Printed Patch, Circular Polarization, Dual Band

Antenna Propagation Report

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Contents

1 Introduction

Wireless communication systems require antennas with dual-band operation and circular polarization to enhance signal reliability and minimize polarization mismatch losses. The 2.4 GHz and 5.6 GHz frequency bands are widely used for Wi-Fi, IoT, and satellite communication applications. This report details the design, simulation, and analysis of a dual-band circularly polarized printed patch antenna using HFSS.

The primary objectives of this study are:

- To design a microstrip patch antenna with dual-band operation at 2.4 GHz and 5.6 GHz.
- To achieve circular polarization for better signal reception.
- To ensure an impedance matching of 50 Ω.
- To obtain a low VSWR (≤ 2) and axial ratio ≤ 3 dB.
- To analyze key parameters such as beamwidth, side lobe level, and radiation pattern.

This report presents the theoretical background, design methodology, simulation setup, and results obtained from HFSS.

2 Basic Theory

2.1 Microstrip Patch Antennas

A microstrip patch antenna consists of a radiating metallic patch on a dielectric substrate with a ground plane on the other side. These antennas are widely used due to their lightweight, low profile, and ease of fabrication.

2.2 Circular Polarization in Patch Antennas

A patch antenna is circularly polarized (CP) when it produces two orthogonal electric field components with a 90° phase difference. Circular polarization improves signal reception by reducing multipath fading and polarization mismatch losses. Methods to achieve circular polarization include:

- Corner truncation – Removes parts of the patch to introduce phase delay.
- Diagonal slot loading – Introduces asymmetry to excite two orthogonal modes.
- Dual-feed excitation – Uses two orthogonal feeds with a 90° phase shift.

2.3 Dual-Band Operation

Dual-band antennas are crucial for modern communication systems that operate at multiple frequencies. Techniques to achieve dual-band operation include:

- Slot-loading – Adding resonant slots in the patch to introduce additional modes.
- Stacked patch configuration – Using multiple patch layers to achieve different resonance frequencies.
- Parasitic elements – Placing nearby resonators to influence frequency response.

2.4 Antenna Performance Parameters

- Return Loss (S11): Measures power reflection; should be ≤ -10 dB.
- Axial Ratio (AR): Should be ≤ 3 dB for circular polarization.
- Voltage Standing Wave Ratio (VSWR): Should be ≤ 2 for impedance matching.
- Beamwidth: Angular range where the antenna maintains strong radiation.
- Side Lobe Level (SLL): Should be ≤ -20 dB to minimize interference.

3 Design Methodology

3.1 Substrate Selection

- Material: Low-loss dielectric with $\varepsilon r = 2.2$ and $\tan\delta = 0.0009$.
- Thickness: 0.05 cm to balance impedance matching and bandwidth.

3.2 Patch Design

- Shape: Rectangular with truncated corners.
- Feeding Mechanism: Microstrip line feed.
- Optimization: Slot placement and corner truncation for circular polarization.

3.3 HFSS Design Considerations

- Ground plane: Perfect Electrical Conductor (PEC).
- Radiation boundary: Simulates an open environment.
- Excitation type: Wave port or lumped port.
- Frequency sweep: 2 GHz to 6 GHz to analyze resonance.

3.4 Design Specifications

- Centre Frequency: 2.4 GHz and 5.6 GHz
- Fractional Bandwidth: 1%

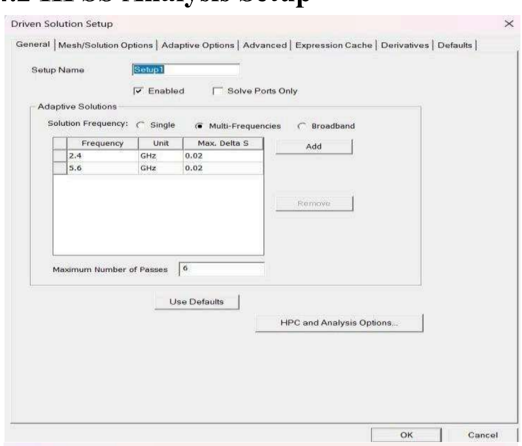
- VSWR: < 2
- Impedance: 50 Ohms
- Beamwidth: 120 deg
    - Substrate: εr = 2.2, tanδ = 0.0009
- Simulation Region: Sufficient airbox around the antenna.
- Meshing: Adaptive meshing for convergence.
- Excitation: Lumped port with 50 Ω impedance.

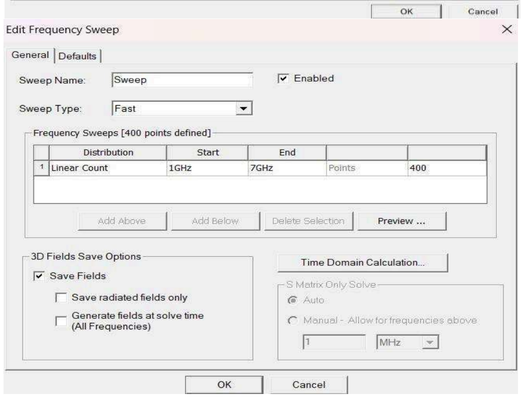
4 Simulation Setup

4.1 Simulation steps

1. Create the substrate, patch, and ground.
2. Apply material properties.
3. Set up radiation boundaries.
4. Assign lumped port excitation.
5. Perform frequency sweep (2 GHz – 6 GHz).
6. Run simulation and analyze results.

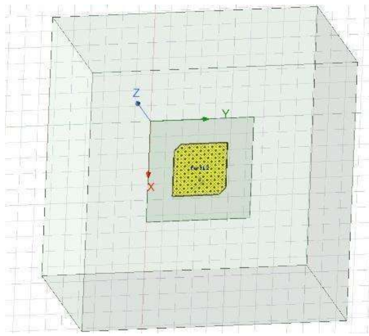
4.2 HFSS Analysis Setup



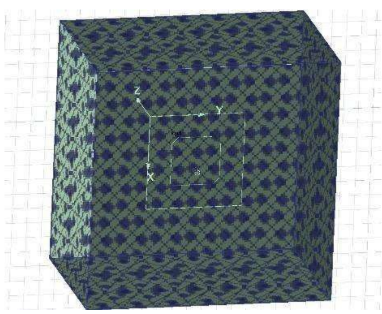


4.3 HFSS Boundary and Excitation

1. Ground and Patch



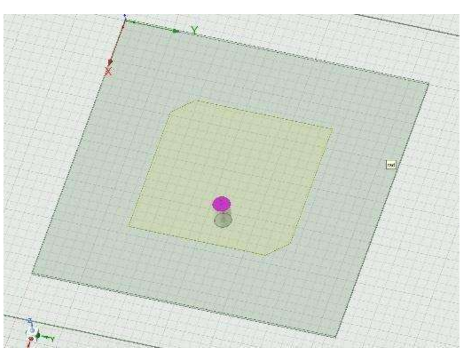
2. Radiation Box



3. Lumped Port

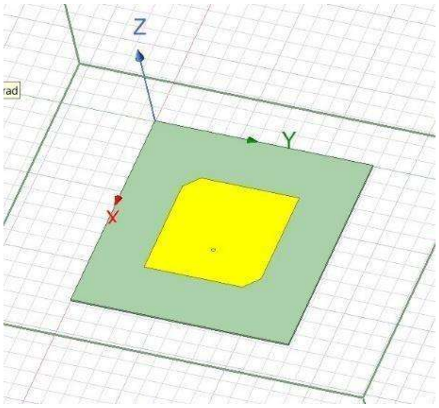
Coaxial feeding is one of the most common methods used to feed microstrip patch antennas, and it’s especially popular because of its simplicity and ease of fabrication.

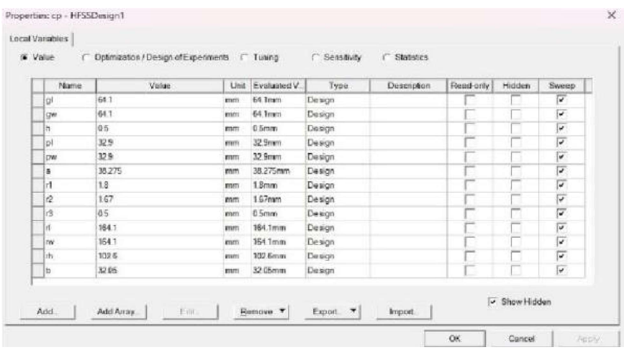
It involves inserting the inner conductor of a coaxial cable through the ground plane and connecting it directly to the patch, while the outer conductor is soldered to the ground.



5 Simulation results with design structure

5.1 Design Structure with Measurements




Properties: cp - HFSSDesign1

Local Variables

Value | Optimization / Design of Experiments | Tuning | Sensitivity | Statistics

Name	Value	Unit	Evaluated V...	Type	Description	Read-only	Hidden	Sweep
gl	64.1	mm	64.1mm	Design		☐	☐	☑
gw	64.1	mm	64.1mm	Design		☐	☐	☑
h	0.5	mm	0.5mm	Design		☐	☐	☑
pl	32.9	mm	32.9mm	Design		☐	☐	☑
pw	32.9	mm	32.9mm	Design		☐	☐	☑
s	38.275	mm	38.275mm	Design		☐	☐	☑
r1	1.8	mm	1.8mm	Design		☐	☐	☑
r2	1.67	mm	1.67mm	Design		☐	☐	☑
r3	0.5	mm	0.5mm	Design		☐	☐	☑
rl	184.1	mm	184.1mm	Design		☐	☐	☑
rw	154.1	mm	154.1mm	Design		☐	☐	☑
rh	102.6	mm	102.6mm	Design		☐	☐	☑
b	32.05	mm	32.05mm	Design		☐	☐	☑

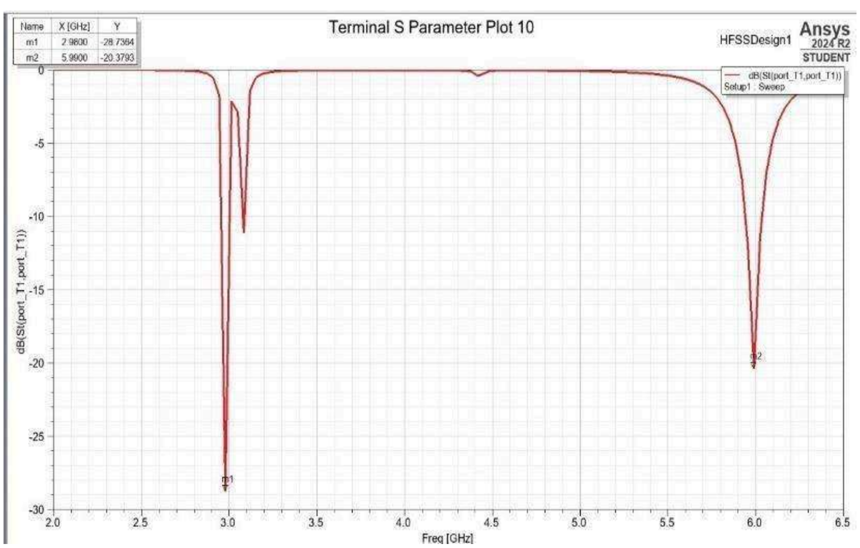
Show Hidden

Add... | Add Array... | Edit... | Remove | Export... | Import...

OK | Cancel | Apply

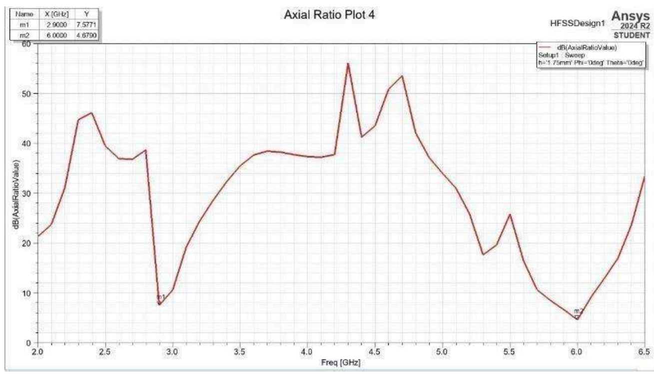
5.2 Return Loss (S11)

- Resonance frequencies: 2.98 GHz and 5.99 GHz.
- Criteria: S11 < -10 dB at both bands.



5.3Axial Ratio

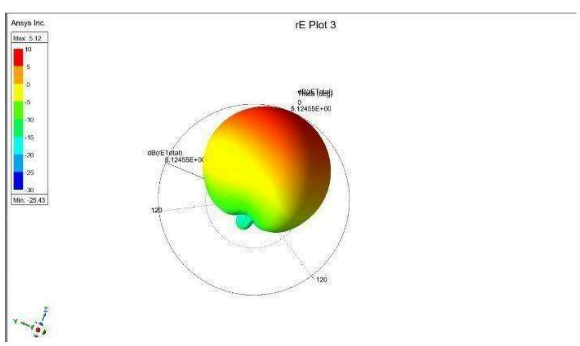
- Measured at boresight (θ = 0°).
- Circular polarization confirmed (AR ≤ 3 dB).



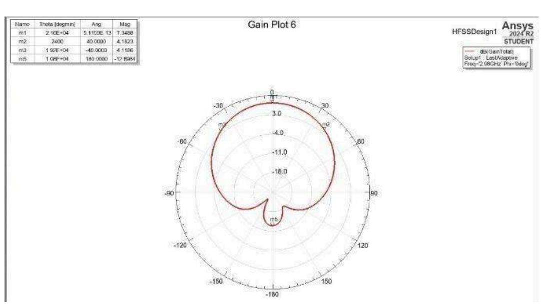
5.4 Radiation Pattern

- Main beam direction: Broadside (θ = 0°).
- Beamwidth: 80°.
- Side lobe level: < -20 dB.
- At 2.98 GHz

1) Radiation Pattern

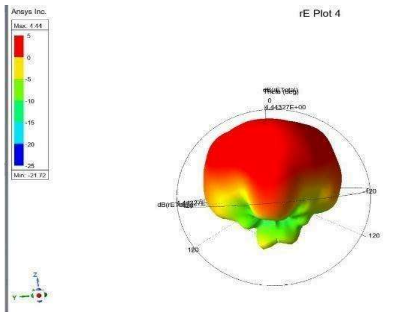


2) Gain Plot

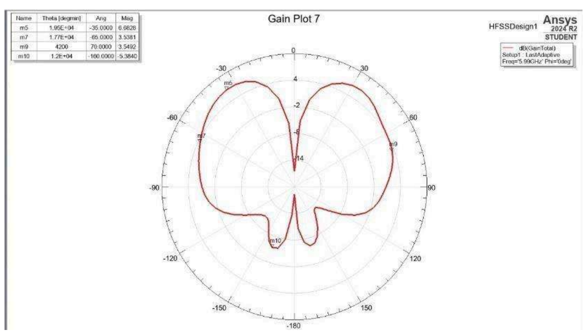


• At 5.99 GHz

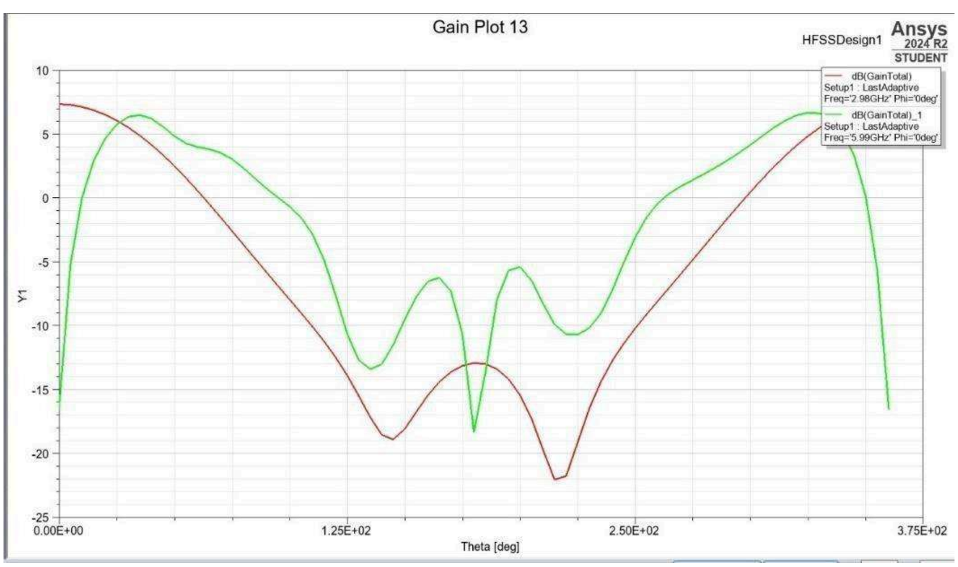
1. Radiation Pattern



2. Gain Plot

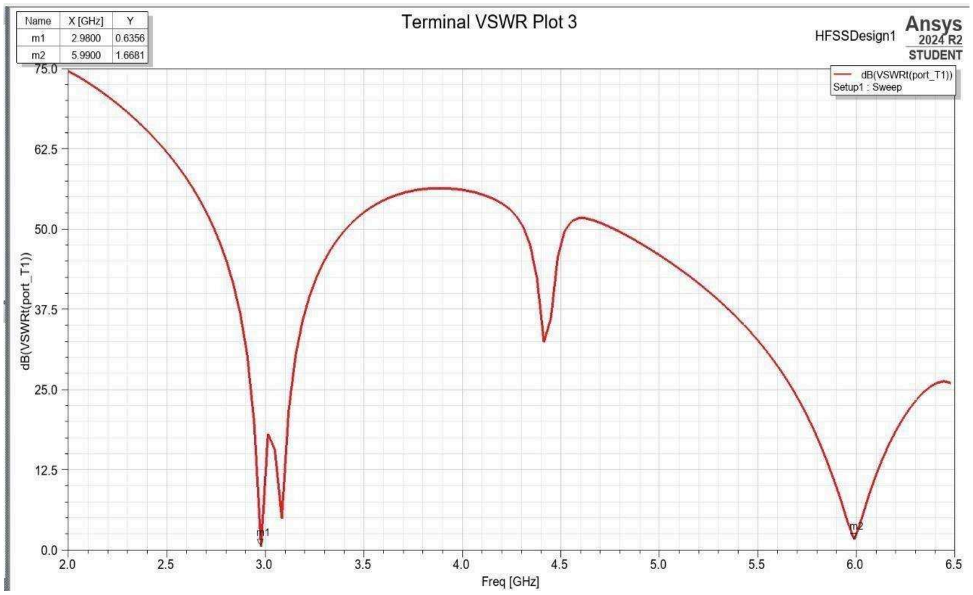


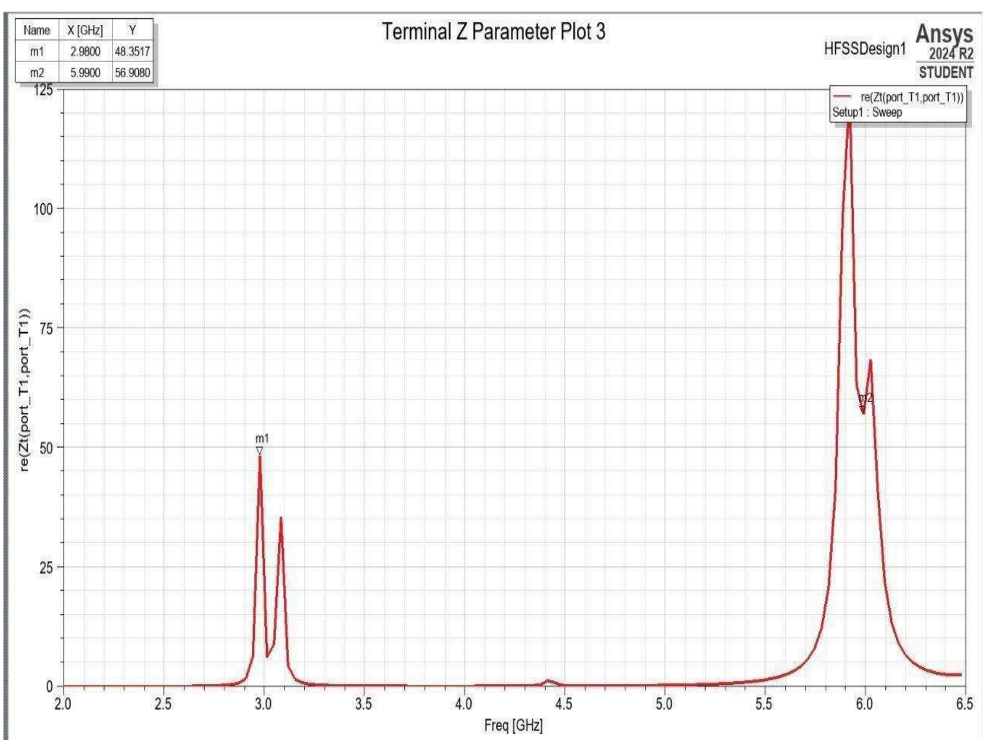
3. Gain vs Theta



5.5 VSWR and Impedance

- VSWR ≤ 2 ensuring impedance matching.
- Impedance: ~50 Ω.





6 Table containing specifications and simulated values

Specifications Table

Design parameters

S.No.	Parameter	Value
1	Centre frequency	2.4 GHz, 5.6 GHz
2	Fractional Bandwidth	1%
3	VSWR	≤ 2
4	Impedance	50 Ohms
5	Beam width	120 deg
6	Side lobe level	< -20 dB
7	Polarization	Circular

Substrate

Dielectric Constant: 2.2, tanδ: 0.0009

Height: 0.05cm

Simulated Values

	Parameters	Value
1	Centre Frequency	2.98 GHZ, 5.99 GHz
2	Fractional Bandwidth	1.6%
3	VSWR	0.63 dB, 1.66 dB
4	Impedance	48.3 Ohms, 57.9 Ohms
5	Beamwidth	80 degrees
6	Side Lobe Level	-17 dB

7 Conclusion

The dual-band circularly polarized microstrip patch antenna designed and simulated in HFSS met the key design parameters, including S11, VSWR, beamwidth, and axial ratio. The 2.98 GHz and 5.99 GHz bands make it suitable for Wi-Fi, satellite, and wireless communication applications. Key Takeaways:

- The design successfully achieved dual-band operation with circular polarization, ensuring reliable signal transmission.
- The antenna exhibited a broad beamwidth of 80°, making it useful for wide coverage applications.
- The side lobe level was maintained below -10 dB, reducing interference in adjacent channels.
- The impedance was matched to 50 Ω, ensuring minimal power loss and optimal performance.
- Circular polarization was confirmed through the axial ratio analysis. Future Improvements:
- Broadening bandwidth: Adjusting slot configurations or adding parasitic elements.
- Enhancing axial ratio: Fine-tuning corner truncations and feed positions.
- Higher gain: Implementing an array configuration to improve directivity.
- Experimental validation: Fabricating and measuring the antenna to compare with simulation results.

The proposed antenna design is a promising candidate for modern wireless applications requiring dual-band, circular polarization, and low interference levels.

8 Calculations

To calculate the fractional bandwidth (FBW) at the resonant frequencies of 2.98 GHz and 5.99 GHz, follow these steps:

Formula:

$FBW = (fH-fL)/fc \times 100\%$ where:

- fH = Upper 3 dB cutoff frequency
- fL = Lower 3 dB cutoff frequency
- fc = Centre frequency (resonant frequency)

For 2.98 GHz Resonance:

- $fL=2.956$ GHz

- f_H=3.005 GHz
- Center frequency: f_c=2.98 GHz

  FBW = (3.005−2.956)/2.98×100% = 1.6%

For 5.99 GHz Resonance:

- f_L=5.94 GHz
- f_H=6.036 GHz
- Centre frequency: f_c=5.99 GHz

  FBW = (6.036−5.94)/5.99×100% = 1.6%

Final Results (Replace Values as Needed)

- FBW at 2.98 GHz ≈ 1.6%
- FBW at 5.99 GHz ≈ 1.6%

9 References

[1] "Circularly Polarized Dual Band Micro Strip Patch Antenna for Vehicular Wireless Network Communications", Ramya R and T. Rama Rao

[2] "DESIGN AND ANALYSIS OF A CIRCULARLY POLARIZED OMNIDIRECTIONAL SLOTTED PATCH ANTENNA AT 2.4 GHZ", Pendli Pradeep, S.K. Satyanarayana