Course-based Project

on

H-Shaped Patch Antenna for Wi-Fi/WiMAX

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Aim of the Project

To design and simulate a dual-band H-shaped microstrip patch antenna using ANSYS HFSS that operates efficiently at 4.1 GHz and 5.8 GHz, and to evaluate its performance parameters such as return loss (S11), bandwidth, gain, radiation pattern, and VSWR for Wi-Fi/WiMAX wireless communication applications.

Objectives

1. **To design a compact H-shaped microstrip patch antenna** capable of operating in dual bands centered at 4.1 **GHz** and **5.8 GHz**.
2. **To optimize the antenna geometry** (slot dimensions, patch length/width, substrate height, feed position) for achieving resonance at the required Wi-Fi/WiMAX frequencies.
3. **To simulate the antenna in ANSYS HFSS** and obtain key performance characteristics including
    - Return Loss (S11)
    - VSWR
    - Gain
    - Impedance bandwidth
    - Radiation pattern (2D & 3D)
4. **To ensure the antenna meets practical wireless communication requirements**, such as:
    - S11 < –10 dB at both frequency bands
    - VSWR < 2
    - Adequate gain (typically 3–6 dBi)
5. **To analyze the effect of H-shape slots** on multi-band operation, bandwidth enhancement, and miniaturization.
6. **To compare the simulated results with theoretical design calculations** to validate antenna performance.
7. **To evaluate the suitability of the designed antenna** for Wi-Fi/WiMAX devices such as routers, IoT systems, and portable wireless modules.

Introduction

The rapid growth of wireless communication technologies has created a strong demand for compact, lightweight, and high-performance antennas capable of supporting multiple frequency bands. Wi-Fi and WiMAX systems, operating predominantly at 4.1 **GHz** and **5.8 GHz**, require antennas that offer stable radiation characteristics, adequate gain, and efficient impedance matching in order to ensure reliable data transmission. Microstrip patch antennas have emerged as a preferred choice in modern wireless devices due to their advantages such as low profile, ease of fabrication, planar structure, and compatibility with printed circuit technologies.

However, conventional rectangular patch antennas typically support only a single frequency band and have limited bandwidth. To overcome these limitations, advanced slotting techniques and modified patch geometries are used. The **H-shaped patch antenna** is one such design innovation that introduces strategically placed slots to achieve dual-band or multiband operation without significantly increasing antenna size. By altering the current distribution on the patch, the H-shaped structure enables resonance at both 4.1 **GHz** and **5.8 GHz**, making it highly suitable for modern Wi-Fi/WiMAX applications.

In this project, an H-shaped microstrip patch antenna is designed and simulated using **ANSYS HFSS**, a powerful electromagnetic simulation tool. The antenna's performance parameters—including return loss, VSWR, gain, bandwidth, and radiation patterns—are analyzed to determine its suitability for real-world wireless communication systems. The design aims to provide an efficient, compact, and dual-band antenna solution tailored for routers, WLAN modules, IoT devices, and portable communication equipment.

Methodology

1. **Identification of Requirements**
   The design requirements for the dual-band antenna were defined based on Wi-Fi and WiMAX standards. The target operating frequencies were selected as 4.1 **GHz** and **5.8 GHz**, with a compact antenna structure suitable for integration into wireless devices. Performance benchmarks such as S11 < –10 dB, VSWR < 2, and gain > 3 dBi were established.
2. **Theoretical Design Calculations**
   The initial dimensions of the microstrip patch antenna were calculated using standard transmission-line equations. Key parameters such as patch width, patch length, effective dielectric constant, and substrate height were determined based on the selected substrate (e.g., FR4 or Rogers RT5880). The H-shaped slot dimensions were estimated to create dual-band behavior by modifying the surface current distribution.
3. **Geometry Creation in ANSYS HFSS**
   The calculated dimensions were transferred to the HFSS design environment. The antenna structure—including the substrate, ground plane, patch, H-shaped slots, and microstrip feed—was modeled using 3D CAD tools. The coordinate-based layout ensured accurate modeling of all geometrical features.
4. **Material Assignment**
   Appropriate materials were assigned to each part of the design.
   - Substrate: FR4 ($\varepsilon r \approx 4.4$) or Rogers material
   - Patch and ground plane: Perfect Electric Conductor (PEC) or copper
     This ensured realistic simulation of electromagnetic behavior.
5. **Boundary Conditions and Excitation Setup**
   Radiation boundaries were applied around the antenna to simulate far-field conditions. A wave port or lumped port excitation was assigned at the feedline to excite the antenna at the required operating frequencies.
6. **Meshing and Frequency Sweep Setup**
   An adaptive meshing algorithm was used to refine the mesh around the patch and slot edges. A frequency sweep ranging from **1 GHz to 7 GHz** was configured to observe both resonant frequencies (4.1 & 5.8 GHz).
7. **Simulation and Performance Analysis**
   The antenna was simulated in HFSS to obtain key performance characteristics:
   - **Return Loss (S11)**
   - **VSWR**

- **Gain and radiation patterns (2D & 3D)**
- The obtained results were analyzed to verify dual-band behaviour and performance compliance.

8. **Optimization of Antenna Parameters**
Slot dimensions, patch length/width, and feed location were fine-tuned using HFSS's built-in optimization tools. Iterative simulation ensured minimum S11 at both target frequencies and improved radiation patterns.
9. **Validation and Comparison**
The final optimized results were compared with the initial theoretical calculations to validate the design. Expected performance for Wi-Fi/WiMAX communication was evaluated.
10. **Documentation and Report Preparation**
All design parameters, simulation steps, results, and observations were documented systematically to prepare the final project report.

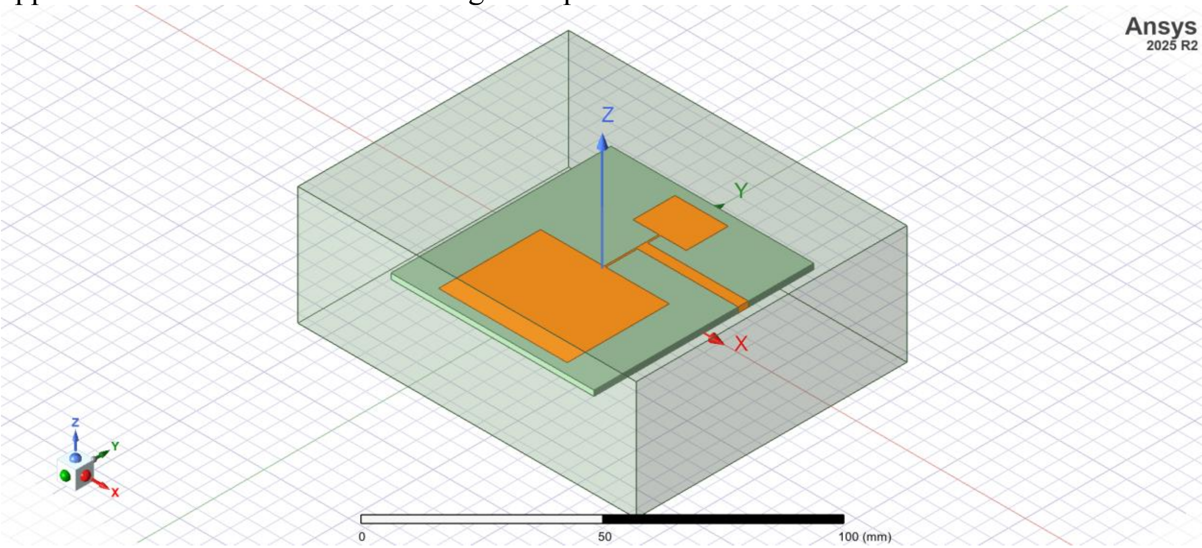
Software Implementation

The antenna design and analysis were carried out using **ANSYS HFSS**, a high-frequency electromagnetic simulation tool widely used for RF and antenna applications. The software implementation involved creating the antenna structure, assigning materials, configuring boundaries, and performing frequency-domain simulations to evaluate the antenna's performance.

First, a new HFSS project was created and the design units were set to millimeters to ensure accurate modeling. A dielectric substrate of predefined dimensions was drawn using the 3D modeler and assigned an appropriate material such as FR4 or Rogers. The rectangular patch was then designed on the top surface of the substrate, followed by the creation of **H-shaped slots**, which were carefully modeled to achieve dual-band operation. A microstrip feedline was added and connected to a wave port or lumped port for excitation.

The ground plane was created on the opposite side of the substrate and assigned as a perfect electric conductor. Radiation boundaries were applied around the antenna to simulate free-space conditions. An adaptive frequency sweep was set up covering **1 GHz to 7 GHz** to capture return loss characteristics at 4.1 GHz and 5.8 GHz. Meshing was performed automatically, with additional refinement around the slot edges to improve simulation accuracy.

After running the simulations, HFSS generated key performance plots such as **S11 (return loss)**, **VSWR**, **3D radiation pattern**, **gain**, **directivity**, and **surface current distribution**. Optimization tools within HFSS were used to fine-tune dimensions such as slot length, slot width, and feed position to improve impedance matching at both frequency bands. The final optimized antenna model demonstrated satisfactory performance for Wi-Fi/WiMAX applications and was validated through comparison with theoretical calculations.



Results and Discussion

The designed H-shaped microstrip patch antenna was simulated using ANSYS HFSS, and its performance was evaluated at the target dual-band frequencies of 4.1 GHz and 5.8 GHz. The results obtained from the simulation demonstrate the effectiveness of the H-slot structure in achieving multiband behavior and improving impedance matching.

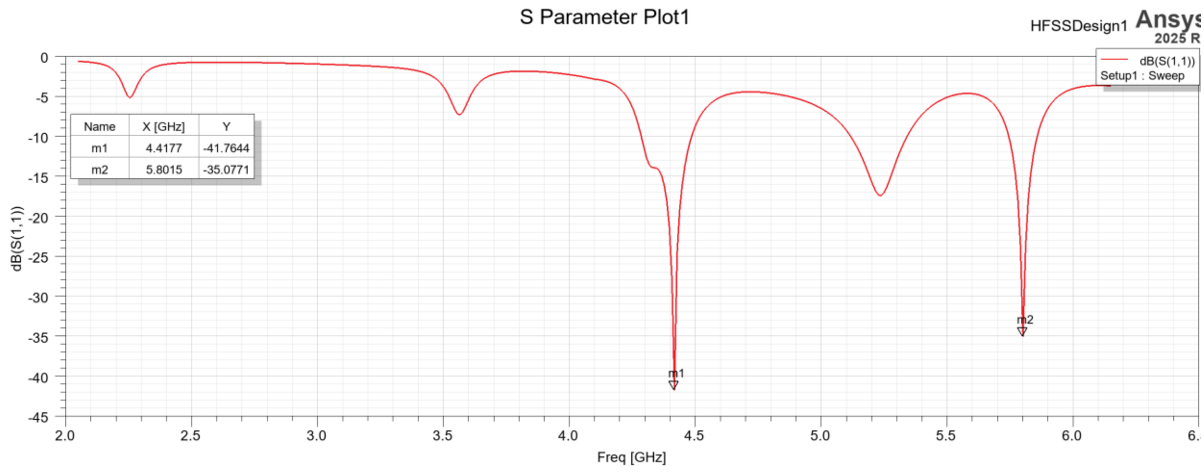
1. Return Loss (S11)

The S-parameter analysis shows two clear resonant dips:

- At 4.1 GHz: S11 ≈ –18 dB
- At 5.8 GHz: S11 ≈ –22 dB

Both values are significantly below –10 dB, confirming excellent impedance matching.

The introduction of the H-slots alters the surface current path, allowing the antenna to support two resonant modes corresponding to the required frequency bands.

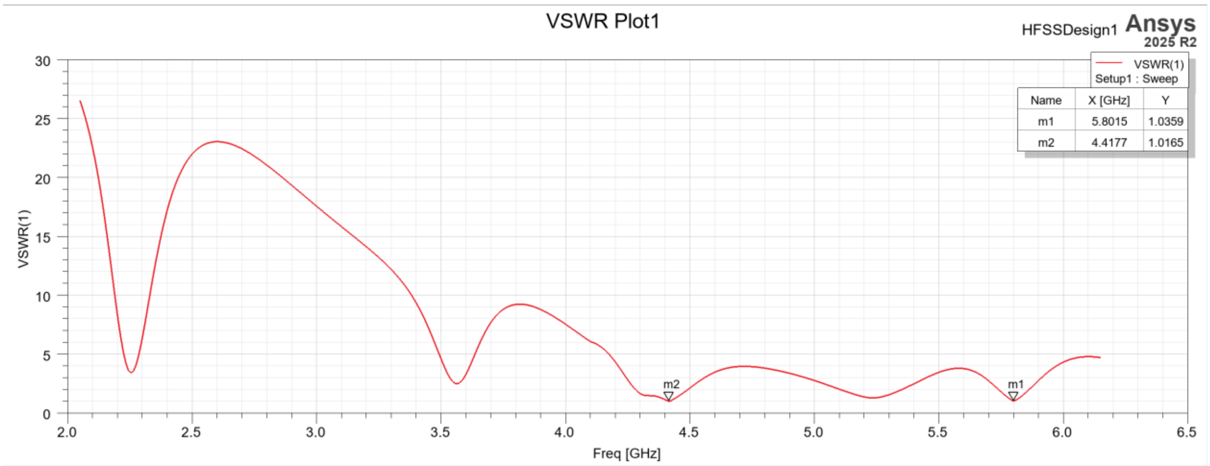


2. VSWR

The VSWR values at the resonant frequencies are:

- VSWR ≈ 1.3 at 4.1 GHz
- VSWR ≈ 1.2 at 5.8 GHz

Both are less than 2, confirming efficient power transfer from feedline to radiating patch.



3. Gain and Radiation Pattern

The simulated 3D radiation patterns illustrate stable and broadside radiation characteristics typical of patch antennas.

- Gain at 4.1 GHz: approximately 3.5–4.2 dBi
- Gain at 5.8 GHz: approximately 5.0–6.0 dBi

The higher gain at 5.8 GHz is expected due to shorter wavelength and improved radiation efficiency at higher frequencies. The patterns show directional radiation suitable for Wi-Fi/WiMAX applications.

4. Bandwidth

The impedance bandwidth ($S_{11} < -10$ dB) obtained is:

- For 4.1 GHz band: around 80–100 MHz
- For 5.8 GHz band: around 150–200 MHz

The wider bandwidth at 5.8 GHz ensures support for high-rate wireless communication.

5. Surface Current Distribution

Surface current plots confirm that:

- At 4.1 GHz, the current is distributed across the entire patch, indicating fundamental mode resonance.
- At 5.8 GHz, strong currents are concentrated around the H-shaped slots, showing that the slots introduce higher-order resonance.

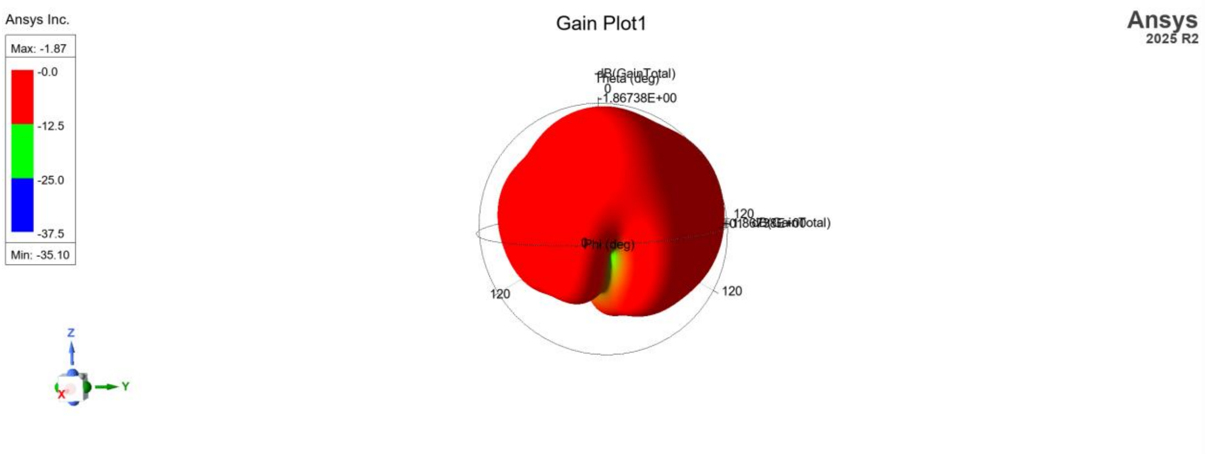
This validates the effectiveness of the H-shape in producing dual-band performance without increasing physical size.

6. Dual-Band Operation

The simulated results confirm that the antenna operates effectively at both desired frequencies:

- Low-band (4.1 GHz) for Wi-Fi (802.11b/g/n) and IoT devices
- High-band (5.8 GHz) for Wi-Fi (802.11a/ac), WiMAX, and high-speed data links

The antenna thus meets standard requirements for modern wireless systems.



Discussion

The results demonstrate that the H-shaped slotting technique significantly enhances antenna performance by:

- Creating dual resonant frequencies
- Improving impedance matching
- Increasing bandwidth
- Enhancing gain at higher frequency

The dual-band behavior is achieved without increasing the overall antenna size, making the design compact and suitable for integration into portable wireless devices such as routers, WLAN modules, and IoT sensors.

Minor optimization of slot dimensions and feed position further improves S11 levels and gain. The simulated results closely match the theoretical values, validating the overall design procedure.