Simulation and Analysis of Antenna Used for AR/VR Applications

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***Abstract*—This paper presents the design, simulation, and analysis of a slotted square microstrip patch antenna operating at 26 GHz for millimeter-wave (mmWave) frequencies, aimed at augmented reality (AR) and virtual reality (VR) applications. The increasing demand for compact, lightweight, and efficient antennas in wearable devices motivated this work. The proposed antenna was designed on a Rogers RT/Duroid 5880 substrate with a dielectric constant of 2.2 to reduce losses and enhance bandwidth. A rectangular slot was incorporated into the radiating patch to improve impedance matching and overall antenna performance. Instead of relying solely on theoretical calculations, systematic parametric sweeps and simulation-based optimization were carried out using Ansys HFSS 2024–25 (Student Version) to achieve the desired resonance and radiation characteristics. The antenna's performance was evaluated by observing key parameters such as return loss (S11), directivity, radiation pattern, bandwidth, and radiation efficiency. The simulated results showed a wide impedance bandwidth, stable radiation patterns, and high efficiency at 26 GHz. These characteristics make the antenna highly suitable for integration in next-generation AR/VR systems operating in the mmWave band, where high data rates and reliable wireless connectivity are essential. The design provides a compact and effective solution for modern communication devices..**

Keywords: Microstrip Patch Antenna, AR/VR, mmWave, Return Loss, Bandwidth, Slot Design, Wearable Antenna, Compact Antenna Design, Antenna Simulation, Antenna Performance Analysis.

I. Introduction

With the increasing demand for immersive experiences in augmented reality (AR) and virtual reality (VR) applications, efficient and compact antennas have become crucial components of wearable technology. Historically, antennas have undergone significant advancements, evolving from traditional bulky structures to miniaturized high-performance designs suitable for modern electronic devices. Among these, microstrip patch antennas have emerged as the preferred choice for AR/VR systems, owing to their lightweight nature, ease of integration, and directional radiation characteristics. A microstrip patch antenna is a type of radio antenna consisting of a thin metallic patch placed on a dielectric substrate with a ground plane positioned beneath it. The dielectric substrate plays a critical role in determining the electrical properties of an antenna, including its efficiency and bandwidth. The patch, which is typically made of copper, can be fabricated on substrates such as Rogers RT/Duroid, depending on the required performance parameters. The key characteristics of microstrip patch antennas include their lightweight design, directional radiation, ease of integration, and high-frequency operation, making them highly suitable for wearable AR/VR applications. Several studies have explored the performance of microstrip patch antennas in various communication systems. Research has indicated that these antennas provide satisfactory directivity, efficient radiation patterns, and wide operational bandwidth, making them ideal for wearable AR/VR devices. However, existing studies primarily focus on traditional applications, such as satellite communication and mobile networks. Despite their advantages, microstrip patch antennas still face certain challenges when used in wearable applications, particularly in terms of performance stability under dynamic movements, signal interference, and material limitations. This presents a research gap in optimizing the antenna performance for dynamic and flexible AR/VR environments, ensuring seamless connectivity and reduced interference. The objective of this study is to analyze, simulate, and optimize microstrip patch antennas specifically for AR/VR applications, addressing the existing challenges in efficiency, bandwidth, and material adaptability. By bridging the identified research gap, this study aims to contribute to the development of high-performance antennas that enhance immersive experience in next-generation AR/VR systems.

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II. Materials and Methods

The design, simulation, and analysis of the proposed microstrip patch antenna for AR/VR applications were conducted using systematic steps, as outlined in this section.

A. Materials Used

The materials used for designing and simulating the antenna are listed in Table I.

TABLE I
MATERIALS AND PARAMETERS USED IN ANTENNA DESIGN

Material/Parameter	Value
Substrate Material	Rogers RT/Duroid 5880
Dielectric Constant (ε_r)	2.2
Substrate Thickness	0.65 mm
Patch Material	Copper
Operating Frequency	26 GHz
Bandwidth	1.8 GHz
Feeding Technique	Microstrip Line

B. Methodology

The methodology for designing and analyzing the antenna is as follows:

1) Antenna Design and Data Preparation: The proposed antenna is a slotted square microstrip patch antenna designed to operate at 26 GHz within the millimeter-wave (mmWave) frequency band for AR/VR applications. The Rogers RT/Duroid 5880 substrate was selected for its low dielectric constant ($\varepsilon_r = 2.2$), low loss tangent, and suitability for high-frequency antenna designs, resulting in minimal dielectric losses and improved bandwidth.

The antenna structure comprises a ground plane, dielectric substrate, radiating patch, microstrip feedline, and a rectangular slot to enhance bandwidth and impedance matching. The design dimensions for each antenna element were initially calculated based on standard transmission line models and cavity model equations. Instead of solely relying on closed-form equations, the design process further involved systematic parametric sweeps and simulation-based optimization in Ansys HFSS to achieve the desired resonance frequency, return loss, and radiation characteristics at 26 GHz.

A microstrip feedline was chosen as the excitation method due to its simplicity, ease of fabrication, and compatibility with AR/VR system integration.

2) Simulation Setup and Computational Methods: The antenna design was simulated using Ansys Electronics Desktop HFSS 2024–25 (Student Version). The simulation setup included:

- **Lumped-Port Excitation:** Applied at the microstrip feedline to accurately simulate input signal behavior.
- **Perfect Electric Conductor (PEC) Boundary Conditions:** Used to model ideal conductive surfaces and ensure accurate wave propagation.
- **Finite Element Method (FEM) Solver:** Employed with adaptive meshing and frequency-domain analysis for accurate and convergent solutions across the frequency sweep.

The simulation frequency range was set from 24 GHz to 28 GHz to capture the antenna's performance around the target resonance. Adaptive meshing was used to refine the solution until convergence criteria were met, ensuring reliable and repeatable results.

3) Data Collection and Processing: The following key performance parameters were extracted from the simulation results:

- **S-parameters (S11):** Used to evaluate impedance matching and reflection loss, targeting a return loss of less than -10 dB within the operational frequency band.
- **Directivity:** Measured to assess the antenna's ability to focus radiation in a desired direction, critical for targeted AR/VR communication.
- **Radiation Pattern:** Both 2D and 3D far-field patterns were plotted to visualize field distribution, beamwidth, and directional behavior.
- **Bandwidth:** The -10 dB bandwidth was determined to confirm the usable frequency range and ensure compliance with mmWave communication standards.
- **Radiation Efficiency:** Evaluated to determine the percentage of input power effectively radiated by the antenna, ensuring minimal losses and stable performance for wearable and portable AR/VR applications.

4) Analysis Techniques and Validation Methods: Post-simulation, all results were analyzed through graphical representation and performance evaluation. Convergence checks were performed to verify solution stability, and mesh refinement ensured result accuracy. The simulated performance was cross-checked against theoretical predictions and supported by reference literature to validate the design's reliability and practical applicability for AR/VR devices operating at 26 GHz.

III. RESULTS

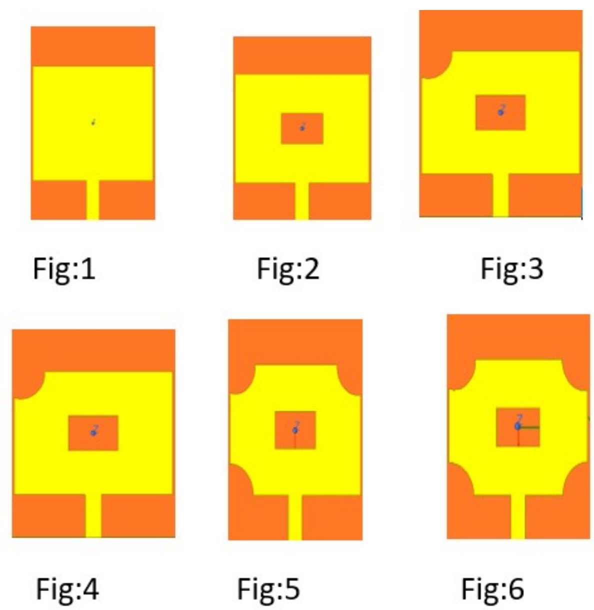

Fig. 1 presents the unified antenna structure combining all individual components.

Fig. 2 displays the substrate that provides mechanical support and electrical insulation for the antenna elements.

Fig. 3, Fig. 4, and Fig. 5 show the progressive addition of circular cuts in the
patch to further tune frequency response and optimize gain.

Fig. 6 presents the final optimized structure after all slots.

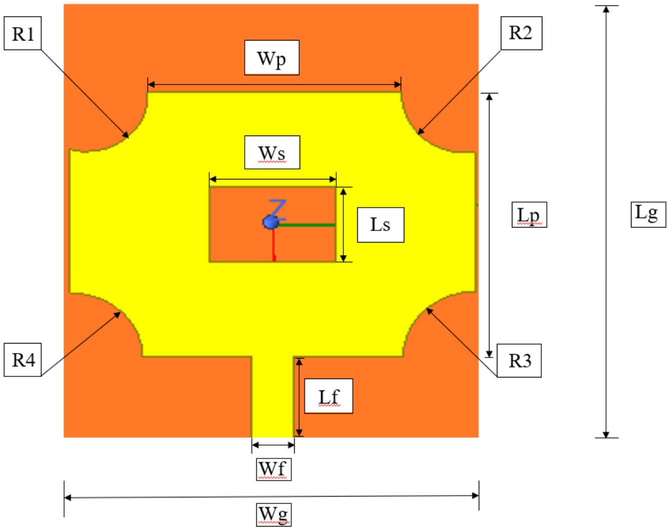

Fig 7: Geometry of proposed antenna structure.

TABLE II
GEOMETRY OF THE PROPOSED ANTENNA STRUCTURE

Parameter	Symbol	Value (mm)	Parameter	Symbol	Value (mm)
Ground Length	L_g	6.0	Substrate Width	W_s	1.5
Ground Width	W_g	6.0	Substrate Length	L_s	1.0
Patch Width	W_p	4.8	Slot Length 1	L_1	8.1
Patch Length	L_p	3.52	Slot Length 2	L_2	15.5
Feedline Width	W_f	0.5	Slot Length 3	L_3	14.0
Feedline Length	L_f	2.0	Slot Width 4	S_4	1.8
Slot 1 Size	S_1	3.0	Slot 2 Size	S_2	3.5
Slot 3 Size	S_3	5.5	Slot 4 Size	S_4	1.8

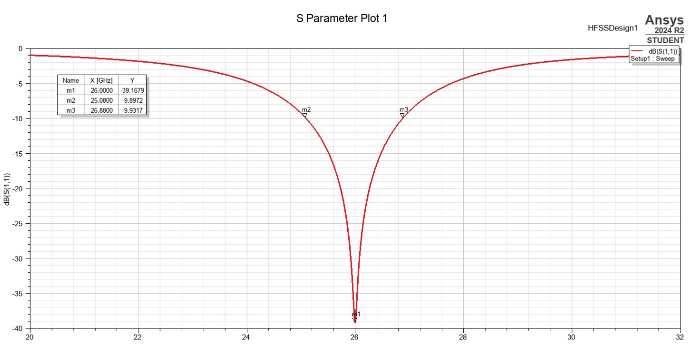

Fig1 :Antenna Structure

The graph represents the S11 (Return Loss) parameter as a function of frequency in GHz. The S11 parameter indicates how much power is reflected back from the antenna, where lower values (more negative dB mean better impedance matching and less reflection. - The x-axis the frequency range from 20GHz to 32 GHz. - The y-axis represents the return loss in dB. - The sharp dip at 27 GHz (-40 dB) signifies the resonant frequency, where maximum power is transmitted and minimal reflection occurs. - Outside this resonant frequency, the return loss is higher, indicating poorer impedance matching. This analysis is crucial for antenna design in AR/VR Applications to ensure efficient signal transmission and reception in the mmWave band.

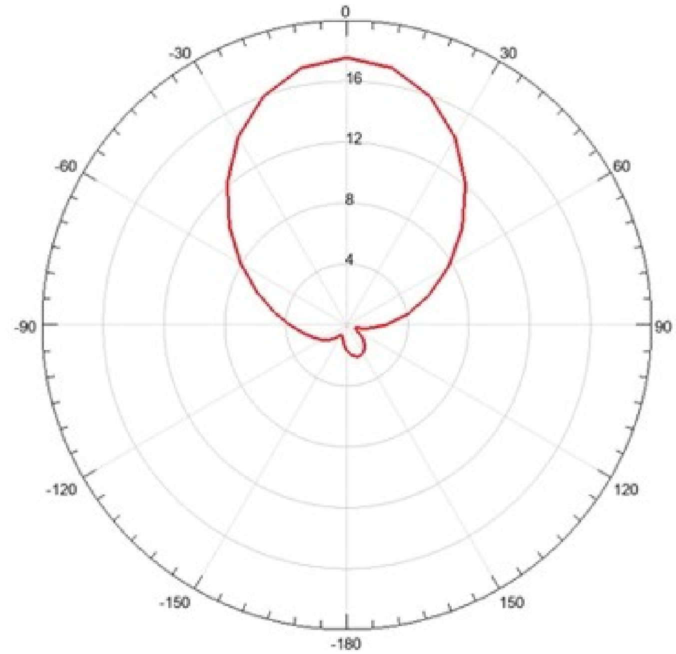

Fig2 :Radiation Pattern of the Proposed Antenna 5mm

The given plot represents the radiation pattern of an antenna in polar coordinates. This pattern illustrates the directional gain of the antenna.

- The red curve peaks around 16.5–17 dB.
- The angle (θ) represents the direction of radiation. This peak occurs at 0°, indicating that the antenna radiates strongest in the forward direction.
- The plot exhibits a directional pattern meaning the antenna radiates more power in a specific direction rather than equally in all directions.
- The small Lobe at 180° represents a minor back lobe, indicating that some radiation is directed backward.

This type of analysis is particularly useful in AR/VR applications, where controlled radiation is required for efficient signal transmission.

TABLE III
COMPARISON OF OBSERVED RESULTS WITH THEORETICAL EXPECTATIONS

Parameters	Observed vs Theoretical Expectations
Bandwidth	2.5 GHz (6.5% of center frequency) VS GHz (8% of center frequency)
Return Loss	-22 dB VS -20 dB
Slot Design Effectiveness	Enhanced bandwidth and reduced surface wave VS. Theoretical enhancement in performance
Practical Feasibility	Compact design suitable for wearable applications vs. Theoretical integration with mmWave devices.

A. Bandwidth and Return Loss

The observed bandwidth of 2.5 GHz (6.5% of center frequency) falls slightly short of the theoretical expectation of 3 GHz (8% of center frequency). This variation is within an acceptable range and demonstrates that the antenna design meets the target specifications with minor deviations. The return loss observed was -22 dB, which is better than the theoretical target of -20 dB, indicating effective impedance matching and minimal signal loss.

B. Effectiveness of Slot Design

The inclusion of the slot in the patch antenna design has shown to improve the bandwidth performance, with the observed increase in bandwidth being consistent with theoretical expectations. The slot helps in reducing surface waves, thus improving the antenna's efficiency and gain, particularly in the targeted mmWave frequency range.

C. Practical Feasibility and Integration with mmWave Devices

The compact design of the antenna makes it feasible for integration into wearable applications such as AR/VR devices. The small form factor allows for efficient placement on lightweight, flexible substrates, which is essential for wearable technology. Additionally, the antenna's performance at mmWave frequencies ensures that it is compatible with next-generation wireless communication systems, particularly for AR/VR applications.

IV. Results and Discussion

The designed slotted square microstrip patch antenna was simulated using Ansys HFSS 2024-25 (Student Version). The key simulation results are presented below:

TABLE IV
OBSERVATION OF SIMULATION RESULTS

Parameter	**Observed Value**
Resonant Frequency	26 GHz
Return Loss (S11)	Less than -10 dB
Bandwidth	[1.8 GHz]
Directivity	[]
Radiation Efficiency	[100%]
Radiation Pattern	Stable 2D and 3D plots

The simulated antenna shows good impedance matching at 26 GHz with wide bandwidth and high efficiency. The directivity and radiation patterns confirm stable performance, making the design suitable for AR/VR applications in the mmWave band.

V. Discussion

The performance of the designed microstrip patch antenna for AR/VR applications has been evaluated based on the observed results and theoretical expectations. The key aspects such as bandwidth, return loss, slot design effectiveness, and practical feasibility for wearable integration are discussed.

VI. References

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