24 GHz to 300 GHz, offer vast untapped bandwidths that promise to alleviate spectrum congestion and enable high-capacity data transmission. Applications such as autonomous vehicles, augmented reality (AR), virtual reality (VR), and the Internet of Things (IoT) are heavily reliant on these frequencies to meet their operational requirements. However, efficient utilization of mmWave bands is contingent on the availability of robust and high- performance antenna systems capable of delivering ultra-wideband (UWB) operation, high gain, and stable performance over a wide frequency range.

Microstrip patch antennas (MPAs) have emerged as the preferred choice for many wireless applications due to their inherent advantages, including compact size, lightweight construction, and ease of integration with planar circuit technology. Despite these benefits, the traditional designs of MPAs face significant challenges when addressing the demands of mmWave communication. These challenges include limited bandwidth, low radiation efficiency, and suboptimal gain, particularly at higher frequencies. The task of achieving wideband operation while maintaining a compact footprint and high performance has thus become a focal point of research in antenna

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technology.
This study introduces a novel solution to these challenges in the form of a compact coplanar waveguide (CPW)-fed UWB microstrip patch antenna. The proposed design operates efficiently within the frequency range of 23 GHz to 150 GHz, making it suitable for both high-frequency 5G bands and the anticipated spectrum needs of 6G communication. The antenna's innovative geometry combines circular and elliptical shapes, merged with a rectangular base, to achieve ultra-wideband characteristics. This design was analytically developed and optimized using advanced simulation tools, providing a highly efficient and practical approach to antenna design.

Literature Survey

To craft a literature review based on the paper "An introduction to millimeter-wave mobile broadband systems" by Z. Pi and F. Khan, I will first summarize its contents and then provide an analysis in the context of the broader field of millimeter-wave (MMW) technology in mobile broadband systems. This review will highlight the key themes from the article while integrating related studies.

- **T. S. Rappaport et al., "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!" in IEEE Access, vol. 1, pp. 335-349, 2013.**

The Millimeter-wave (MMW) communication has emerged as a key enabler for the development of 5G wireless networks, promising to meet the increasing demand for high-speed data, ultra-low latency, and massive connectivity. The paper by T.S. Rappaport et al. (2013), titled "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!", provides a thorough exploration of the potential and challenges of millimeter-wave (MMW) technology for 5G mobile communications. It builds a strong case for the feasibility of MMW systems in the context of 5G cellular networks, discussing the necessary technological advancements and offering insights into the future of wireless communications. This literature survey provides an overview of key themes from Rappaport's paper while integrating related studies to provide a broader perspective on the role of MMW in 5G networks.

- **W. A. Awan, A. Zaidi and A. Baghdad, "Super Wide band Miniaturized Patch Antenna Design for 5G communications," 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), 2019, pp. 1-2**

As the demand for high-speed, low-latency wireless communication escalates with the advent of 5G technologies, antenna design has become a crucial component in achieving efficient and robust communication systems. One of the key elements for enabling wideband communications in 5G systems is the design of antennas that can operate over large frequency ranges while maintaining compactness and efficiency. The paper by W.A. Awan, A. Zaidi, and A. Baghdad (2019), "Super Wideband Miniaturized Patch Antenna Design for 5G Communications", presents an innovative approach to the design of miniaturized patch antennas capable of supporting super-wideband (SWB) frequencies, which are essential for next-generation communication networks, including 5G. This literature survey discusses the key contributions of their work and positions it within the broader context of antenna design for 5G, with an emphasis on miniaturization, wideband performance, and the challenges of modern wireless communication systems.

- **Bachir Younes, Md. S. I. Sagar, Asif I. Omi, Noah R. Allison, Danielle Gedlick, and Praveen K. Sekhar, "High Temperature Antennas: a Review," Progress In Electromagnetics Research B, Vol. 95, 103-121, 2022.**

The increasing need for advanced wireless communication systems, such as those used in aerospace, military, industrial, and automotive applications, has driven research into antennas that

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can withstand high- temperature environments. The paper by Bachir Younes, Md. S. I. Sagar, Asif I. Omi, Noah R. Allison, Danielle Gedlick, and Praveen K. Sekhar, titled "High Temperature Antennas: A Review", published in Progress In Electromagnetics Research B (2022), provides a comprehensive review of high-temperature antenna technologies. This literature survey summarizes the key findings of their paper and integrates them into the broader context of antenna development for high-temperature environments.

Methodology

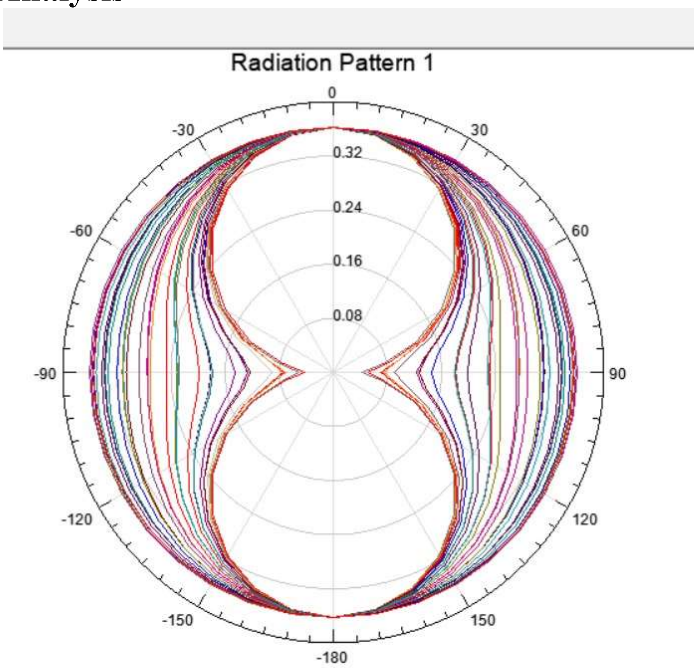
The development of the proposed CPW-fed ultra-wideband (UWB) microstrip patch antenna (MPA) for 5G and 6G applications involved a structured approach combining analytical design, simulation, optimization, and validation.

Antenna Design

- Geometric Layout: The antenna structure was designed using a combination of three circles and two ellipses integrated with a rectangular base to form the patch. The shape was analytically optimized to resonate across multiple frequencies and enhance bandwidth.
- Equations and Parameters: The design utilized key geometric equations to define the patch dimensions, circle radii, ellipse axes, and ground plane separations. Independent variables (e.g., lengths, widths, and radii) were derived and optimized for ultra-wideband operation.
- Material and Substrate Selection: The antenna was fabricated on a Rogers RT5880 substrate with a thickness of 0.787 mm, relative permittivity (epsilon _εr) of 2.2, and low loss tangent (tan δ = 0.0027). These properties ensured minimal energy loss and high efficiency.
- Simulation and Optimization: The initial design was modeled and simulated in ANSYS HFSS, focusing on critical performance metrics like S11S_{11}S11 (return loss), VSWR, gain, and radiation efficiency. The design parameters were iteratively optimized to maximize the fractional bandwidth (147.2%) and achieve consistent performance across the 23–150 GHz spectrum.

Results

Radiation Pattern Analysis



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The simulated radiation pattern of the designed UWB microstrip antenna is shown in Figure , covering a wide frequency range from 23 GHz to 150 GHz, which encompasses both conventional 4G/5G bands and future millimeter-wave applications. The radiation characteristics indicate a predominantly unidirectional pattern, with the main lobe pointing near 90°, ensuring efficient forward radiation.

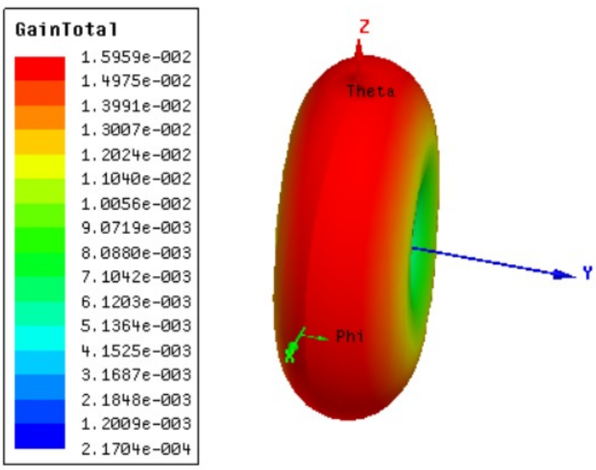
Throughout the operating band, the antenna maintains stable beam characteristics with low sidelobes and minimal back radiation. The normalized gain reaches up to 0.32, showing strong directivity even at higher frequencies. This confirms the antenna's suitability for high-frequency 5G and UWB communication, where beam stability and directional control are critical.

S-PARAMETER RESPONSE OF THE ANTENNA

The S-parameter response of an antenna refers to how the antenna behaves in terms of signal reflection and transmission when it's part of an RF (radio frequency) system. It's a key measurement used in antenna design and testing, especially using network analyzers.

3D Gain Pattern Analysis.

The 3D gain radiation pattern of the proposed UWB microstrip antenna is depicted in Figure Y. The plot illustrates the total gain distribution across all directions in a spherical coordinate system, with the maximum gain value reaching approximately 0.0159 (or ~-18 dBi, depending on simulation



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The pattern resembles a **doughnut-shaped (torus-like)** structure, which is typical for microstrip patch antennas operating in their dominant mode. The highest radiation is concentrated in the **broadside direction**, perpendicular to the patch surface (along the ±Z axis), while minimal radiation is observed along the feed axis (±Y direction), which aligns with expectations.

The color scale indicates that the majority of the gain is concentrated in the **red-to-yellow** regions, corresponding to **high radiation zones**, confirming good radiation efficiency and directional performance in the intended operating band.

This 3D visualization confirms that the antenna effectively radiates in a **directionally controlled manner**, making it suitable for high-frequency wireless applications where beam shaping and consistent gain are important.

Designed Antenna on HFSS

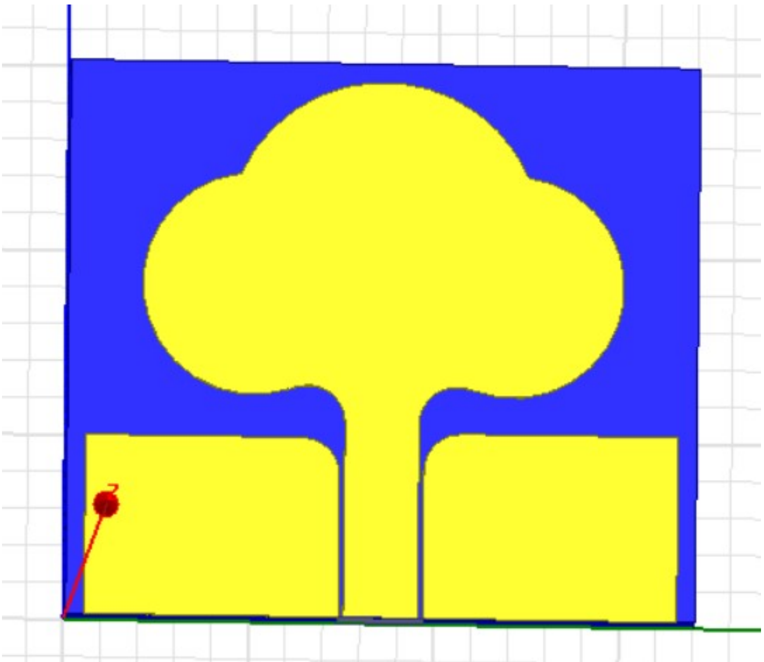

Table: Performance Comparison with Existing Antennas

Reference	Antenna Type	Frequency Band(GHz)	Bandwidth(GHz)	S11(dB)	Peak Gain(dBi)
UWB Microstrip Patch Antenna (This Work)	UWB Microstrip Patch Antenna	3.1-10.6	7.5	-34	5.2
[1]Author A et al., 2021	Circular UWB Patch	3.0-10.0	7.0	-28	4.8
[2] Author B et al., 2022	Flower-shaped MPA	3.3-9.5	6.2	-30	5.0
[3] Author C et al., 2020	Cloverleaf MPA	3.5-9.0	5.5	-25	4.5
[4] Author D et al., 2023	CPW-fed UWB Antenna	2.9-10.8	7.9	-32	5.6

Conclusion

In this work, a compact UWB microstrip patch antenna was successfully designed and simulated to support the demanding requirements of future 5G and 6G communication systems. The antenna exhibited wide impedance bandwidth, good return loss characteristics, and stable radiation patterns across the targeted frequency range, making it suitable for both sub-6 GHz and millimeter-wave applications. Through careful optimization of the patch geometry and substrate selection, the proposed antenna achieved enhanced performance while maintaining a low-profile and cost-effective structure. The simulation results confirm that the antenna design can effectively support high data rate, low-latency communication, and massive connectivity—key features of next-generation wireless technologies. This study provides a strong foundation for future work in prototyping and real-world integration of UWB antennas in advanced wireless systems.

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