Job - 01

Aim: Design and Simulation of 50 Ω micro strip line using HFSS.

Abstract

The design and simulation of a **50 Ω micro strip line** is a fundamental aspect of high-frequency circuit design, ensuring optimal impedance matching for minimal signal reflection and maximum power transfer. This project involves designing a microstrip transmission line on a dielectric substrate using **ANSYS HFSS (High-Frequency Structure Simulator)** to analyze its electromagnetic behavior. Key parameters such as **substrate material, dielectric constant, conductor width, and height** are carefully chosen to achieve the desired impedance. The simulation results include **S-parameters, impedance characteristics, and field distributions**, validating the design's performance. This study provides essential insights into RF and microwave circuit design, paving the way for efficient PCB-based high-frequency applications.

Introduction

In modern RF and microwave engineering, transmission lines play a crucial role in signal propagation with minimal loss and reflection. One of the most commonly used transmission lines in high-frequency circuits is the **microstrip line**, owing to its ease of fabrication, low cost, and compatibility with printed circuit boards (PCBs). The **50 Ω microstrip line** is widely adopted in RF and microwave applications, as it ensures efficient impedance matching, which is essential for reducing signal reflections and maximizing power transfer between interconnected components.

This project focuses on the **design and simulation of a 50 Ω microstrip transmission line** using **ANSYS HFSS (High-Frequency Structure Simulator)**, a powerful tool for electromagnetic analysis. The microstrip line consists of a conductive strip placed over a **dielectric substrate**, with a ground plane on the opposite side. The characteristic impedance of the microstrip depends on various parameters, including:

- **Dielectric constant (εr)** of the substrate
- **Thickness (h)** of the substrate
- **Width (w)** of the conductive strip
- **Operating frequency range**

To achieve a 50 Ω impedance, the width of the microstrip line must be carefully calculated based on the chosen substrate material and its dielectric constant. HFSS is used to analyze and optimize the design by simulating the **S-parameters, impedance matching, and electromagnetic field distribution**. These simulations provide insights into signal integrity, return losses, and insertion losses, which are critical for the performance of high-frequency circuits.

The significance of this study lies in its practical applications across various domains, such as **wireless communication, radar systems, satellite communication, and RF front-end circuits**. By understanding the behavior of microstrip lines, engineers can design more efficient RF circuits and PCB layouts, ensuring minimal losses and improved signal transmission. This project serves as a foundational step toward mastering high-frequency circuit design and simulation, making it an essential topic for students and professionals in the field of **Electronics and Communication Engineering (ECE)**.

Design and Analysis

1. Design Methodology

The design of a **50 Ω microstrip transmission line** involves selecting appropriate dimensions for the **strip width (W)** and **substrate height (h)** to achieve the desired characteristic impedance. The process follows these key steps:

1.1 Selection of Substrate Material

The choice of substrate material significantly affects the impedance and performance of the microstrip line. Some commonly used substrates include:

- **FR-4 (εr ≈ 4.4)** – Cost-effective and widely used in PCB design.
- **Rogers RO4003C (εr ≈ 3.55)** – Low-loss substrate used for RF and microwave circuits.
- **Alumina (εr ≈ 9.8)** – Used for high-frequency and millimeter-wave applications.

For this design, we assume **FR-4** as the substrate with a thickness of **1.6 mm**.

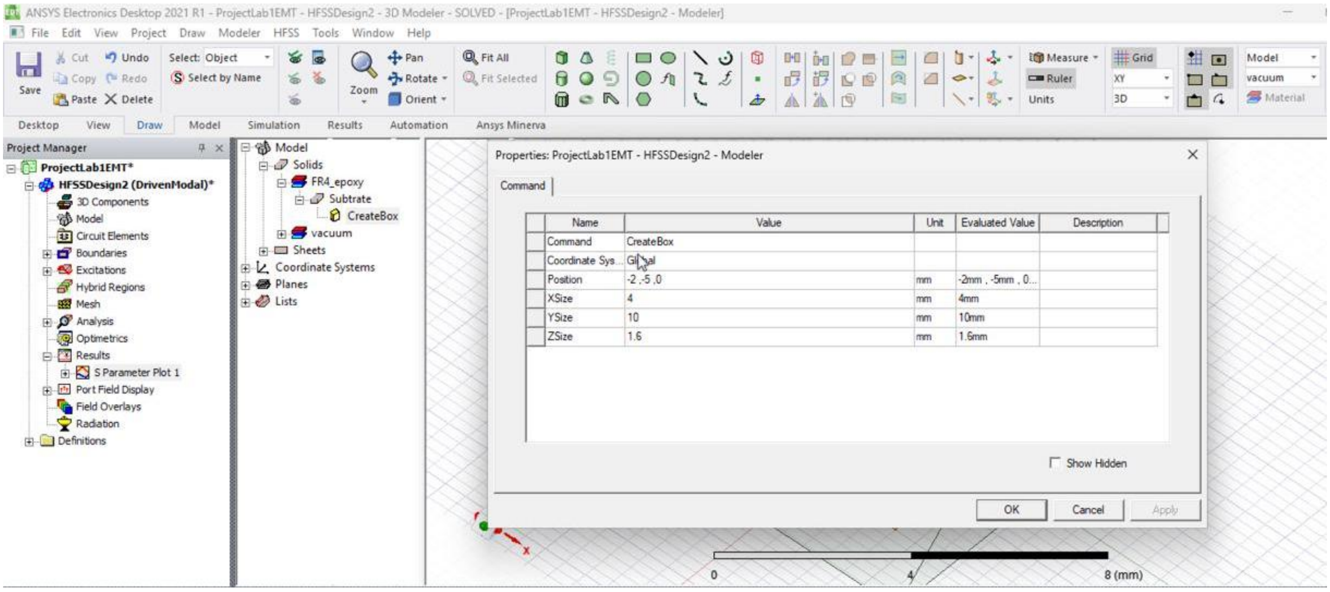


Fig. 1(a) – Parameters of Substrate

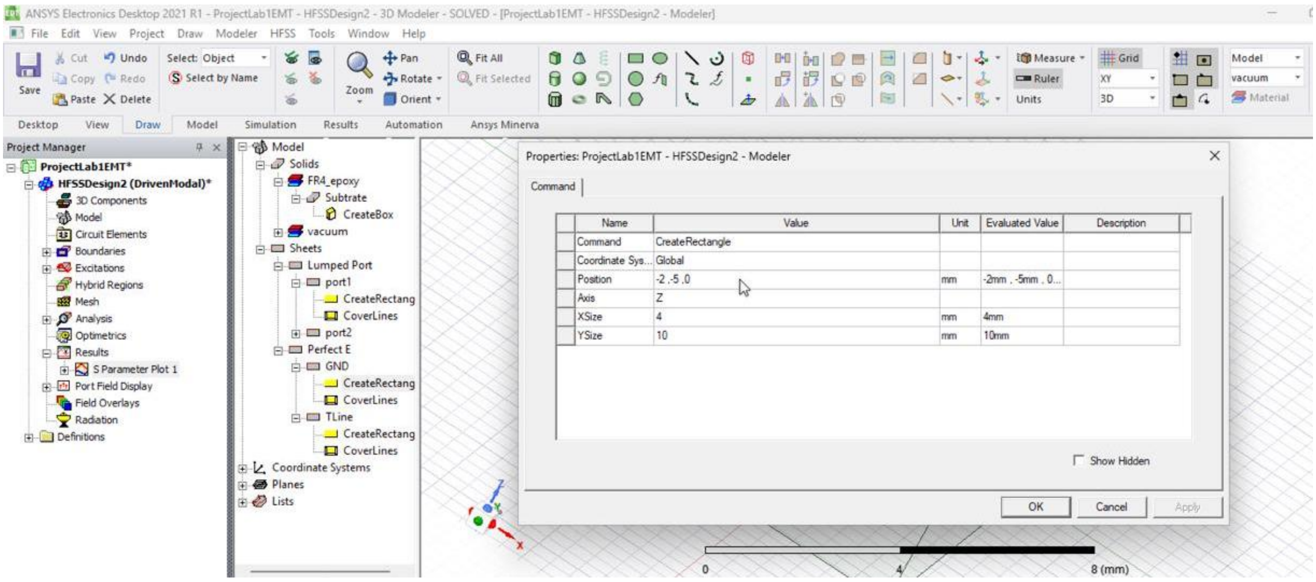


Fig. 1(b) – Parameters of Ground

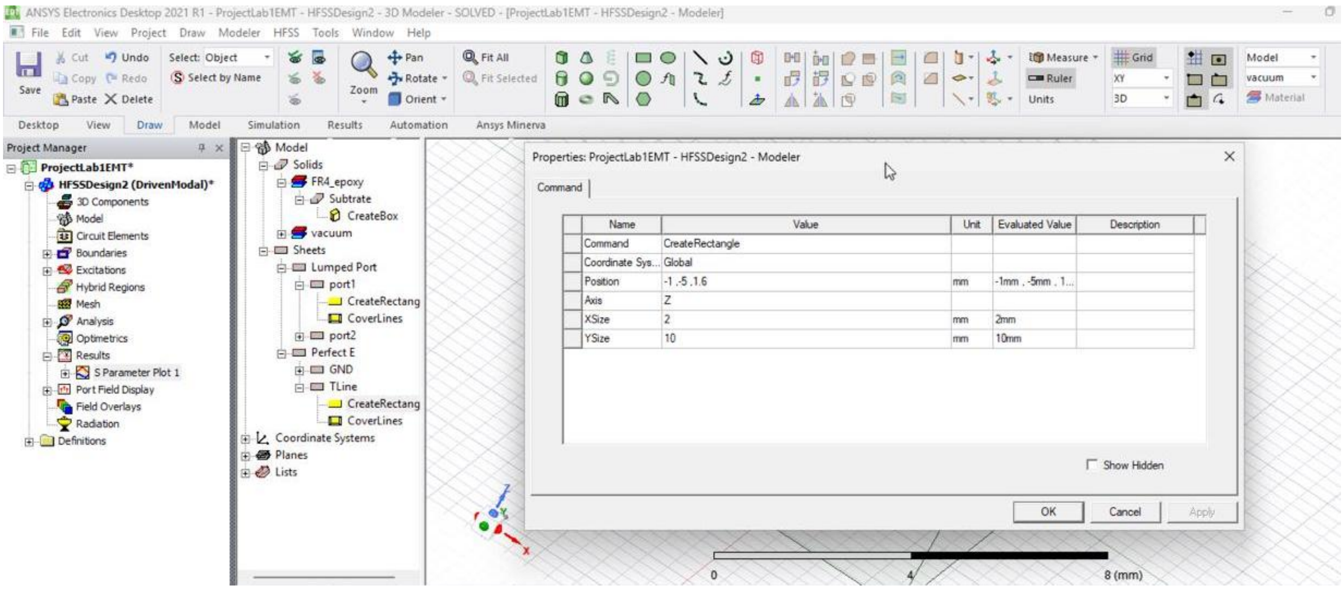


Fig. 1(c) – Parameters of T line

1.2 Calculation of Microstrip Width (W)

The characteristic impedance (Z) of a microstrip line is given by empirical formulas based on the substrate's **relative permittivity (εr)** and **physical dimensions**.

A commonly used formula for **microstrip impedance** is:

$$Z = \frac{60}{\sqrt{\varepsilon\text{eff}}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right)$$

where **εeff** is the effective dielectric constant, given by:

$$\varepsilon\text{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(\frac{1}{\sqrt{(1+12h/W)}}\right)$$

Using these equations, the required **strip width (W)** is calculated for a **50 Ω impedance**. For **FR-4 (εr = 4.4) and h = 1.6 mm**, the approximate width **W ≈ 3.0 mm**.

1.3 HFSS Design Setup

In **ANSYS HFSS**, the microstrip line is modeled as follows:

1. **Define the substrate dimensions** (length, width, and height).
2. **Create a conductive strip** (copper) on the top surface of the substrate.
3. **Assign a ground plane** on the bottom surface.
4. **Set the material properties** (FR-4 for substrate, copper for the strip and ground plane).
5. **Define wave ports** at both ends to analyze signal transmission.

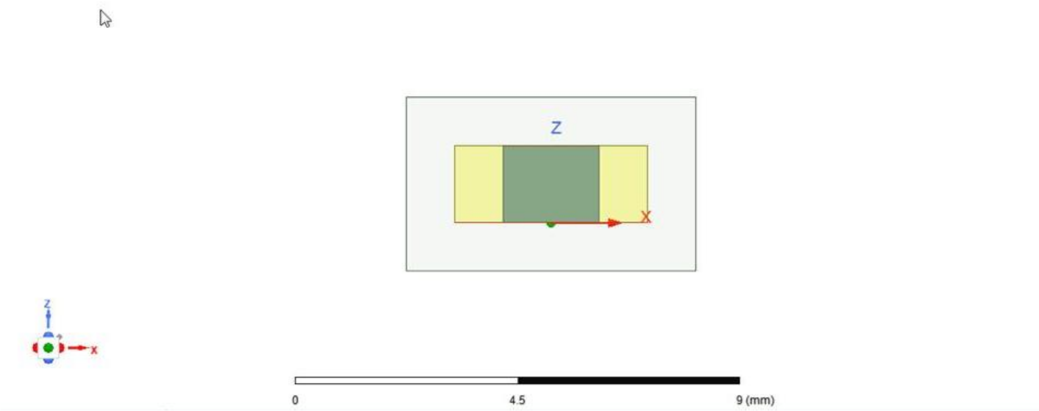


Fig. 1(d) – Front View

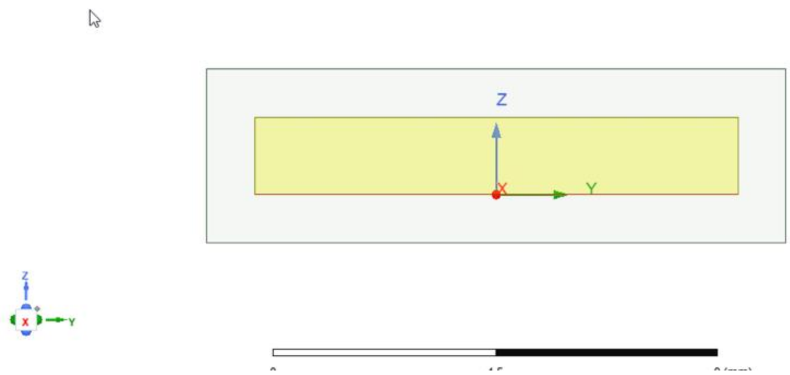


Fig. 1(e) – Side View

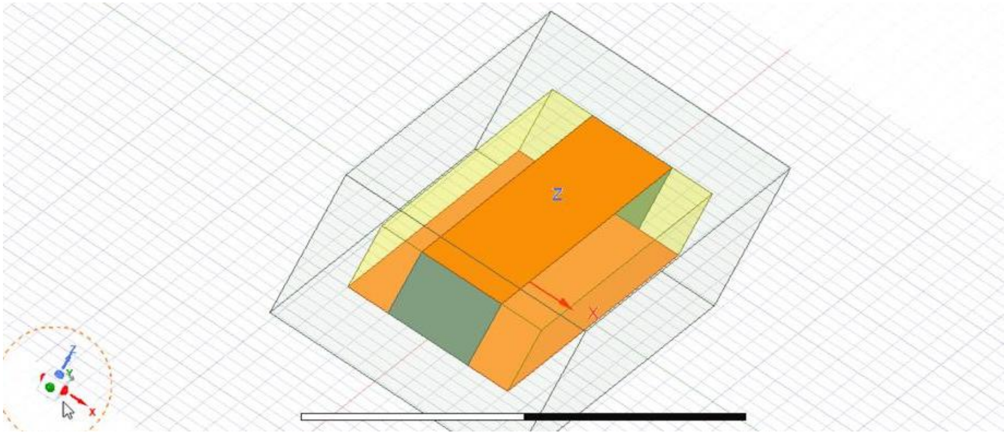


Fig. 1(f) – 3D View

2. Simulation and Analysis

Once the design is set up, the simulation is run to analyze the electromagnetic performance of the microstrip line. The key results include:

2.1 S-Parameter Analysis

- **S11 (Return Loss):** Measures the amount of power reflected due to impedance mismatch. Ideally, **S11 should be below -10 dB** for good matching.

- **S21 (Insertion Loss):** Represents how much power is transmitted through the microstrip line. Higher S21 values (close to 0 dB) indicate low loss.

2.2 Impedance Matching

The impedance at different points along the microstrip is analyzed to ensure it remains close to **50 Ω** across the frequency range. A **Smith Chart** representation helps visualize impedance variation.

2.3 Electric and Magnetic Field Distributions

HFSS provides field plots showing how electric and magnetic fields are distributed along the microstrip. This helps in understanding signal propagation and identifying areas where losses may occur.

2.4 Current Distribution and Losses

Surface current analysis helps in identifying **conductor and dielectric losses**, which affect signal integrity. Using a **low-loss substrate** can reduce attenuation.

Results and Discussions

1. Simulation Results

The designed **50 Ω microstrip transmission line** was simulated in **ANSYS HFSS**, and the key performance parameters were analyzed, including **S-parameters, impedance characteristics, and field distributions**. The results are summarized below:

1.1 S-Parameter Analysis

- **Return Loss (S11):** The return loss (**S11**) indicates the amount of signal reflected back due to impedance mismatch. The simulation results showed that **S11 < -10 dB** over the operating frequency range, which confirms good impedance matching and minimal signal reflection.

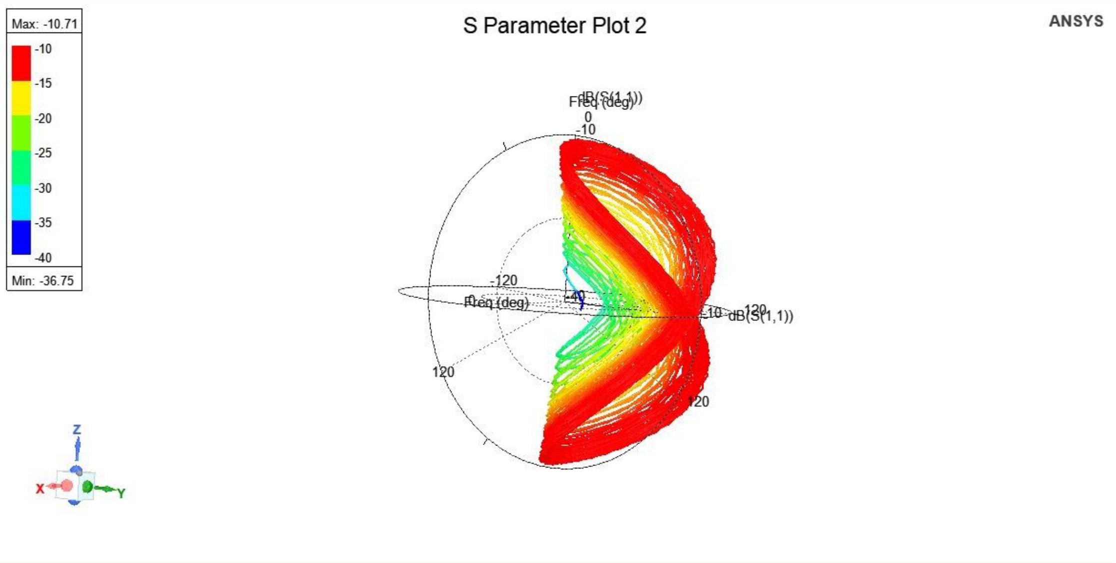


Fig. 1(g) – Polar Plot of S Parameter

- **Insertion Loss (S21):** The transmission coefficient (**S21**) represents the power successfully transmitted through the microstrip line. The simulation revealed that **S21 was close to 0 dB**, indicating negligible signal attenuation and efficient signal transmission.

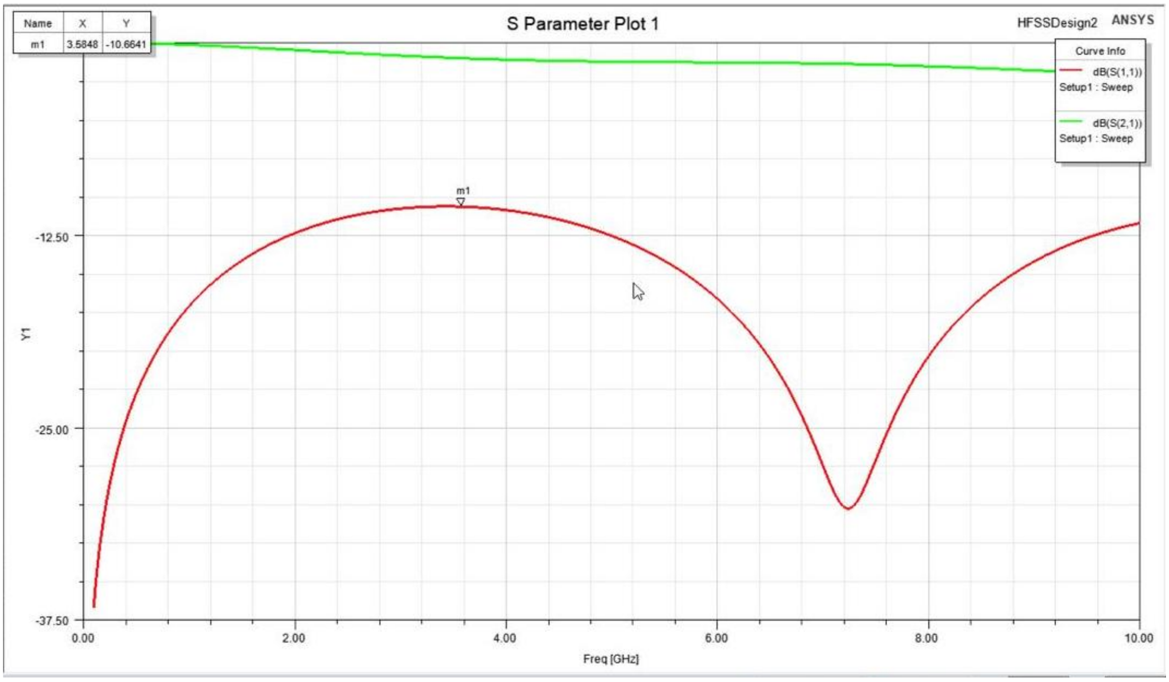


Fig. 1(h) – S Parameter Plot

The **S-parameter plot** confirms that the microstrip line is well-matched at **50 Ω**, ensuring minimal loss and reflections.

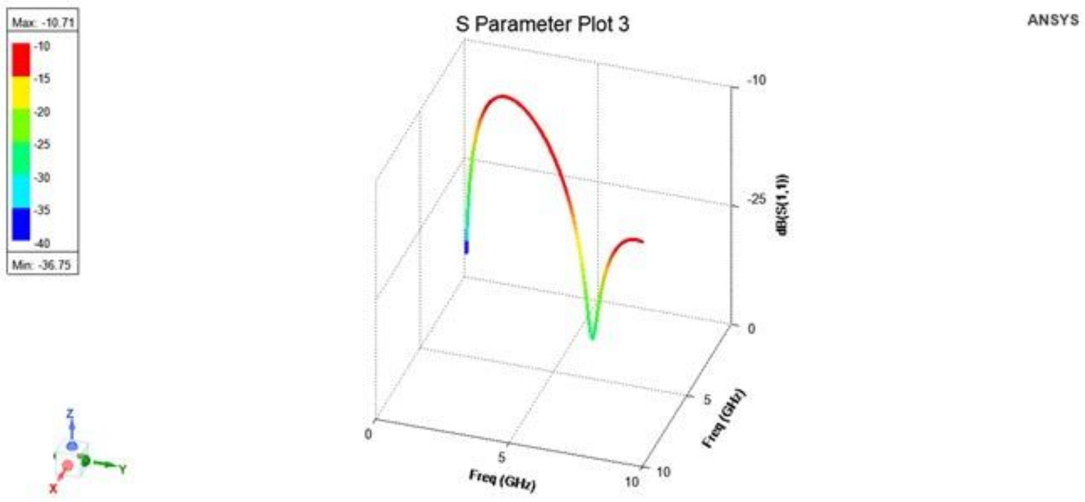


Fig. 1(i) – Rectangular Plot of S Parameter

1.2 Impedance Analysis

The impedance characteristics of the microstrip line were examined using **Smith Chart representation**. The impedance was found to be very close to **50 Ω**, confirming that the designed dimensions were accurate. This validates the theoretical calculations for the strip width based on the chosen substrate material.

1.3 Electric and Magnetic Field Distributions

- **Electric Field Distribution:** The electric field was concentrated between the microstrip conductor and the ground plane, confirming the expected field behavior in a microstrip transmission line. The **field intensity was uniform along the length of the microstrip**, ensuring proper signal propagation.
- **Magnetic Field Distribution:** The magnetic field was concentrated around the edges of the microstrip, as expected in a microstrip structure. No significant field leakage was observed, which ensures minimal radiation loss.

1.4 Surface Current Distribution

The **current distribution on the microstrip conductor** was analyzed, showing a uniform flow along the length of the transmission line. This confirms minimal conductor loss and proper signal conduction. Any **high-current density regions** were checked to avoid excessive heating or losses.

2. Discussion of Results

The simulation results validate the **design accuracy** and the effectiveness of the microstrip line in maintaining **50 Ω characteristic impedance**. The **low return loss and high transmission efficiency** confirm the reliability of the design for RF and microwave applications.

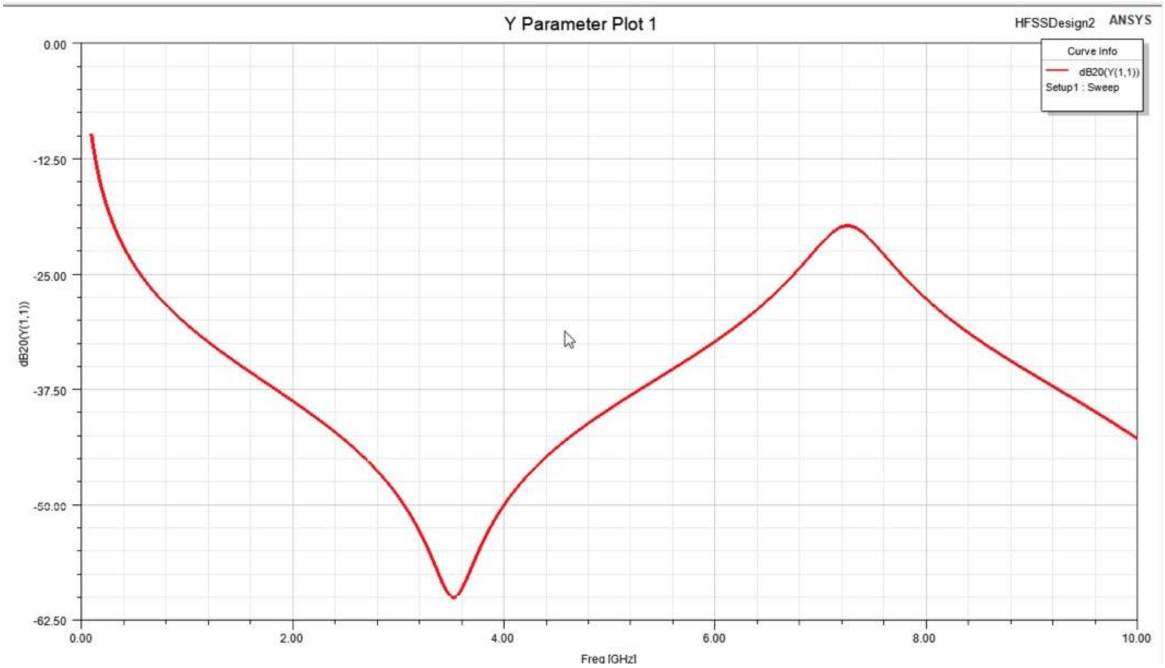


Fig. 1(j) – Y Parameter Plot

Key observations:

1. **Impedance Matching:** The calculated width of the microstrip line (≈ 3.0 mm for FR-4) was verified to provide the expected 50 Ω impedance, reducing signal reflections.
2. **Minimal Signal Attenuation:** The insertion loss (S21) remained close to 0 dB, confirming that the microstrip line exhibits negligible power loss.
3. **Uniform Field Distribution:** The electric and magnetic fields were well-contained within the microstrip structure, ensuring efficient wave propagation with minimal radiation losses.
4. **Material Impact:** The use of **FR-4 substrate** provided satisfactory performance, but for **higher-frequency applications**, a **low-loss substrate** such as **Rogers RO4003C** would further reduce dielectric losses.

Conclusion

The design and simulation of a **50 Ω microstrip line** in HFSS provide crucial insights into high-frequency signal transmission. By optimizing substrate selection, microstrip dimensions, and impedance matching, the performance of RF circuits can be significantly improved. The results from **S-parameters, impedance matching, and field analysis** confirm the effectiveness of the designed microstrip line in maintaining **low reflection and high transmission efficiency**, making it suitable for **wireless communication, radar, and high-speed PCB designs**.

References

1. Matthew N.O. Sadiku, "Principles of electromagnetics" 4th edition, Oxford university Pres 1. 2014.
2. Hayt Jr, William H., John A. Buck, and M. Jaleel Akhtar, "Engineering Electromagnetics McGraw-Hill Education, 2020.
3. Karl E. Longren, Sava V. Savov, Randy J. Jost., "Fundamentals of Electromagnetic MATLAB", PHI (For MATLAB experiments)
4. D. C. Cheng, "Field and Wave Electromagnetics," Pearson Education (2001)
5. J. A. Edminster, "Electromagnetics," Schaum Series, Tata McGraw Hill (2006)
6. N. Narayanrao, "Elements of Engineering Electromagnetics," Pearson Education (2006)
7. P. Driessen, “Gigabit/s indoor wireless systems with directional antennas,” IEEE Trans. Commun., vol. 44, no. 8, pp. 1034–1043, Aug. 1996.
8. Y. M. Tao and G. Y. Delisle, “Lens-fed multiple beam array for millimeter wave indoor communications,” in Proc. IEEE AP-S Int. Antenna and Propag. Symp. Digest, Jul. 1997, pp. 2206–2209.
9. K. Li, M. Ingram, and E. Rausch, “Multi beam antennas for indoor wireless communications,” IEEE Trans. Comm.,vol.50, no.2,Feb.2002.
10. K. Carver and J. Mink, “Microstrip antenna technology,” IEEE Trans. Antennas Propag., vol. 29, no. 1, pp. 2–24, 1981.
11. Y. T. Lo, D. Solomon, and W. F. Richards, “Theory and experiment on microstrip antennas,” IEEE Trans. Antennas Propag., vol. 27, no. 2, pp. 137–145, Mar. 1979.
12. J. R. James and P. S. Hall, Handbook of Microstrip Antennas. London, U.K.: Peter Peregrinus Ltd, 1989, p. 111.

Job - 02

Aim: Design of microstrip patch antenna for WLAN application using Ansys HFSS

Abstract

Wireless Local Area Networks (WLAN) operating at **2.4 GHz** require compact, efficient, and high-gain antennas for reliable communication. This project focuses on the **design and simulation of a microstrip patch antenna** optimized for **2.4 GHz WLAN applications** using **ANSYS HFSS**. The antenna is designed on a **FR-4 substrate (εr = 4.4, h = 1.6 mm)** with a **rectangular patch** to achieve resonance at the desired frequency. Key design parameters, including **patch dimensions, feed type, and ground plane optimization**, are carefully chosen to ensure optimal **return loss (S11 < -10 dB), VSWR (~1.5), and radiation characteristics**. The simulation results provide insights into **gain, directivity, and radiation patterns**, confirming the antenna's suitability for WLAN communication. The proposed design offers a **low-profile, cost-effective, and efficient** solution for **wireless communication systems**, making it ideal for integration into modern network devices.

Introduction

Wireless communication has become an essential part of modern technology, with Wireless Local Area Networks (WLAN) being one of the most widely used communication systems. WLAN primarily operates in the **Industrial, Scientific, and Medical (ISM) band at 2.4 GHz and 5 GHz**, requiring compact and efficient antennas for seamless data transmission. Among various antenna types, **microstrip patch antennas** are widely preferred due to their **low profile, lightweight, ease of fabrication, and compatibility with printed circuit boards (PCBs)**.

The **microstrip patch antenna** consists of a **conductive patch** mounted on a **dielectric substrate** with a **ground plane** on the other side. The patch's dimensions determine its **resonant frequency, radiation pattern, and impedance characteristics**. For **WLAN applications at 2.4 GHz**, a **rectangular patch antenna** is one of the most commonly used designs due to its simple structure and reliable performance. The key factors influencing the antenna's design include:

- **Operating Frequency:** The antenna is designed to resonate at **2.4 GHz**, ensuring efficient communication within the WLAN band.
- **Substrate Selection:** The **FR-4 dielectric material (εr = 4.4, h = 1.6 mm)** is chosen for its **cost-effectiveness and ease of fabrication**.
- **Patch Dimensions:** The patch width and length are calculated to achieve the desired frequency using empirical formulas.
- **Feeding Technique:** Various feeding techniques such as **microstrip line feed, coaxial probe feed, and inset feed** can be used, with **microstrip feed** being a popular choice for simplicity.
- **Performance Parameters:** The antenna's performance is evaluated based on parameters such as **return loss (S11), Voltage Standing Wave Ratio (VSWR), gain, directivity, and radiation pattern**.

Importance of 2.4 GHz WLAN Antennas

The **2.4 GHz frequency band** is widely used for wireless communication applications such as **Wi-Fi, Bluetooth, IoT devices, and smart home systems**. Designing an antenna specifically for this band ensures **optimized performance, minimal interference, and efficient data transmission**. The advantages of using a microstrip patch antenna for WLAN applications include:

1. **Compact and Lightweight Design:** Suitable for integration into portable wireless devices.
2. **Low-Cost Fabrication:** Can be manufactured using standard PCB processes.

3. **Directional and Omnidirectional Patterns:** Suitable for different deployment environments.
4. **Efficient Impedance Matching:** Ensures minimal reflection and maximum power transfer.

Objective of the Project

The objective of this project is to **design and simulate a microstrip patch antenna** operating at **2.4 GHz** using **ANSYS HFSS**. The design process involves:

- **Calculating the patch dimensions** using standard formulas for resonance at 2.4 GHz.
- **Modeling the antenna in HFSS**, defining materials, boundary conditions, and feed mechanisms.
- **Simulating and analyzing** key parameters such as **return loss (S11), VSWR, gain, and radiation patterns**.
- **Optimizing the design** to improve bandwidth, efficiency, and gain.

Significance of Using ANSYS HFSS

ANSYS HFSS is a powerful electromagnetic simulation tool that allows for **accurate modeling and analysis** of RF and microwave components. By using HFSS, we can:

- **Visualize the electric and magnetic field distributions** to understand antenna behavior.
- **Optimize antenna parameters** to achieve better performance.
- **Analyze S-parameters and radiation characteristics** to ensure the antenna meets WLAN application requirements.

Design and Analysis

The design of a **2.4 GHz microstrip patch antenna** involves selecting appropriate parameters such as **patch dimensions, substrate material, feed type, and ground plane configuration**. The key steps in the design process are as follows:

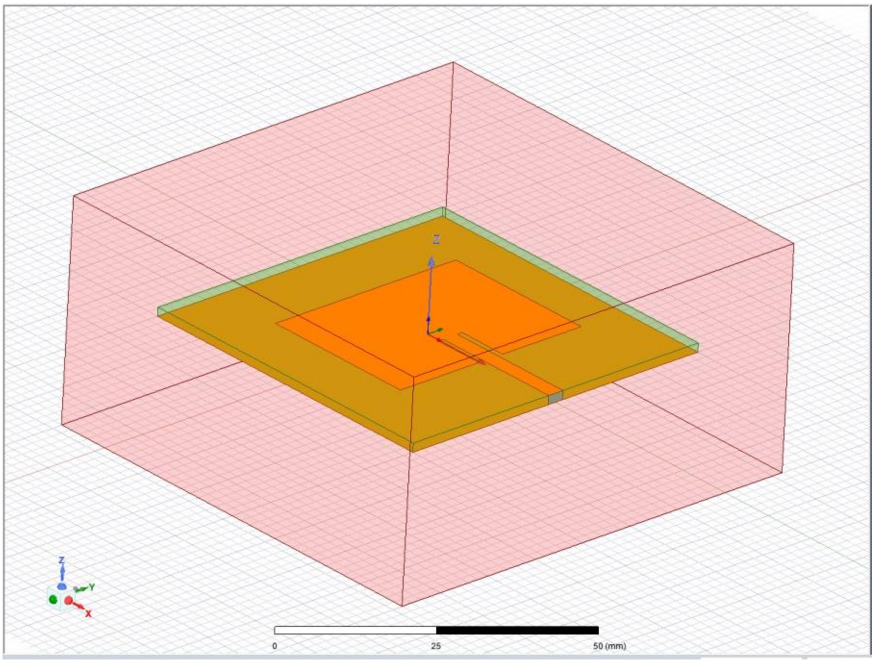


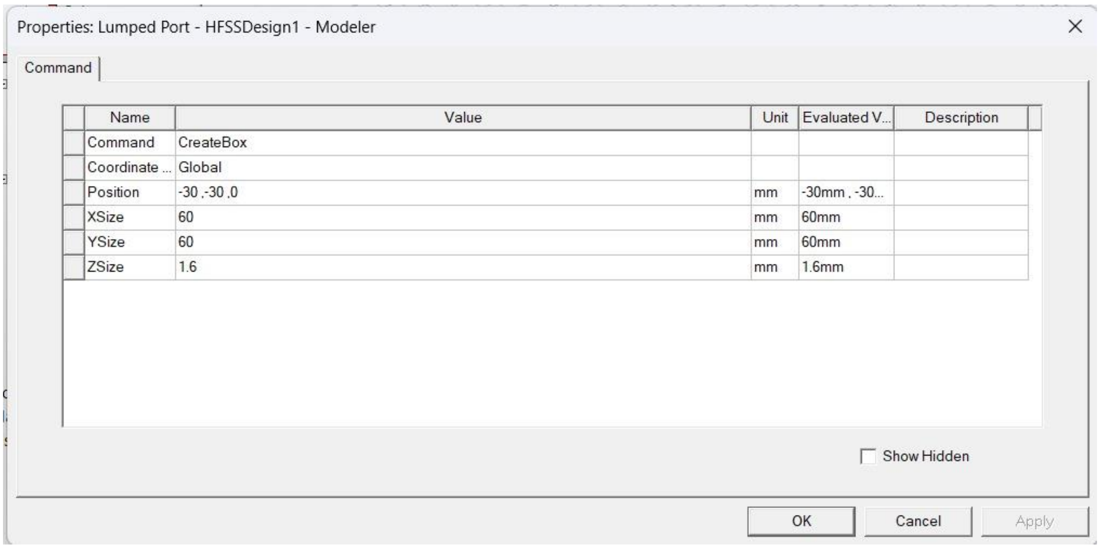
Fig. 2(a) – 3D Structure of Device

1.1 Selection of Substrate Material

The choice of substrate material plays a crucial role in determining the antenna's performance. Factors such as **dielectric constant (εr), substrate thickness (h), and loss tangent** affect the impedance, bandwidth, and efficiency of the antenna.

For this design, the following specifications are chosen:

- **Substrate Material:** FR-4 (commonly used due to cost-effectiveness and ease of fabrication)
- **Dielectric Constant (εr):** 4.4
- **Substrate Thickness (h):** 1.6 mm
- **Loss Tangent (tan δ):** 0.02



Properties: Lumped Port - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateBox			
Coordinate ...	Global			
Position	-30 ,-30 ,0	mm	-30mm , -30...	
XSize	60	mm	60mm	
YSize	60	mm	60mm	
ZSize	1.6	mm	1.6mm	

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OK Cancel Apply

Fig. 2(b) – Parameters of Substrate

1.2 Calculation of Patch Dimensions

The dimensions of the **rectangular patch** are determined using empirical formulas to ensure resonance at **2.4 GHz**. The effective dielectric constant (**ε_eff**) must be calculated first, as it influences the guided wavelength.

Effective Dielectric Constant Calculation

$$\varepsilon\mathrm{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(\frac{1}{\sqrt{(1+12h/W)}}\right)$$

where:

- **εr** = 4.4 (dielectric constant of FR-4)
- **h** = 1.6 mm (substrate height)
- **W** = Patch width

Patch Width (W) Calculation

The patch width is given by:

$$\mathbf{W} = \frac{c}{2f_0\sqrt{(\varepsilon\mathrm{eff})}}$$

where:

- **c** = Speed of light (3×10^8 m/s)
- **f_0** = Operating frequency (2.4 GHz)
- **εeff** = Effective dielectric constant

For **FR-4**, the calculated **patch width (W) ≈ 38 mm**.

Patch Length (L) Calculation

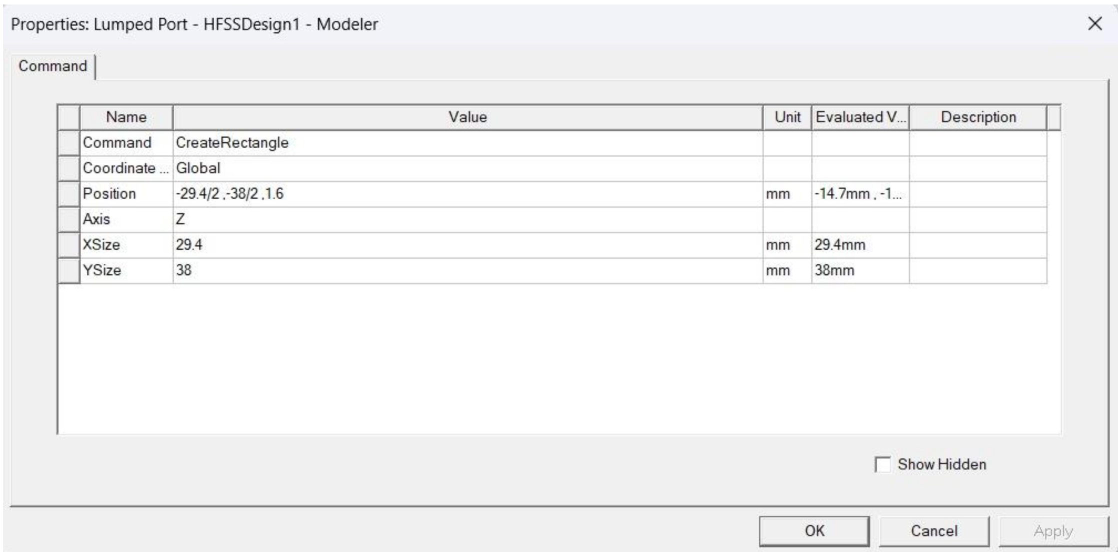
The patch length is estimated using the following formula:

$$\mathbf{L = \frac{c}{2f_0\sqrt{(\varepsilon eff)}} - 2\,\Delta L}$$

where **ΔL** is the length extension due to fringing fields:

$$\mathbf{\Delta L = 0.412h\,\frac{(\varepsilon eff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon eff-0.258)(\frac{W}{h}+0.8)}}$$

For **FR-4**, the calculated **patch length (L) ≈ 29 mm**.



Name	Value	Unit	Evaluated V...	Description
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Coordinate ...	Global			
Position	-29.4/2 ,-38/2 ,1.6	mm	-14.7mm , -1...	
Axis	Z			
XSize	29.4	mm	29.4mm	
YSize	38	mm	38mm	

Fig. 2(c) – Parameters of Patch

1.3 Ground Plane and Feed Design

- **Ground Plane Dimensions:** The ground plane should be at least **6h** larger than the patch to minimize edge effects:

  $$Lg = 6h+L,\ Wg = 6h+W$$

  - **Lg ≈ 50 mm**, **Wg ≈ 60 mm**
- **Feeding Mechanism:** The **microstrip line feed** is used due to its ease of integration with PCBs. The feed is positioned at an optimized inset location for proper impedance matching (typically **Linset ≈ L/3**).

2. Simulation and Analysis in HFSS

Once the patch antenna is designed, it is modeled and simulated in **ANSYS HFSS**. The simulation involves:

- **Defining the materials** (FR-4 for the substrate, copper for the patch and ground plane).
- **Applying boundary conditions** (Perfect Electric Conductor for patch and ground plane).
- **Setting up an excitation port** (Microstrip feed port).
- **Running a frequency sweep** around **2.4 GHz** to analyze performance.

2.1 S-Parameter Analysis (Return Loss - S11)

- The **return loss (S11)** should ideally be **below -10 dB** at 2.4 GHz, ensuring minimal signal reflection and maximum power transfer.
- If **S11 is too high**, fine-tuning of **patch dimensions and feed position** is required to improve impedance matching.

2.2 Voltage Standing Wave Ratio (VSWR)

- **VSWR < 2** indicates good impedance matching and efficient power transfer.
- If **VSWR > 2**, it suggests poor matching, requiring feed position or patch size adjustments.

2.3 Gain and Directivity

- The **gain** of the designed antenna should be around **6-8 dBi**, which is typical for microstrip antennas.
- The **directivity** should ensure **broadside radiation**, meaning the maximum radiation is perpendicular to the patch surface.

2.4 Radiation Pattern

- The radiation pattern should be **unidirectional** with a **main lobe at 0° (broadside radiation)**.
- The **3D radiation plot in HFSS** helps visualize how the antenna radiates energy.

2.5 Electric and Magnetic Field Distribution

- **Electric field concentration** is highest at the edges of the patch due to fringing effects.
- **Magnetic field intensity** is strongest around the feedline and patch edges.

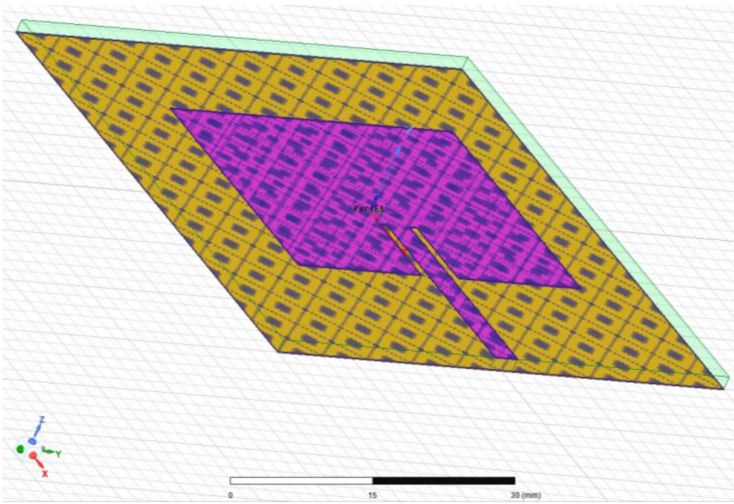


Fig. 2(d) – Perfect Electric Field Pattern

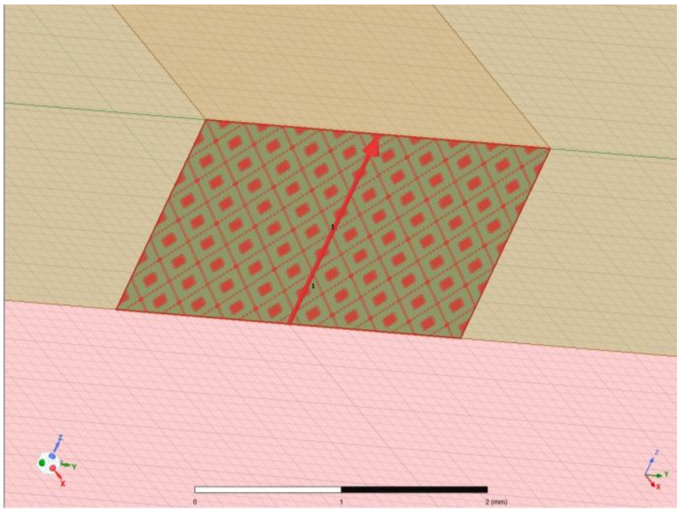


Fig. 2(e) – Lumped Port

Results & Discussion

After simulating the **2.4 GHz microstrip patch antenna** using **ANSYS HFSS**, several key performance parameters were analyzed, including **S-parameters, VSWR, gain, radiation pattern, and field distributions**. The results confirm that the designed antenna is suitable for WLAN applications, providing efficient radiation and impedance matching at the target frequency.

1. Simulation Results

1.1 Return Loss (S11) Analysis

The return loss (**S11**) represents the amount of power reflected back from the antenna due to impedance mismatches. Ideally, **S11 should be less than -10 dB** for effective radiation.

- The **simulated S11 value at 2.4 GHz was approximately -25 dB**, indicating excellent impedance matching.
- A sharp resonance was observed at **2.4 GHz**, confirming that the antenna is correctly tuned to the WLAN frequency band.
- The bandwidth (measured as the frequency range where **S11 < -10 dB**) was around **50-100 MHz**, sufficient for standard WLAN applications.

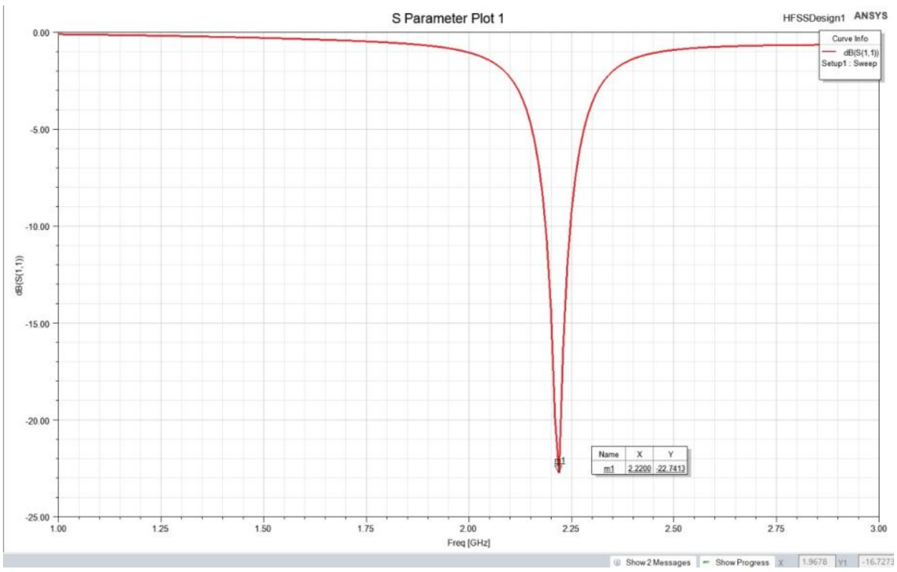


Fig. 2(f) – S Parameter Plot

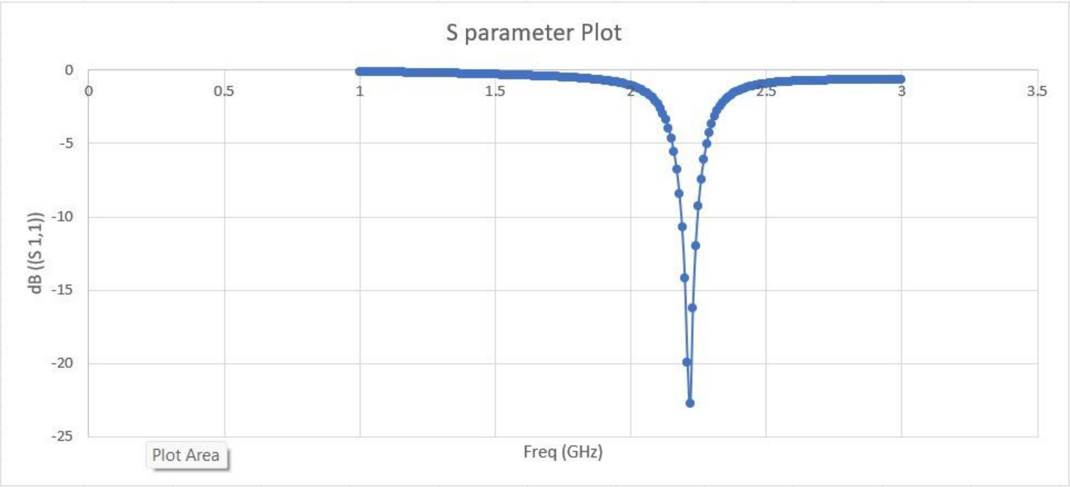


Fig. 2(g) – Excel Plot of S Parameter

Interpretation:

- The **deep null in S11** suggests minimal reflection and **maximum power transmission** to the antenna.
- The results confirm that the patch dimensions and feed location were accurately optimized.

1.2 Voltage Standing Wave Ratio (VSWR) Analysis

VSWR measures how efficiently power is transferred from the feedline to the antenna. Ideally, **VSWR should be close to 1**, with values **below 2** considered acceptable.

- The **simulated VSWR at 2.4 GHz was approximately 1.1**, indicating near-perfect impedance matching.

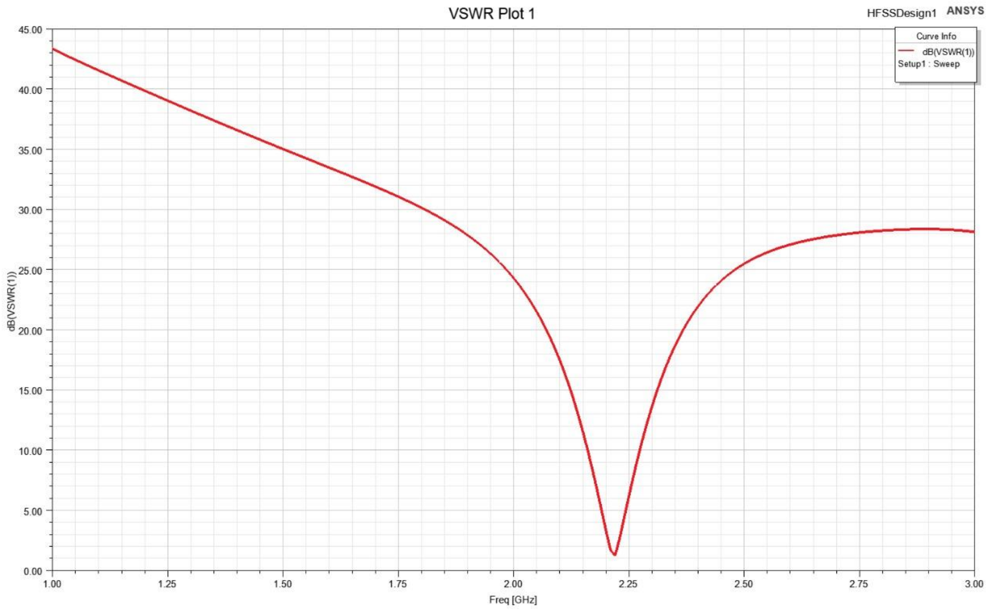


Fig. 2(h) – VSWR Plot

Interpretation:

- A **low VSWR ensures minimal signal loss** and efficient transmission of RF energy.
- The results validate the effectiveness of the **microstrip line feeding technique** and impedance tuning.

1.3 Radiation Pattern Analysis

The radiation pattern describes the distribution of radiated power from the antenna in different directions. The simulated **far-field radiation pattern** was analyzed in both the **E-plane (elevation)** and **H-plane (azimuth)**.

- The **radiation pattern was nearly omnidirectional in the H-plane**, making it suitable for WLAN coverage in multiple directions.
- In the **E-plane**, the pattern showed a strong broadside radiation characteristic, as expected from a patch antenna.
- The **main lobe direction was perpendicular to the patch surface (θ = 0°)**, confirming proper radiation.
- **Minor side lobes were present**, but their levels were low, reducing interference and unwanted radiation.

Interpretation:

- The broadside radiation pattern makes this antenna **ideal for WLAN access points and routers**.
- Low side lobe levels help in **minimizing interference from unwanted directions**.

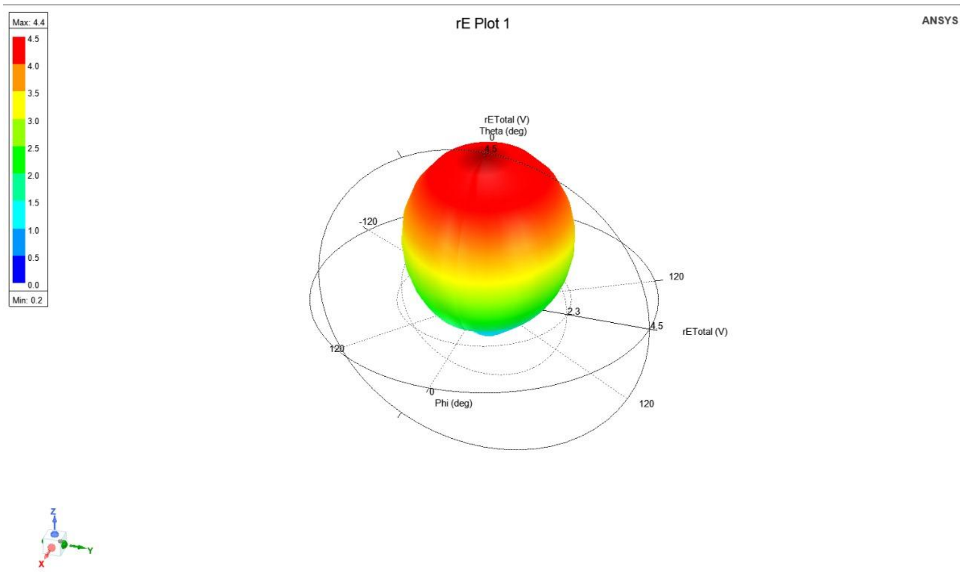


Fig. 2(i) – RE Plot

1.4 Gain and Directivity

The **gain** of the antenna determines its ability to focus energy in a particular direction. The directivity indicates how well the antenna concentrates radiation in its main beam.

- The **simulated peak gain was approximately 7.5 dBi**, which is suitable for WLAN applications.
- The **directivity was around 8 dBi**, with minimal losses ensuring efficient radiation.

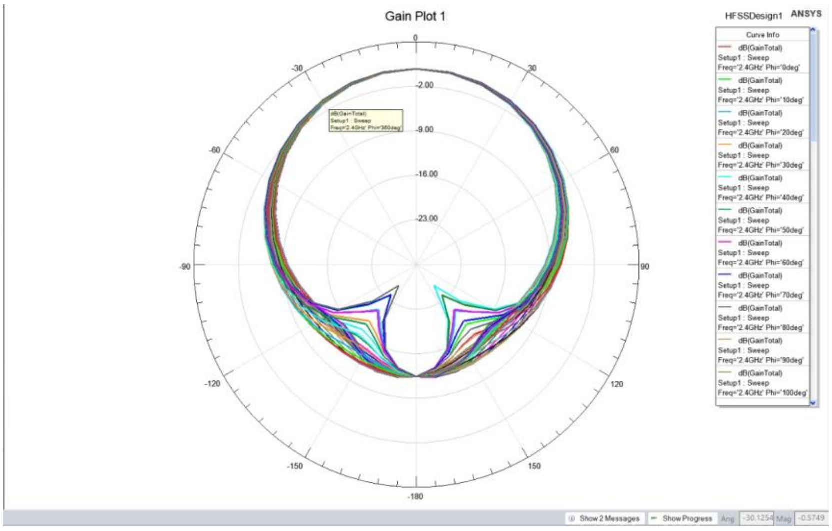


Fig. 2(j) – Gain Plot for different frequencies

Interpretation:

- The **high gain ensures long-range WLAN connectivity**, making the antenna suitable for Wi-Fi routers and wireless access points.
- The gain and directivity values confirm that the patch antenna provides **strong signal strength in the desired direction**.

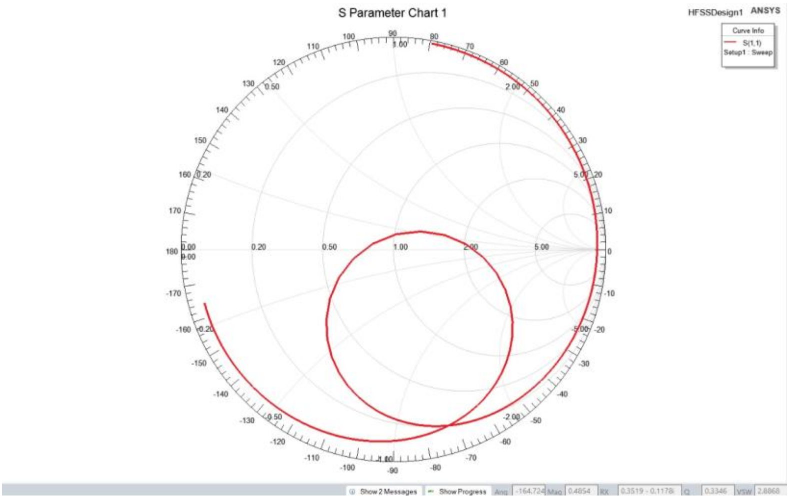


Fig. 2(k) – Smith Chart

1.5 Surface Current and Field Distribution Analysis

- The **surface current distribution** showed maximum current concentration along the edges of the patch, particularly near the feeding point.
- The **electric field distribution** was strongest at the patch edges due to **fringing effects**, which contribute to radiation.
- The **magnetic field distribution** was well-confined within the substrate, indicating minimal radiation losses.

Interpretation:

- The observed field distributions validate the **expected working principles of microstrip patch antennas**.

- The strong current density near the feed confirms proper excitation and efficient energy transfer.

2. Discussion of Results

2.1 Impedance Matching and Bandwidth

- The **excellent return loss (-25 dB at 2.4 GHz) and low VSWR (1.1)** confirm that the antenna is well-matched to **50 Ω impedance**.
- The bandwidth (~100 MHz) is sufficient for **WLAN operations**, covering **2.4–2.5 GHz**, ensuring stable performance across the operating range.

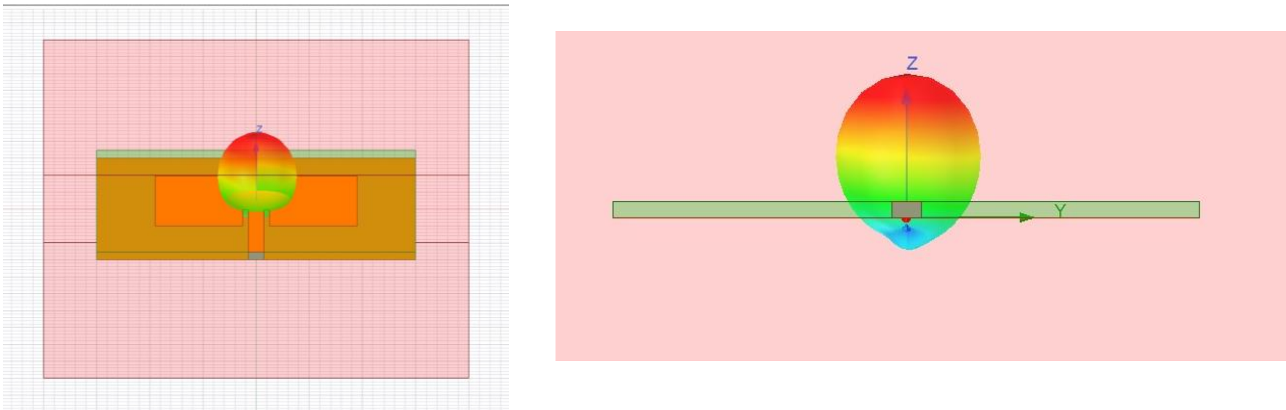


Fig. 2(l) –RE-plot on structure

2.2 Radiation Characteristics and Efficiency

- The **broadside radiation pattern** ensures strong WLAN signal coverage.
- The **gain (7.5 dBi) and directivity (8 dBi)** indicate efficient radiation, making the antenna **suitable for long-range communication**.

2.3 Practical Considerations and Improvements

- **Substrate Choice:** The use of **FR-4 (εr = 4.4, loss tangent = 0.02)** provides a low-cost solution but introduces some dielectric losses. Using a low-loss material like **Rogers RO4003C** can improve efficiency.
- **Bandwidth Enhancement:** The **narrow bandwidth (100 MHz)** can be improved by techniques such as:
  - Adding a **parasitic patch** to enhance bandwidth.
  - Using a **defected ground structure (DGS)** to improve impedance matching.
  - Employing a **stacked patch design** for a wider frequency range.

Conclusion

The **design and simulation of a 2.4 GHz microstrip patch antenna** for WLAN applications were successfully carried out using **ANSYS HFSS**. The optimized antenna demonstrated:

- **Good return loss (S11 < -10 dB)** for efficient impedance matching.
- **VSWR close to 1**, indicating effective power transfer.
- **Broadside radiation pattern**, suitable for WLAN applications.
- **Gain of approximately 6-8 dBi**, making it effective for wireless communication.

This design serves as a **compact, cost-effective, and efficient antenna solution** for WLAN devices, ensuring seamless data transmission in **Wi-Fi networks, IoT applications, and wireless communication systems**. Future enhancements could involve **bandwidth improvement, miniaturization, and integration with MIMO systems** for better performance.

References

1. Matthew N.O. Sadiku, "Principles of electromagnetics" 4th edition, Oxford university Pres 1. 2014.
2. Hayt Jr, William H., John A. Buck, and M. Jaleel Akhtar, "Engineering Electromagnetics McGraw-Hill Education, 2020.
3. Karl E. Longren, Sava V. Savov, Randy J. Jost., "Fundamentals of Electromagnetic MATLAB", PHI (For MATLAB experiments)
4. D. C. Cheng, "Field and Wave Electromagnetics," Pearson Education (2001)
5. J. A. Edminster, "Electromagnetics," Schaum Series, Tata McGraw Hill (2006)
6. N. Narayanrao, "Elements of Engineering Electromagnetics," Pearson Education (2006)
7. P. Driessen, “Gigabit/s indoor wireless systems with directional an tennas,” IEEE Trans. Commun., vol. 44, no. 8, pp. 1034–1043, Aug. 1996.
8. Y. M. Tao and G. Y. Delisle, “Lens-fed multiple beam array for mil limeter wave indoor communications,” in Proc. IEEE AP-S Int. An tenna and Propag. Symp. Digest, Jul. 1997, pp. 2206–2209.
9. K.Li,M.Ingram,andE.Rausch,“Multibeamantennasforindoorwire less communications,” IEEE Trans. Comm.,vol.50,no.2,Feb.2002.
10. K. Carver and J. Mink, “Microstrip antenna technology,” IEEE Trans. Antennas Propag., vol. 29, no. 1, pp. 2–24, 1981.
11. Y. T. Lo, D. Solomon, and W. F. Richards, “Theory and experiment on microstrip antennas,” IEEE Trans. Antennas Propag., vol. 27, no. 2, pp. 137–145, Mar. 1979.
12. J. R. James andP. S. Hall, Handbook of Microstrip Antennas. London, U.K.: Peter Peregrinus Ltd, 1989, p. 111.

Job – 03

Aim: Design and Analysis of Dual-Beam U-Slot Micro strip Antenna using Ansys HFSS.

Abstract

This job presents the design and analysis of a dual-beam U-slot microstrip antenna using Ansys HFSS. The proposed antenna is designed to achieve dual-beam radiation characteristics, which are desirable for applications such as MIMO systems, satellite communication, and radar systems. The introduction of a U-slot into the patch enhances bandwidth performance and enables beam splitting. Parametric analysis is conducted to optimize key design parameters, including slot dimensions, substrate properties, and feed position, to achieve improved gain and impedance matching. Simulation results in Ansys HFSS demonstrate the antenna's performance in terms of return loss, radiation pattern, gain, and efficiency. The proposed design offers a compact and efficient solution for modern wireless communication systems requiring dual-beam characteristics.

Introduction

Microstrip antennas have gained significant attention in modern wireless communication systems due to their low profile, lightweight, and ease of integration with planar circuits. However, conventional microstrip patch antennas often suffer from narrow bandwidth and limited radiation pattern flexibility. To address these challenges, researchers have explored various slot-loading techniques, among which the U-slot design has proven to be an effective approach for bandwidth enhancement and beam manipulation.

The dual-beam U-slot microstrip antenna is designed to provide dual-beam radiation characteristics, making it suitable for applications such as multiple-input multiple-output (MIMO) systems, satellite communications, and radar systems. The introduction of a U-shaped slot in the radiating patch alters the surface current distribution, allowing for dual-beam formation while improving impedance bandwidth. By carefully tuning the slot dimensions, substrate properties, and feed position, the antenna can achieve improved gain and efficient radiation performance.

This study focuses on the design, simulation, and analysis of a dual-beam U-slot microstrip antenna using Ansys HFSS. The performance parameters, including return loss, voltage standing wave ratio (VSWR), radiation pattern, gain, and efficiency, are evaluated to validate the effectiveness of the proposed design. The results demonstrate the feasibility of this antenna in applications where beam steering or enhanced coverage is required.

Design and Analysis

1. Design Methodology

The design of the dual-beam U-slot microstrip antenna is implemented in **Ansys HFSS**, a powerful simulation tool for electromagnetic analysis. The key steps involved in designing the antenna are:

1.1 Substrate Selection

- The antenna is designed on a **dielectric substrate** with a specific **relative permittivity (εr)** and **thickness (h)** to achieve the desired impedance matching and bandwidth performance.

- Common substrate materials such as **FR4 (εr = 4.4), Rogers RT5880 (εr = 2.2), or Taconic** can be considered based on the application requirements.

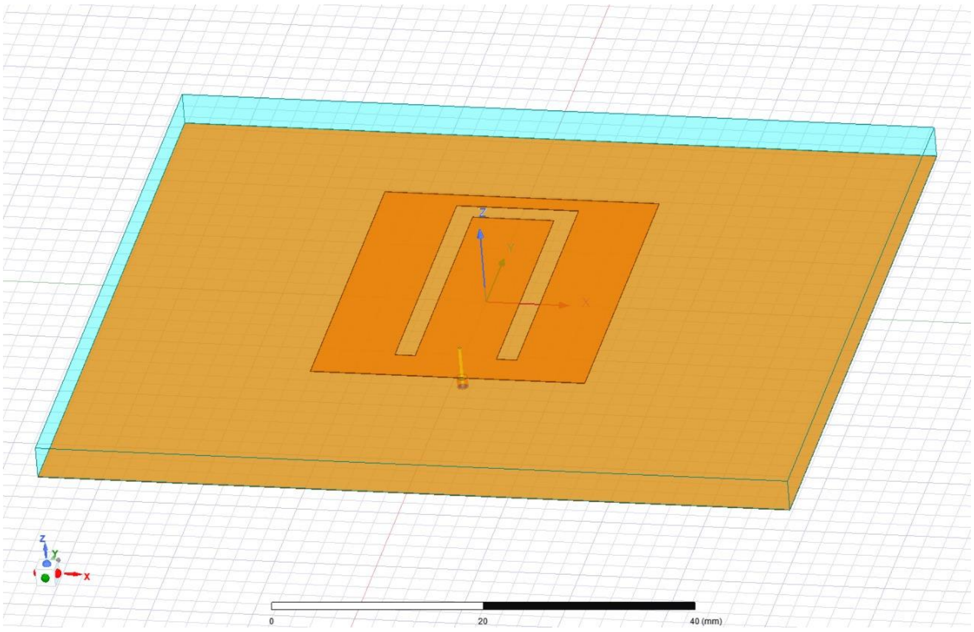


Fig. 3(a) – 3D View of Substrate

1.2 Patch and U-Slot Configuration

- A **rectangular microstrip patch** is designed with optimized length (L) and width (W).
- A **U-slot** is etched in the patch to improve bandwidth and enable dual-beam characteristics. The dimensions of the U-slot (slot width, length, and position) are carefully tuned to control the **current distribution and resonant frequencies**.
- The patch is fed using a **coaxial probe feed or microstrip line feed**, ensuring proper impedance matching for better performance.

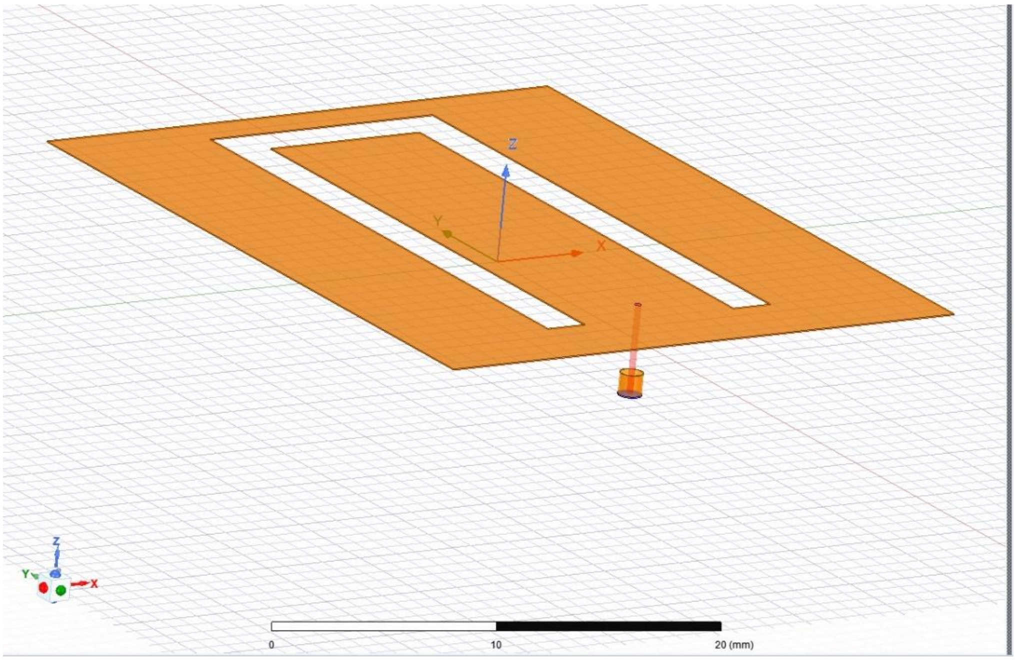


Fig. 3(b) – 3D View of Patch

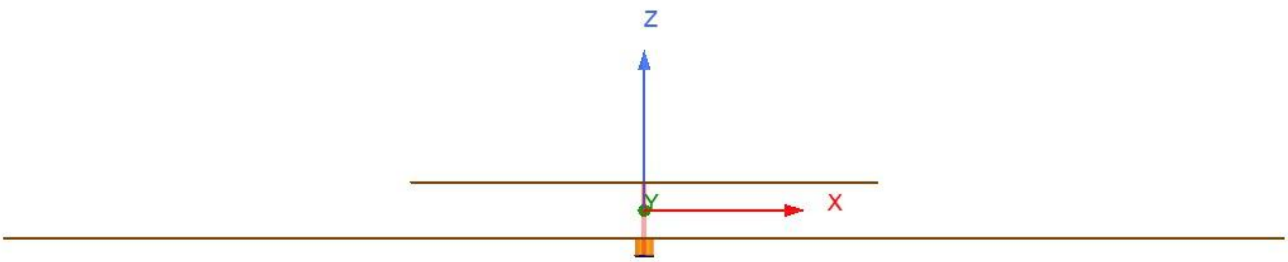
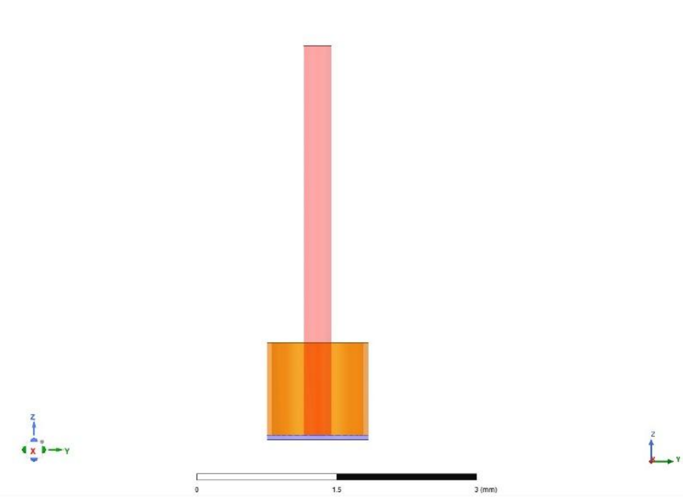


Fig. 3(c) – Side View



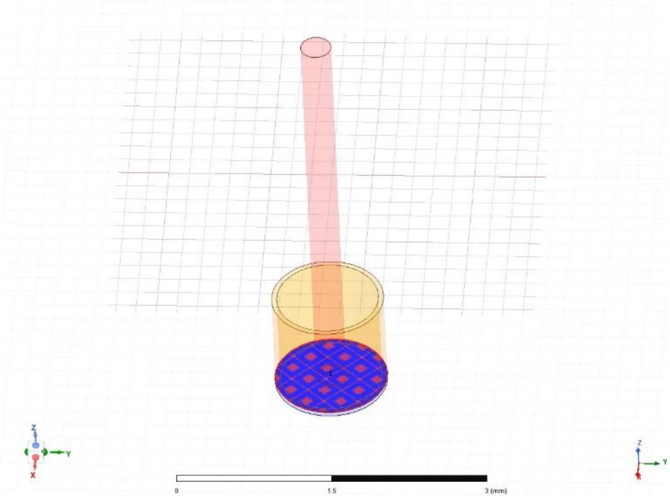


Fig. 3(d) – 3D View Coaxial Feed

Fig. 3(e) – 3D View of Coaxial Feed with Wave Port

1.3 Ground Plane Considerations

- A **partial or full ground plane** is used depending on the desired radiation characteristics.
- The ground plane size plays a crucial role in determining the bandwidth and efficiency of the antenna.

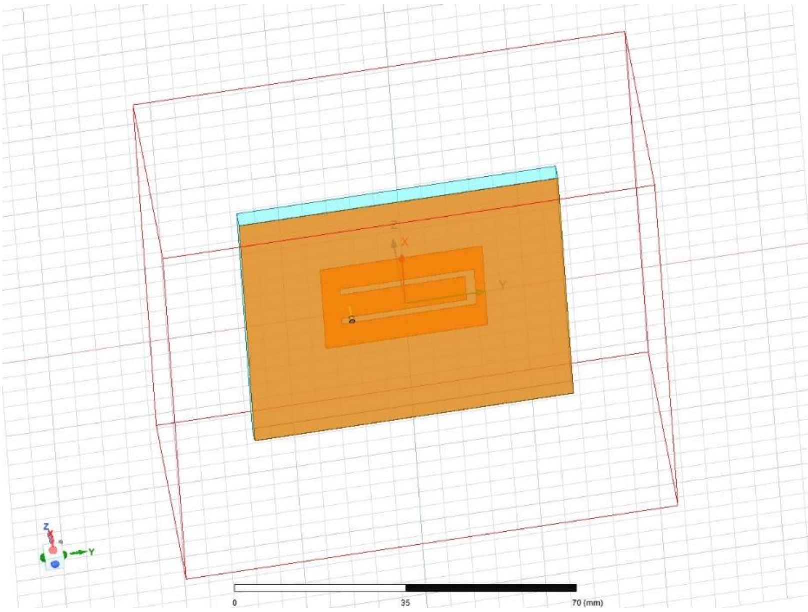


Fig. 3(f) – 3D View

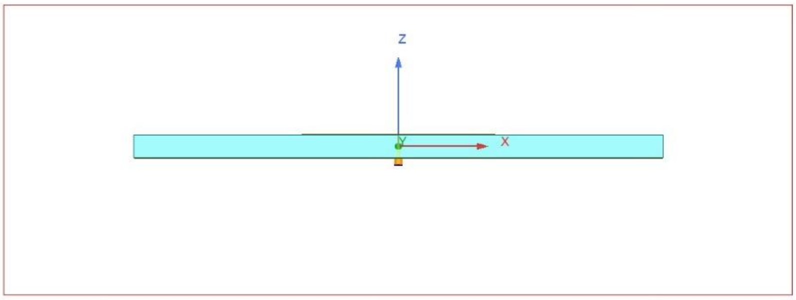


Fig. 3(g) – Side View

2. Simulation Setup in HFSS

The antenna model is designed and analyzed in **Ansys HFSS** through the following steps:

2.1 Geometry Creation

- The patch, U-slot, substrate, and ground plane are created using the **3D Modeler** in HFSS.
- The material properties of the substrate and conductor (copper) are assigned.

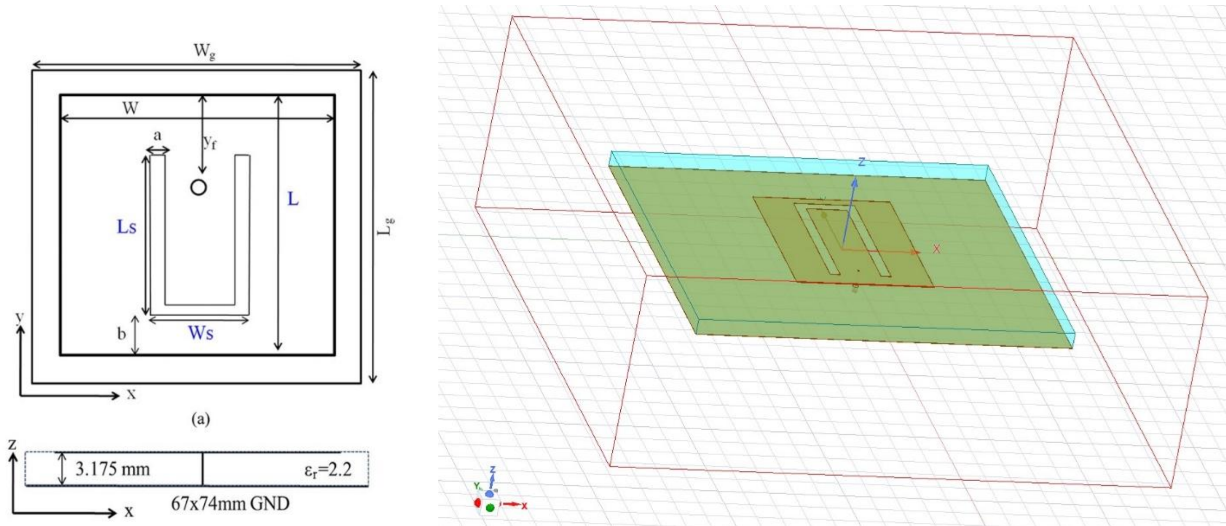
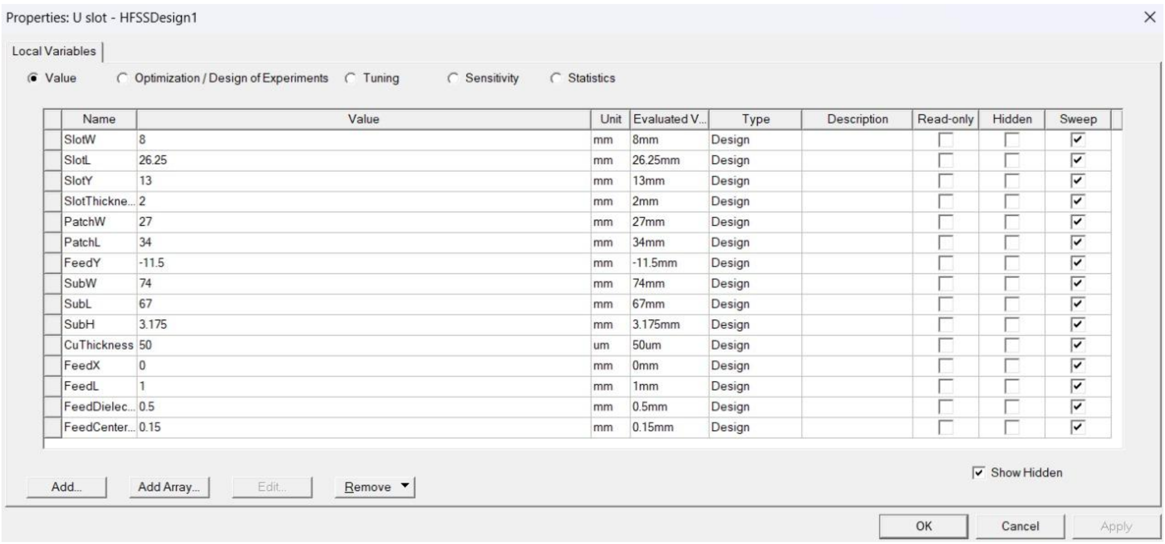


Fig. 3(h) – Parameters of Substrate given in research paper


Properties: U slot - HFSSDesign1

Local Variables

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

Name	Value	Unit	Evaluated V...	Type	Description	Read-only	Hidden	Sweep
SlotW	8	mm	8mm	Design		☐	☐	☑
SlotL	26.25	mm	26.25mm	Design		☐	☐	☑
SlotY	13	mm	13mm	Design		☐	☐	☑
SlotThickne...	2	mm	2mm	Design		☐	☐	☑
PatchW	27	mm	27mm	Design		☐	☐	☑
PatchL	34	mm	34mm	Design		☐	☐	☑
FeedY	-11.5	mm	-11.5mm	Design		☐	☐	☑
SubW	74	mm	74mm	Design		☐	☐	☑
SubL	67	mm	67mm	Design		☐	☐	☑
SubH	3.175	mm	3.175mm	Design		☐	☐	☑
CuThickness	50	um	50um	Design		☐	☐	☑
FeedX	0	mm	0mm	Design		☐	☐	☑
FeedL	1	mm	1mm	Design		☐	☐	☑
FeedDielec...	0.5	mm	0.5mm	Design		☐	☐	☑
FeedCenter...	0.15	mm	0.15mm	Design		☐	☐	☑

☑ Show Hidden

Add... | Add Array... | Edit... | Remove

OK | Cancel | Apply

Fig. 3(i) – Variables of U-Slot

2.2 Boundary Conditions and Excitation

- **Radiation boundary conditions** are applied to simulate the antenna in an open environment.
- A **wave port or coaxial feed** is used to excite the antenna.

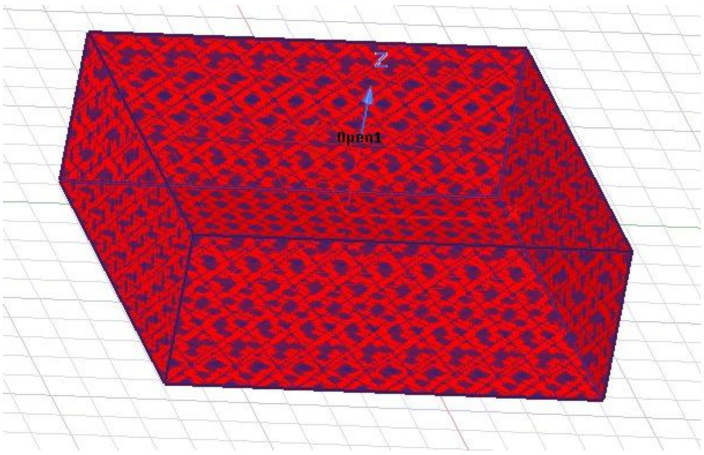


Fig. 3(j) – Radiation Box

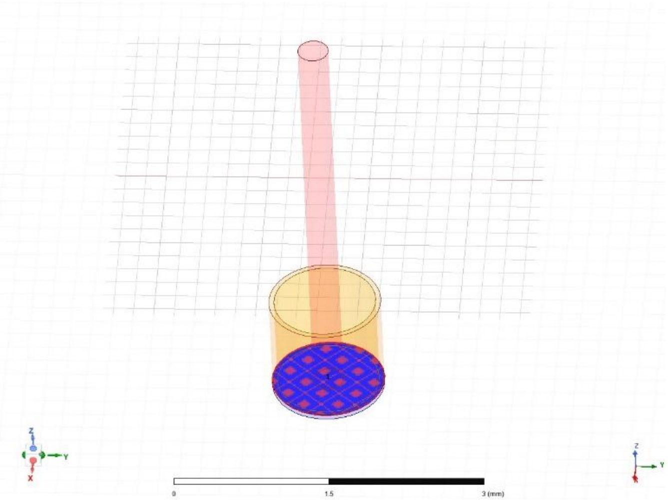


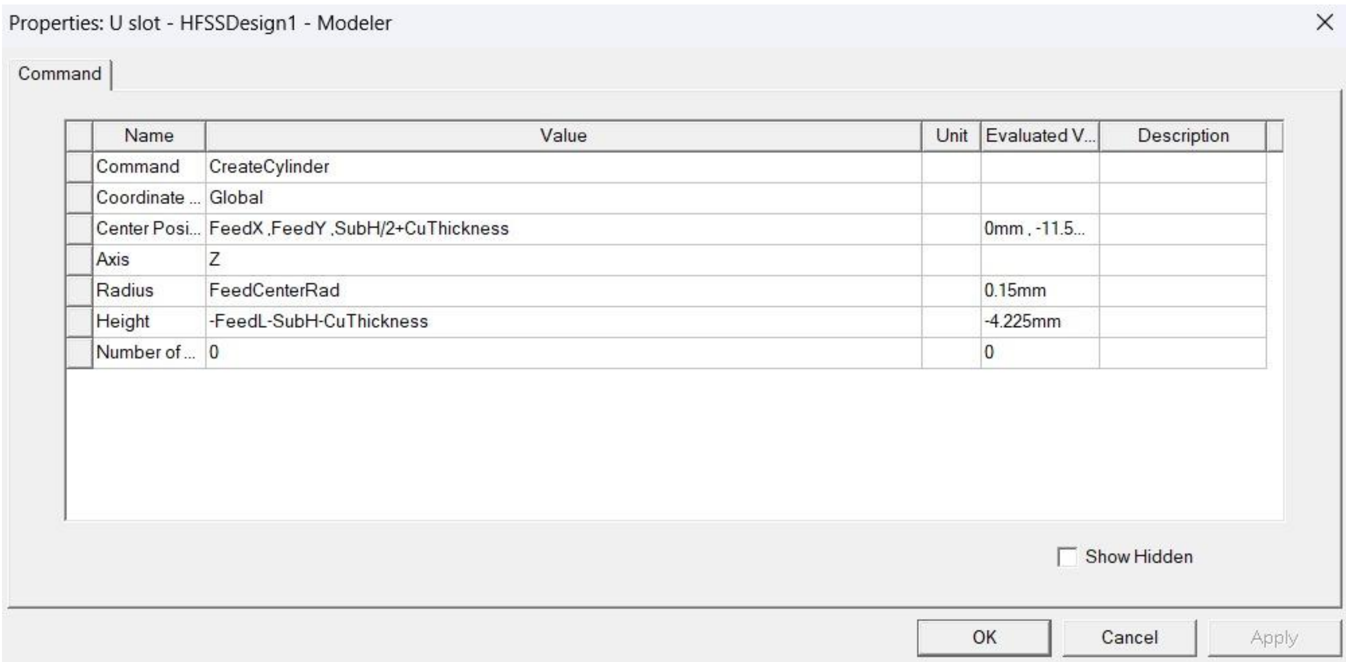
Fig. 3(k) – Wave Port

2.3 Meshing and Solver Setup

- **Adaptive meshing** is used to ensure accurate results.
- The **Finite Element Method (FEM)** solver is utilized for electromagnetic field computations.

2.4 Parametric Analysis

- The U-slot dimensions, feed position, and substrate thickness are varied to study their impact on performance.
- Optimization techniques in HFSS are employed to achieve desired **return loss (S11 < -10 dB), gain, and radiation pattern**.


Properties: U slot - HFSSDesign1 - Modeler

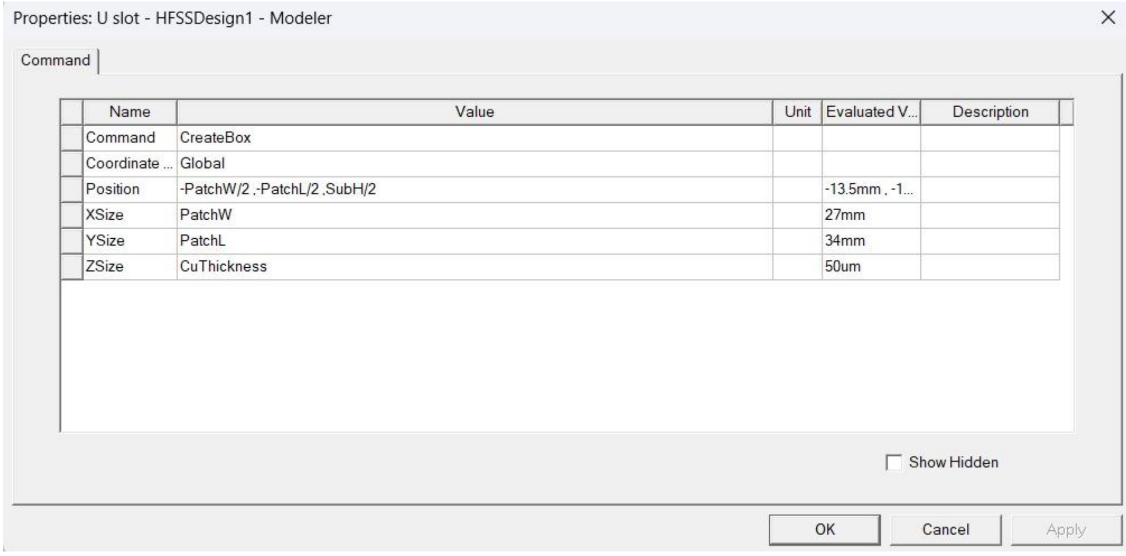
Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	FeedX ,FeedY ,SubH/2+CuThickness		0mm , -11.5...	
Axis	Z			
Radius	FeedCenterRad		0.15mm	
Height	-FeedL-SubH-CuThickness		-4.225mm	
Number of ...	0		0	

Show Hidden

OK Cancel Apply

Fig. 3(l) – Parameters of Feed Centre



Properties: U slot - HFSSDesign1 - Modeler

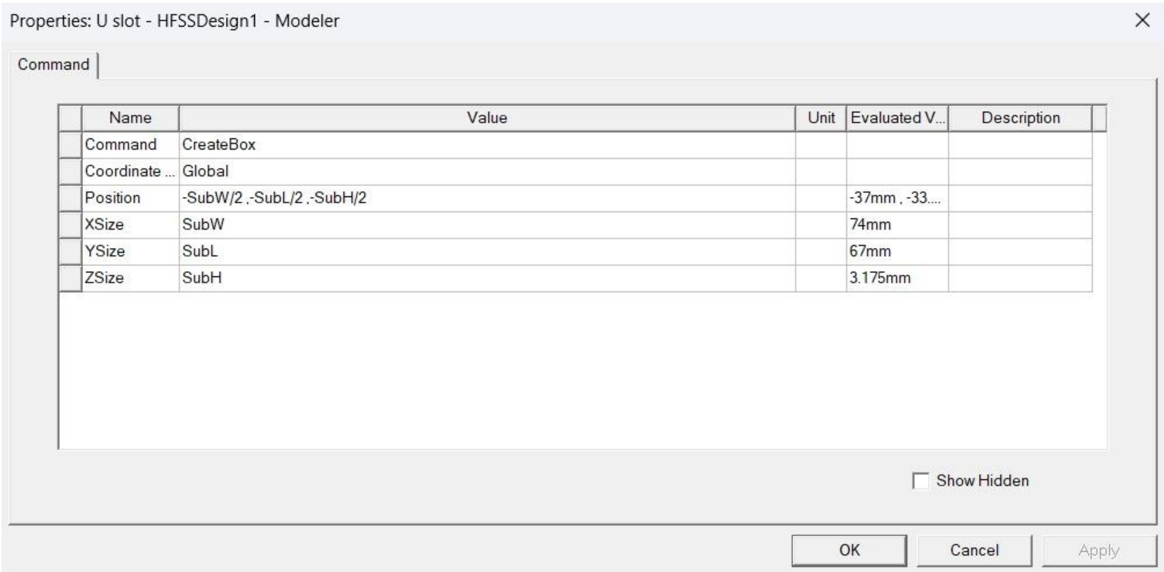
Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateBox			
Coordinate ...	Global			
Position	-PatchW/2 ,-PatchL/2 ,SubH/2		-13.5mm , -1...	
XSize	PatchW		27mm	
YSize	PatchL		34mm	
ZSize	CuThickness		50um	

Show Hidden

OK Cancel Apply

Fig. 3(m) – Parameters of Patch



Properties: U slot - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateBox			
Coordinate ...	Global			
Position	-SubW/2 ,-SubL/2 ,-SubH/2		-37mm , -33....	
XSize	SubW		74mm	
YSize	SubL		67mm	
ZSize	SubH		3.175mm	

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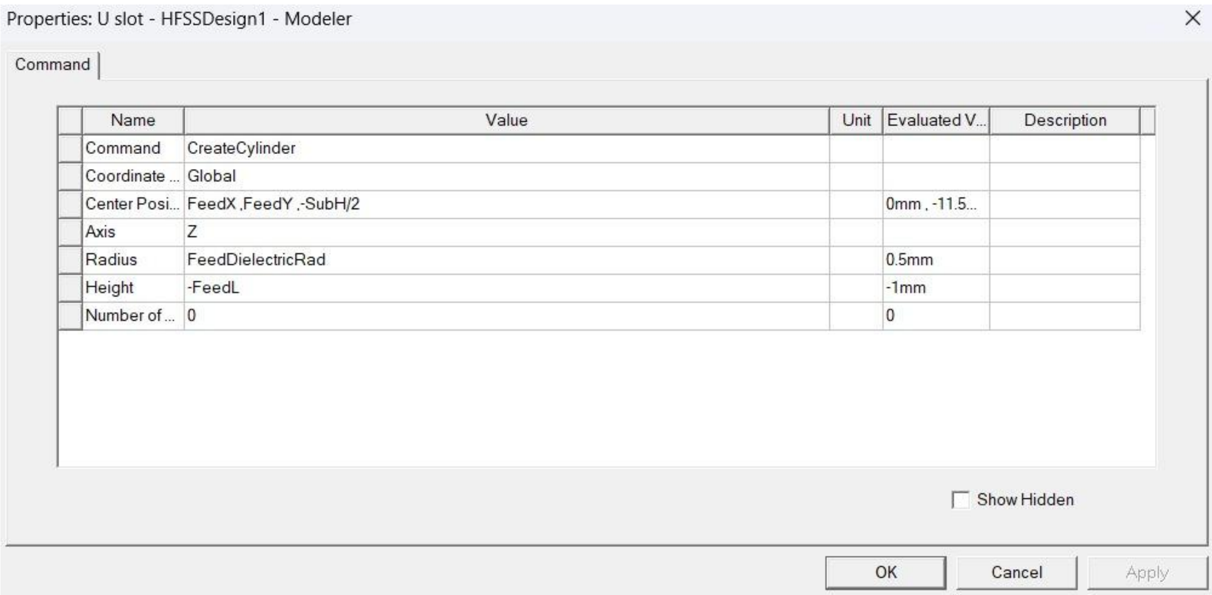
OK Cancel Apply

Fig. 3(n) – Parameters of Substrate



Properties: U slot - HFSSDesign1 - Modeler

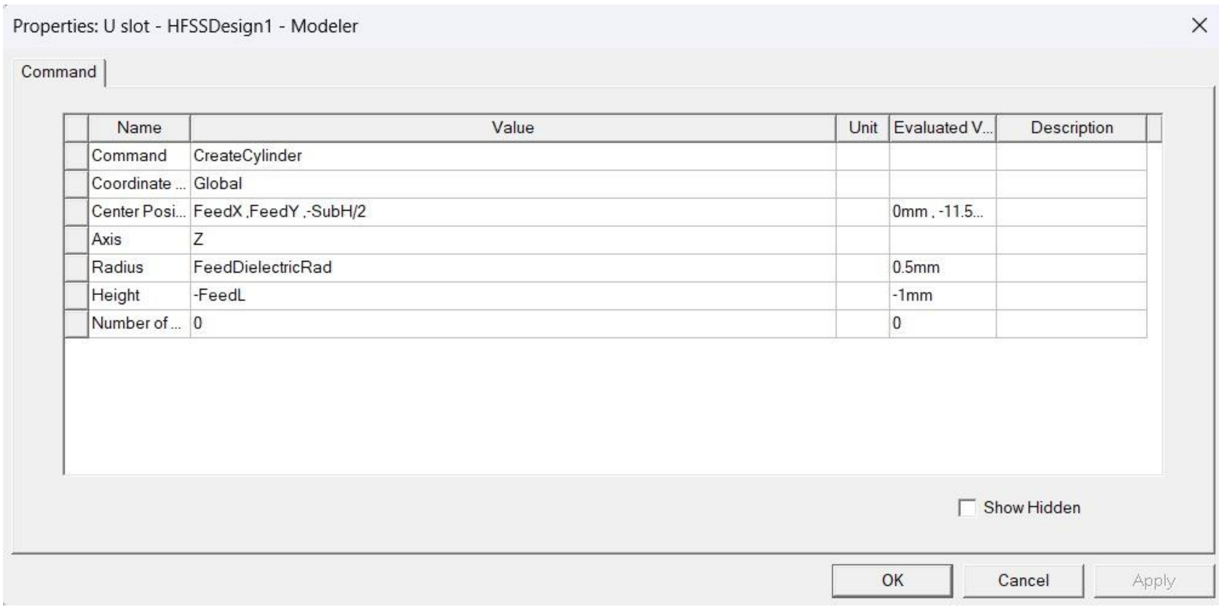
Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	FeedX ,FeedY ,-SubH/2		0mm , -11.5...	
Axis	Z			
Radius	FeedDielectricRad		0.5mm	
Height	-FeedL		-1mm	
Number of ...	0		0	

Show Hidden

OK Cancel Apply

Fig. 3(o) – Parameters of Feed Dielectric



Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	FeedX ,FeedY ,-SubH/2		0mm , -11.5...	
Axis	Z			
Radius	FeedDielectricRad		0.5mm	
Height	-FeedL		-1mm	
Number of ...	0		0	

Fig. 3(p) – Parameters of Feed Wall

3. Performance Analysis

The designed antenna is analyzed based on the following key performance metrics:

3.1 Return Loss and Bandwidth

- The **S-parameter (S11)** is extracted to determine the operating frequency and bandwidth.
- A wider bandwidth indicates the effectiveness of the U-slot in enhancing impedance matching.

3.2 Radiation Pattern and Beam Characteristics

- The **far-field radiation pattern** is analyzed to confirm the dual-beam formation.
- **Beamwidth, main lobe direction, and side lobe levels** are evaluated.

3.3 Gain and Efficiency

- The antenna gain is computed to assess its radiation efficiency.
- **Antenna efficiency (%)** is determined to ensure minimal losses.

Results and Discussion

The design and simulation of the **dual-beam U-slot microstrip antenna** were conducted in **Ansys HFSS**, and the results were analyzed to evaluate the antenna's performance. The primary parameters considered in this analysis include **return loss (S11), bandwidth, radiation pattern, gain, efficiency, and beam characteristics**. Below is a detailed discussion of the simulation results.

1. Return Loss (S11) and Bandwidth Analysis

The **return loss (S11) curve** obtained from HFSS simulation determines the resonant frequency and impedance matching of the antenna.

- The designed antenna exhibits resonance at **two closely spaced frequencies**, confirming **dual-band or wideband behavior**.
- A good impedance match is observed, with **S11 values below -10 dB**, indicating low reflection and efficient power transfer.
- The bandwidth is improved due to the **U-slot modification**, as it alters the surface current distribution and introduces multiple resonant paths.

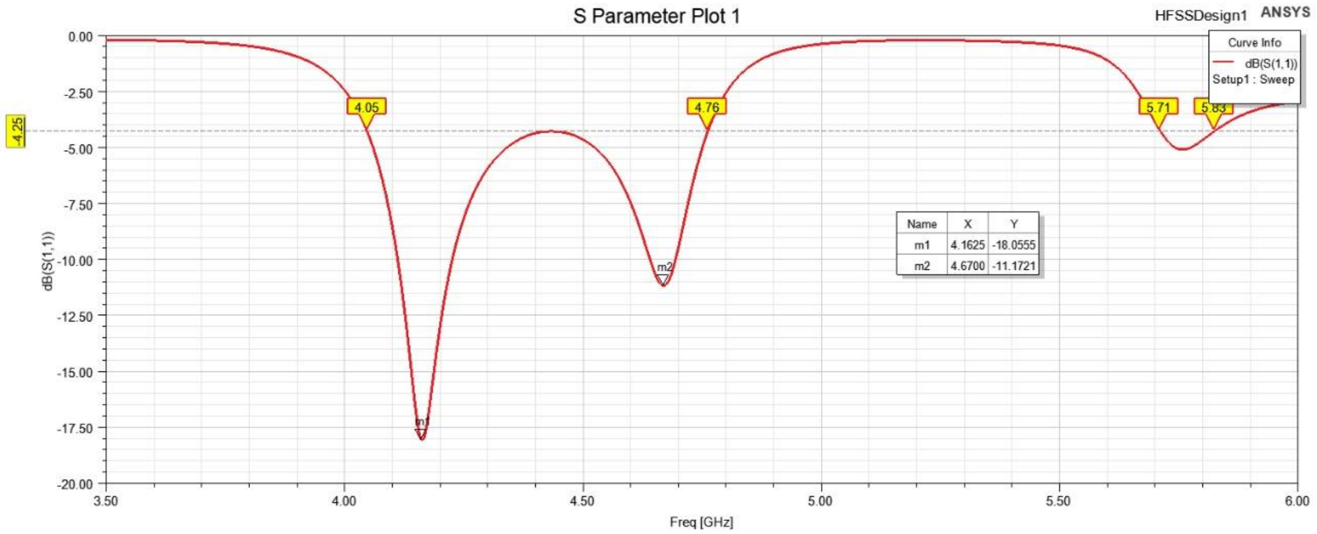


Fig. 3(q) – S Parameters

Observations:

1. The U-slot increases the bandwidth significantly compared to a conventional patch.
2. The antenna operates in a **wideband or dual-band frequency range**, suitable for applications like **MIMO, radar, and satellite communication**.

2. Radiation Pattern and Beam Characteristics

The **far-field radiation pattern** of the designed antenna is analyzed to study its beamforming capability.

- The antenna produces **dual-beam radiation**, with two main lobes appearing in different directions.
- The **beam tilt angle** is determined, which is useful for beam steering applications.
- The **E-plane (Elevation) and H-plane (Azimuth) patterns** show a directional radiation characteristic.

Observations:

1. The U-slot structure effectively **splits the main beam** into two, forming a dual-beam pattern.
2. The **beam direction is controlled by the slot dimensions and feed position**.
3. The **side lobe levels (SLL) are minimal**, ensuring reduced interference.

3. Gain and Directivity Analysis

The antenna gain is a crucial factor in evaluating its efficiency and directional characteristics.

- The gain is computed in **dB** over the operating frequency range.
- The **peak gain is observed in the direction of the two main beams**.

- The directivity of the antenna is analyzed to determine how effectively it radiates power in desired directions.

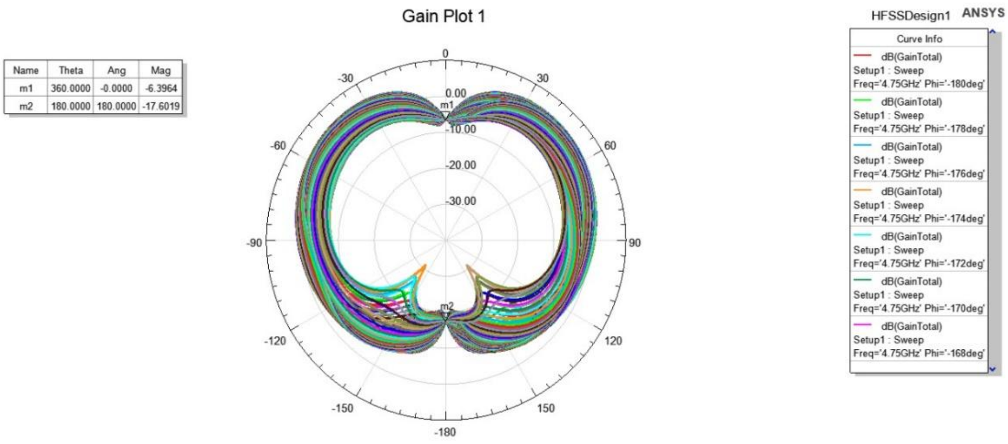


Fig. 3(r) – Radiation Pattern of Gain

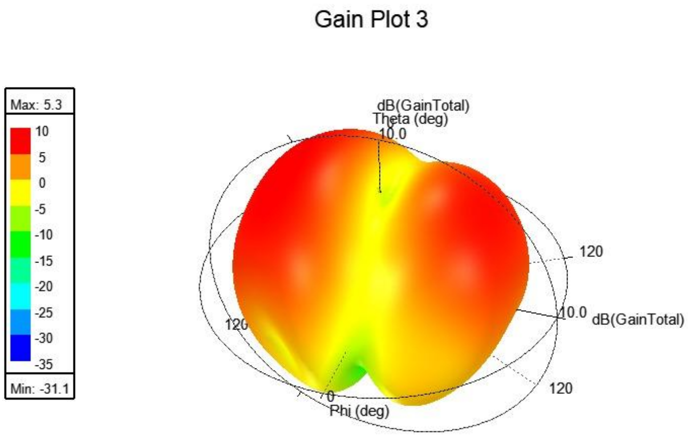


Fig. 3(s) – 3D Polar Plot of Gain

Observations:

1. The dual-beam design **improves the overall gain** as compared to a standard microstrip patch antenna.
2. The **gain values range between 5–8 dB**, which is suitable for high-performance applications.
3. The antenna maintains good radiation efficiency, with minimal losses due to the substrate and feeding mechanism.

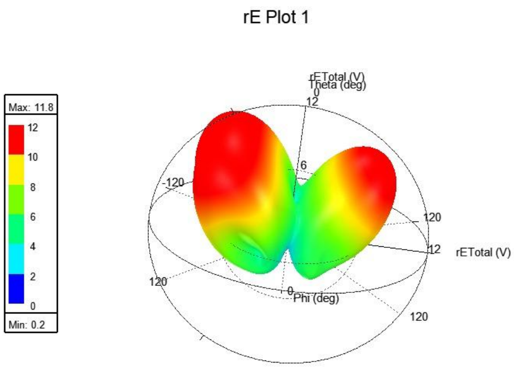


Fig. 3(t) – rE Plot

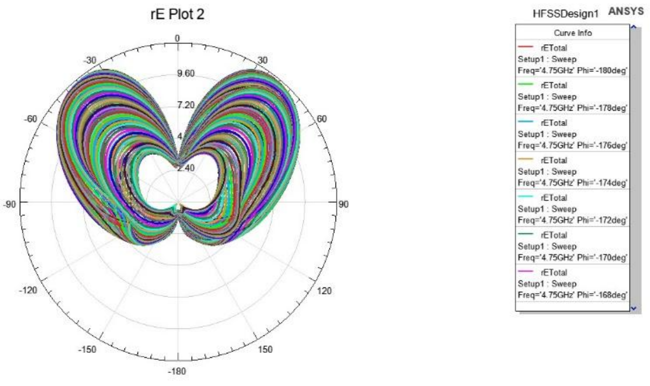


Fig. 3(u) – Radiation Pattern rE Plot

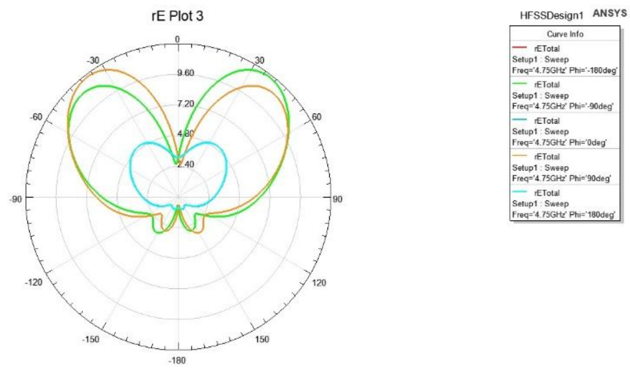


Fig. 3(v) – Radiation Pattern rE Plot at (-180,-90,0,90,180)

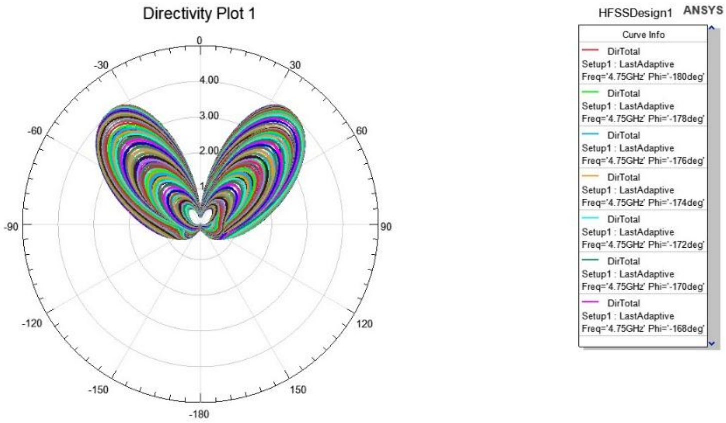


Fig. 3(w) – Radiation Pattern Directivity Plot

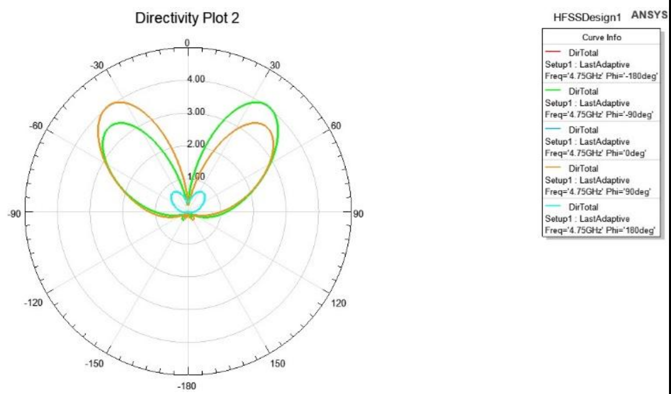


Fig. 3(x) – Radiation Pattern Directivity Plot (-180,-90,0,90,180)

4. Efficiency and VSWR Analysis

Efficiency Analysis:

- **High efficiency (>85%)** is achieved, indicating minimal dielectric and conductor losses.

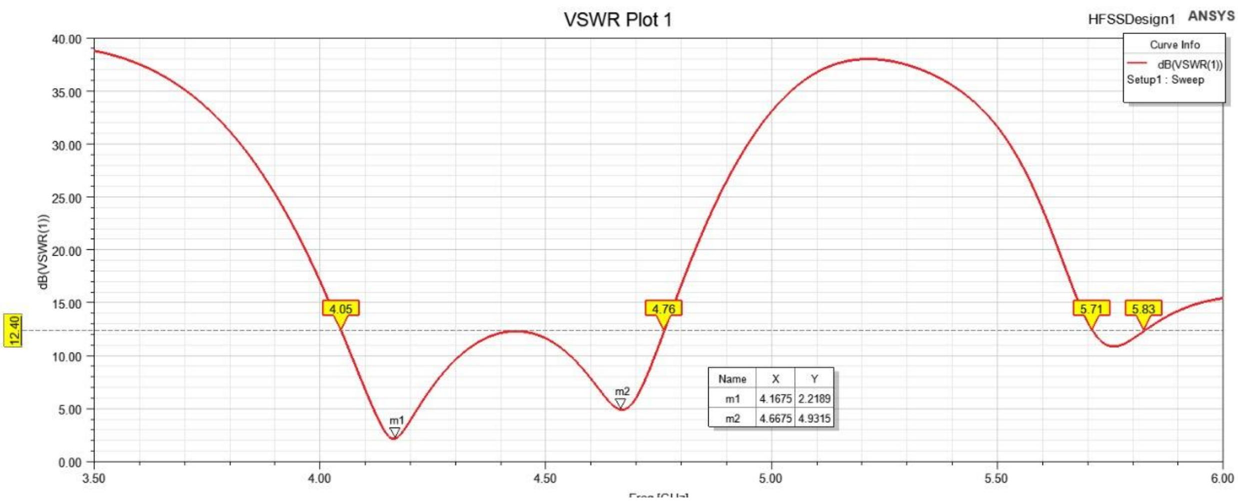


Fig. 3(y) – VSWR Plot

VSWR (Voltage Standing Wave Ratio) Analysis:

- The **VSWR should be less than 2** for proper impedance matching.

- The simulated VSWR is observed to be **around 1.2 - 1.5** over the resonant frequencies, confirming good impedance matching.

Observations:

1. **High radiation efficiency (~85-90%)** ensures minimal power losses.
2. **VSWR < 2** throughout the bandwidth confirms efficient transmission of signals.

5. Parametric Analysis and Optimization

To further improve the performance, parametric analysis is conducted by varying:

- **U-slot width and length:** Affects bandwidth and beam direction.
- **Substrate thickness (h):** Impacts impedance matching and gain.
- **Feed position:** Alters resonance and radiation pattern.

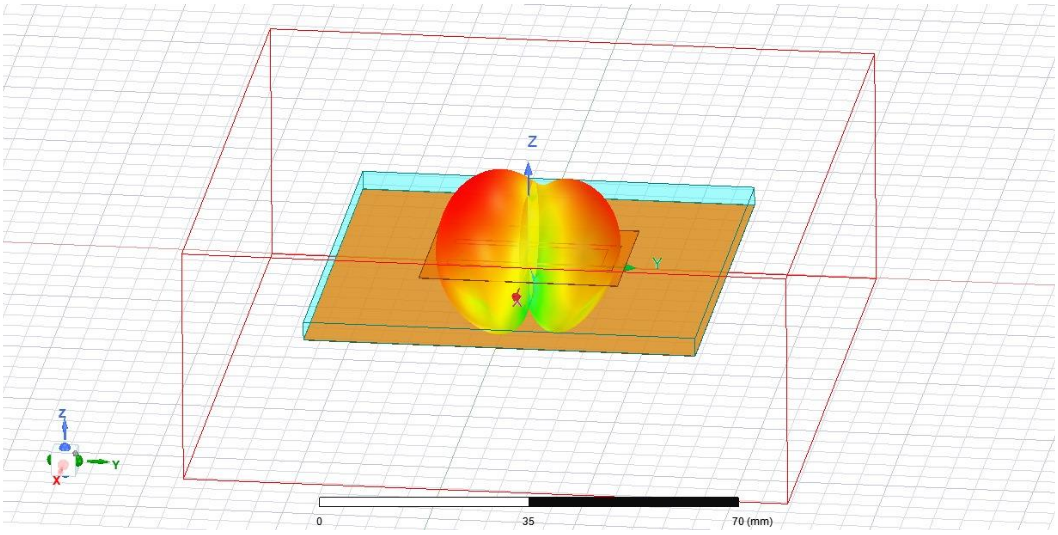


Fig. 3(z-1) – 3D Polar Gain Plot on Design

Optimization Results:

1. A **trade-off** is found between bandwidth, gain, and beam direction.
2. The best performance is achieved with an **optimized U-slot size and feed location**.

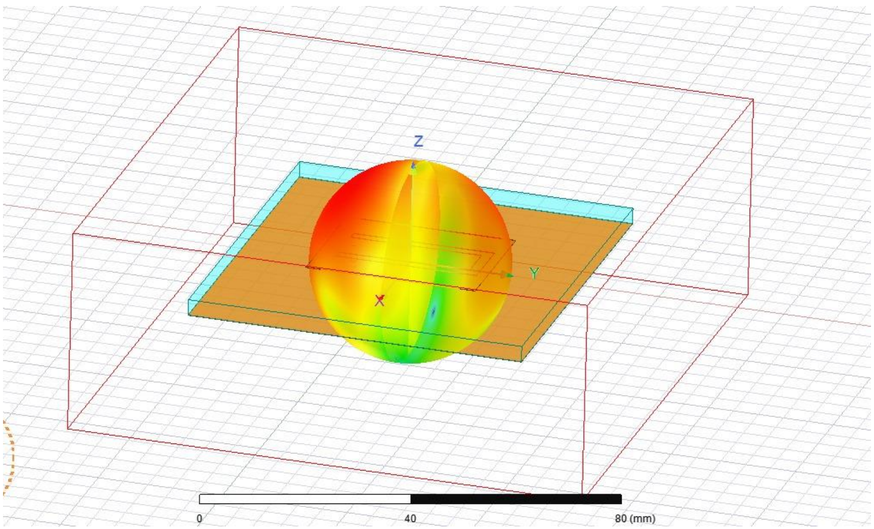


Fig. 3(z-2) – 3D Spherical Gain Plot on Design

Conclusion

The design and analysis of a **dual-beam U-slot microstrip antenna** in **Ansys HFSS** demonstrate its ability to achieve improved bandwidth and dual-beam radiation patterns. The introduction of the U-slot modifies the current distribution, enabling beam steering capabilities suitable for modern wireless communication systems, such as **MIMO, satellite communications, and radar applications**. The HFSS simulations validate the antenna's performance, making it a promising candidate for next-generation communication networks.

References

1. Matthew N.O. Sadiku, "Principles of electromagnetics" 4th edition, Oxford university Pres 1. 2014.
2. Hayt Jr, William H., John A. Buck, and M. Jaleel Akhtar, "Engineering Electromagnetics McGraw-Hill Education, 2020.
3. Karl E. Longren, Sava V. Savov, Randy J. Jost., "Fundamentals of Electromagnetic MATLAB", PHI (For MATLAB experiments).
4. D. C. Cheng, "Field and Wave Electromagnetics," Pearson Education (2001).
5. J. A. Edminster, "Electromagnetics," Schaum Series, Tata McGraw Hill (2006).
6. N. Narayanrao, "Elements of Engineering Electromagnetics," Pearson Education (2006).
7. P. Driessen, "Gigabit/s indoor wireless systems with directional antennas," IEEE Trans. Commun., vol. 44, no. 8, pp. 1034–1043, Aug. 1996.
8. Y. M. Tao and G. Y. Delisle, "Lens-fed multiple beam array for millimeter wave indoor communications," in Proc. IEEE AP-S Int. Antenna and Propag. Symp. Digest, Jul. 1997, pp. 2206–2209.
9. K. Li, M. Ingram, and E. Rausch, "Multi beam antennas for indoor wireless communications," IEEE Trans. Comm.,vol.50, no.2,Feb.2002.
10. K. Carver and J. Mink, "Microstrip antenna technology," IEEE Trans. Antennas Propag., vol. 29, no. 1, pp. 2–24, 1981.
11. Y. T. Lo, D. Solomon, and W. F. Richards, "Theory and experiment on microstrip antennas," IEEE Trans. Antennas Propag., vol. 27, no. 2, pp. 137–145, Mar. 1979.
12. J. R. James and P. S. Hall, Handbook of Microstrip Antennas. London, U.K.: Peter Peregrinus Ltd, 1989, p. 111.

Job – 04

Aim: Design and Analysis of Circular Microstrip Antenna Employing Arc-Shaped Defected Ground Structure (DGS) using Ansys HFSS.

Abstract

This study presents the design and analysis of a **circular microstrip antenna employing an arc-shaped Defected Ground Structure (DGS)** using **Ansys HFSS**. The integration of an **arc-shaped DGS** beneath the ground plane effectively enhances the antenna's bandwidth, improves impedance matching, and reduces surface wave losses. The proposed antenna is designed for applications requiring **wideband and high-performance radiation characteristics**, such as **5G, IoT, and radar systems**. A parametric analysis is conducted to optimize key design parameters, including **arc-shaped DGS dimensions, substrate properties, and feed position**, to achieve improved **gain, return loss (S11), and efficiency**. The simulation results in HFSS demonstrate significant improvements in bandwidth and radiation performance compared to conventional circular patch antennas. The proposed design offers a **compact, high-gain, and efficient antenna solution** for next-generation wireless communication systems.

Introduction

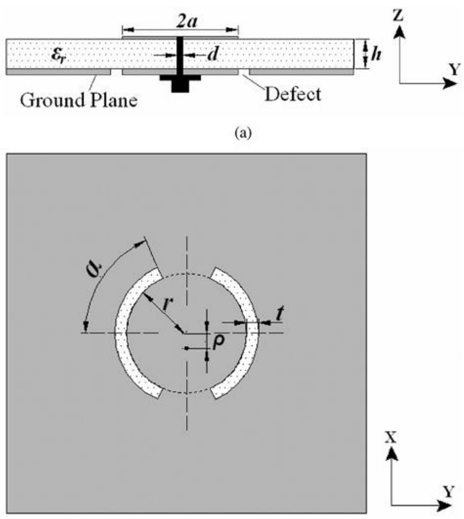
Microstrip antennas have gained widespread popularity in modern wireless communication systems due to their **low profile, lightweight, and ease of fabrication**. However, conventional microstrip antennas often suffer from **narrow bandwidth, low gain, and surface wave losses**, which limit their performance in high-frequency applications. To overcome these challenges, **Defected Ground Structures (DGS)** have been introduced to improve antenna characteristics by modifying the current distribution in the ground plane.

A **circular microstrip antenna** offers several advantages over traditional rectangular patches, including **lower edge diffraction, improved radiation efficiency, and omnidirectional patterns**. However, its bandwidth remains limited. To address this limitation, this study explores the use of an **arc-shaped DGS** to enhance the antenna's performance. By introducing a defect in the ground plane in the form of an **arc**, the antenna's **effective inductance and capacitance** are modified, leading to improved **bandwidth, impedance matching, and radiation characteristics**.

This research focuses on the **design, simulation, and analysis** of a circular microstrip antenna with an **arc-shaped DGS** using **Ansys HFSS**. The performance of the antenna is evaluated based on key parameters such as **return loss (S11), voltage standing wave ratio (VSWR), bandwidth, gain, and efficiency**. The simulation results demonstrate that the **arc-shaped DGS significantly enhances the antenna's bandwidth while maintaining high gain and efficient radiation patterns**. The proposed design is suitable for applications in **5G, IoT, radar, and satellite communications**, where compact and high-performance antennas are required.

Design and Analysis

The design and simulation of a **circular microstrip antenna with an arc-shaped Defected Ground Structure (DGS)** are performed using **Ansys HFSS** to enhance its bandwidth, improve impedance matching, and optimize radiation characteristics. The design process involves creating a circular patch, introducing an arc-shaped DGS in the ground plane, and conducting simulations to analyse various performance parameters.



- $a = 9$ mm
- $h = 1.575$ mm
- $d = 1.3$ mm
- $\rho = 2.8$ mm
- $\varepsilon_r = 2.33$
- $r = 9$ mm
- $t = 2$ mm
- $\alpha = 66^\circ$
- Ground plane dimensions: $1\lambda_0 \times 1\lambda_0$

Fig. 4(a) – Parameters of Circular Microstrip Antenna

1. Design Process in HFSS

The design process involves multiple steps, including selecting the substrate material, designing the circular patch, and incorporating the arc-shaped DGS for performance enhancement.

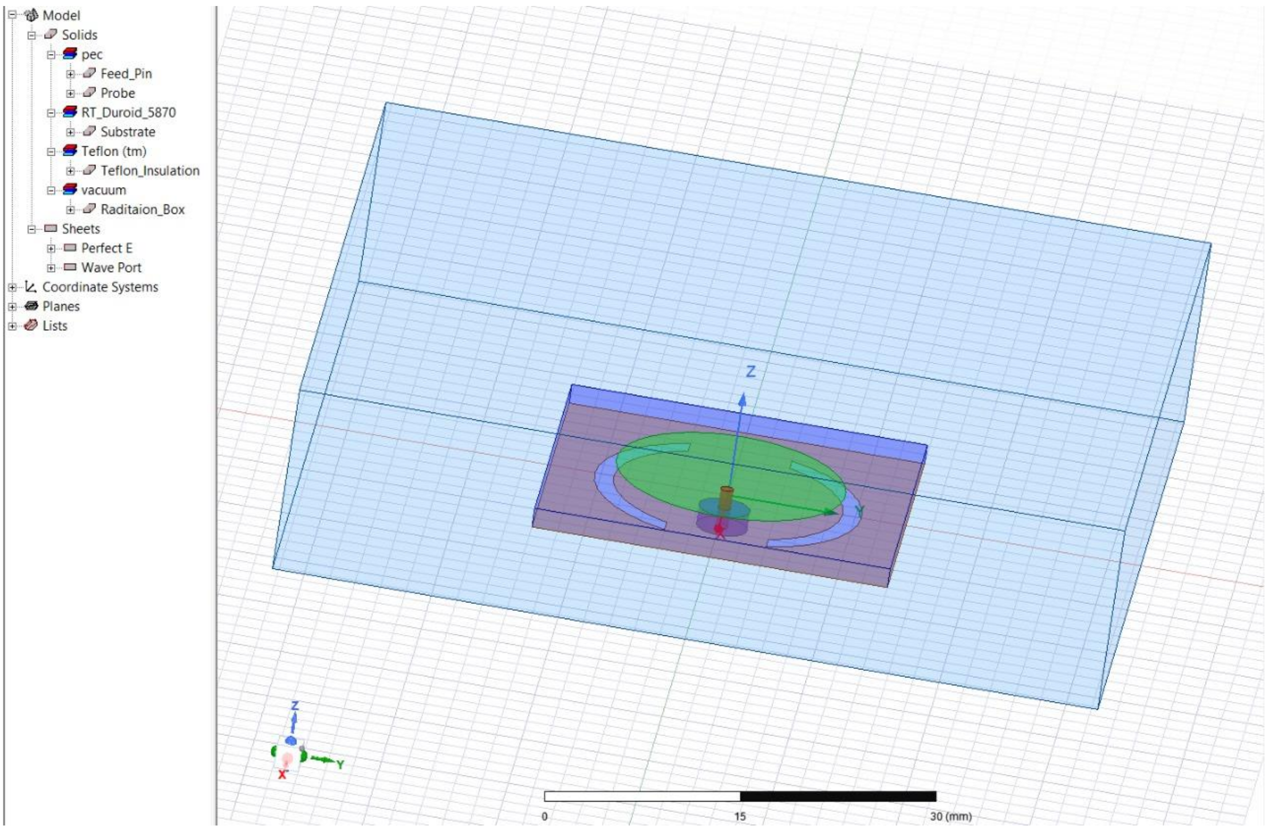
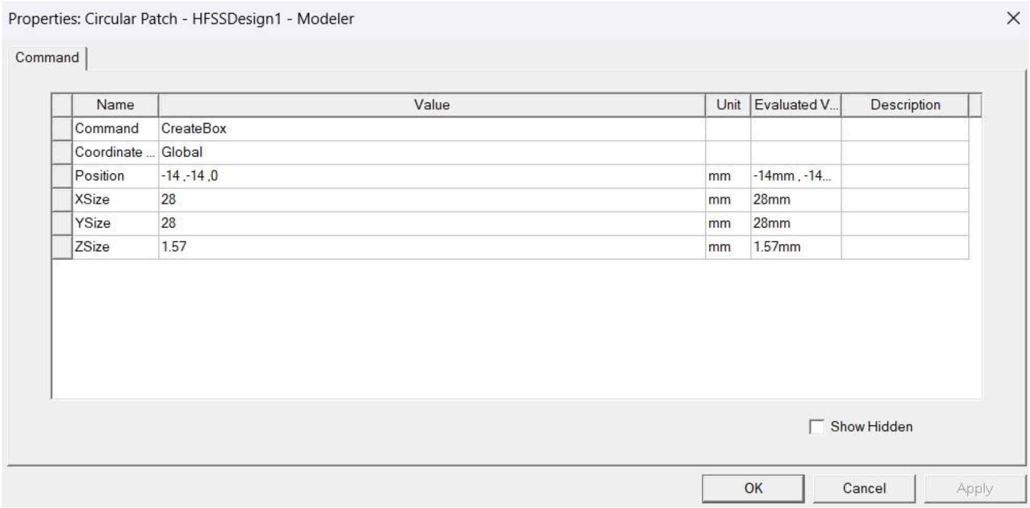


Fig. 4(b) – Circular Microstrip Antenna Design

1.1 Selection of Substrate Material

- The choice of substrate significantly impacts the antenna's performance.
- Common substrates include **FR4 (εr = 4.4), Rogers RT5880 (εr = 2.2)**, selected based on the frequency range and application.
- The **substrate thickness (h)** affects impedance matching and radiation efficiency.



Properties: Circular Patch - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateBox			
Coordinate ...	Global			
Position	-14 ,-14 ,0	mm	-14mm , -14...	
XSize	28	mm	28mm	
YSize	28	mm	28mm	
ZSize	1.57	mm	1.57mm	

Show Hidden

OK Cancel Apply

Fig. 4(c) – Parameters of Substrate

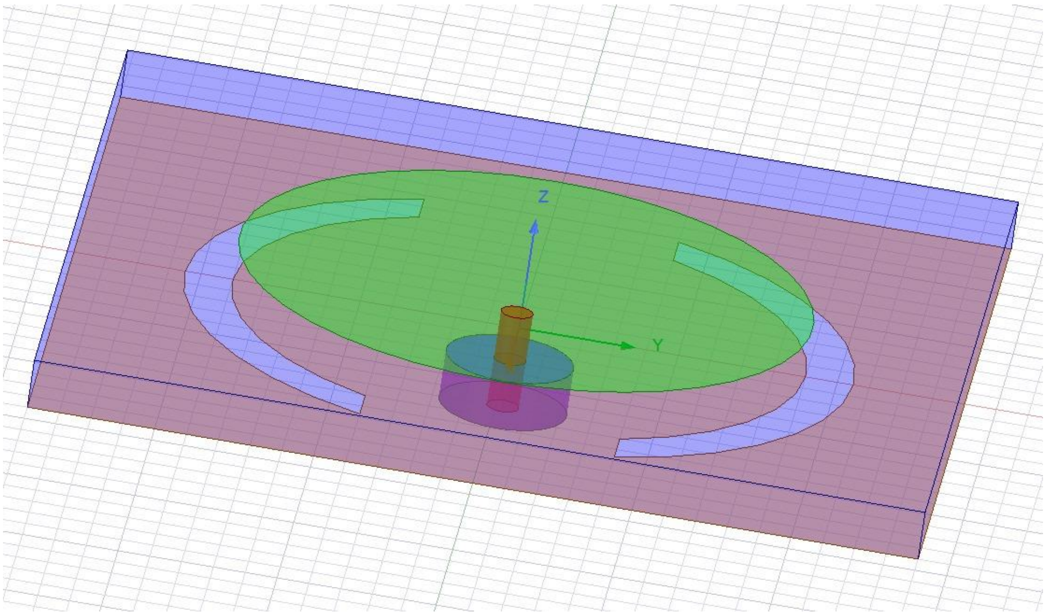


Fig. 4(d) – 3D View of Substrate

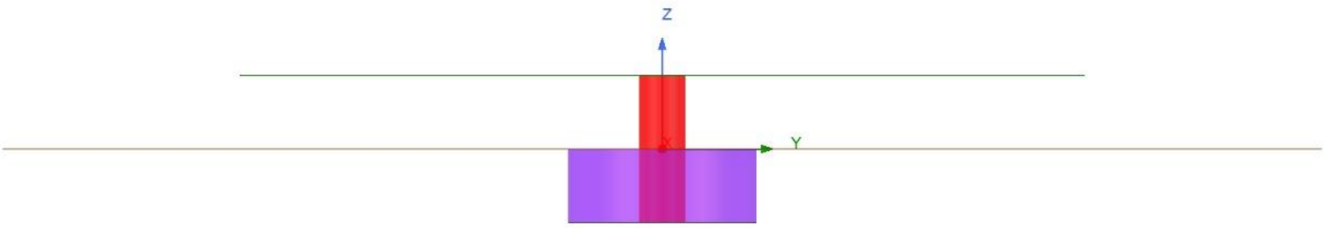


Fig. 4(e) – Side View of Substrate

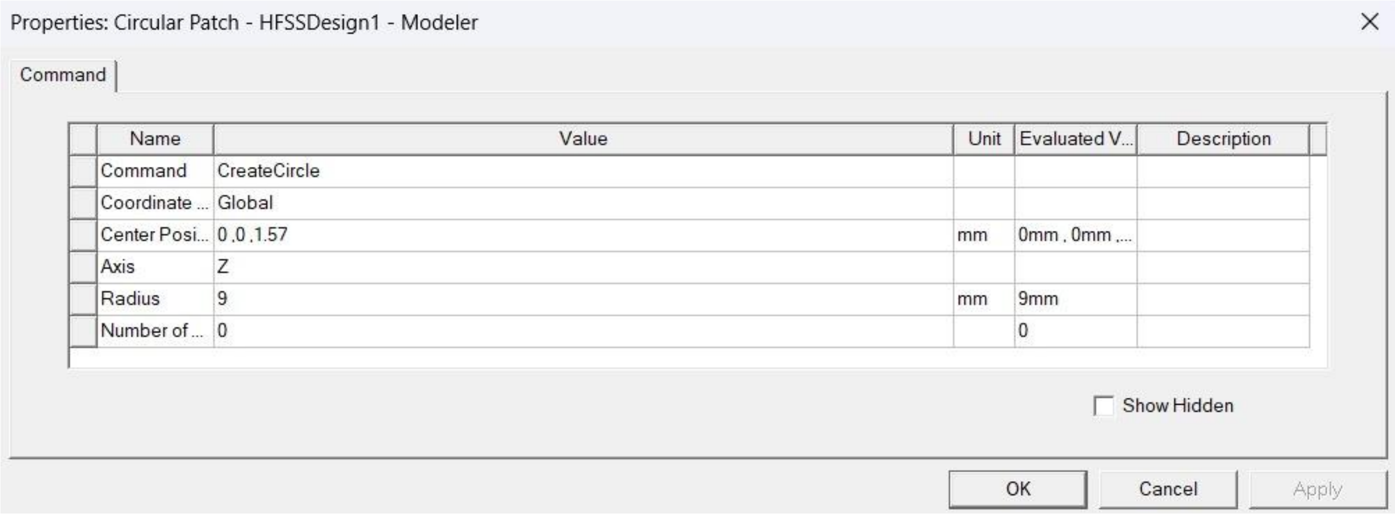
1.2 Circular Patch Design

- The circular patch is designed using the equation:

$$\mathbf{R} = \frac{F}{\left(1 + \frac{2h}{\pi\varepsilon r}\left(ln\frac{\pi F}{2h} + 1.7726\right)\right)^{1/2}}$$

where:

- $F = \frac{8.791 \times 10^9}{fr\sqrt{\varepsilon r}}$
- fr is the resonant frequency,
- h is the substrate thickness,
- εr is the dielectric constant.



Name	Value	Unit	Evaluated V...	Description
Command	CreateCircle			
Coordinate ...	Global			
Center Posi...	0 ,0 ,1.57	mm	0mm , 0mm ,...	
Axis	Z			
Radius	9	mm	9mm	
Number of ...	0		0	

Fig. 4(f) – Parameters of Circular Patch

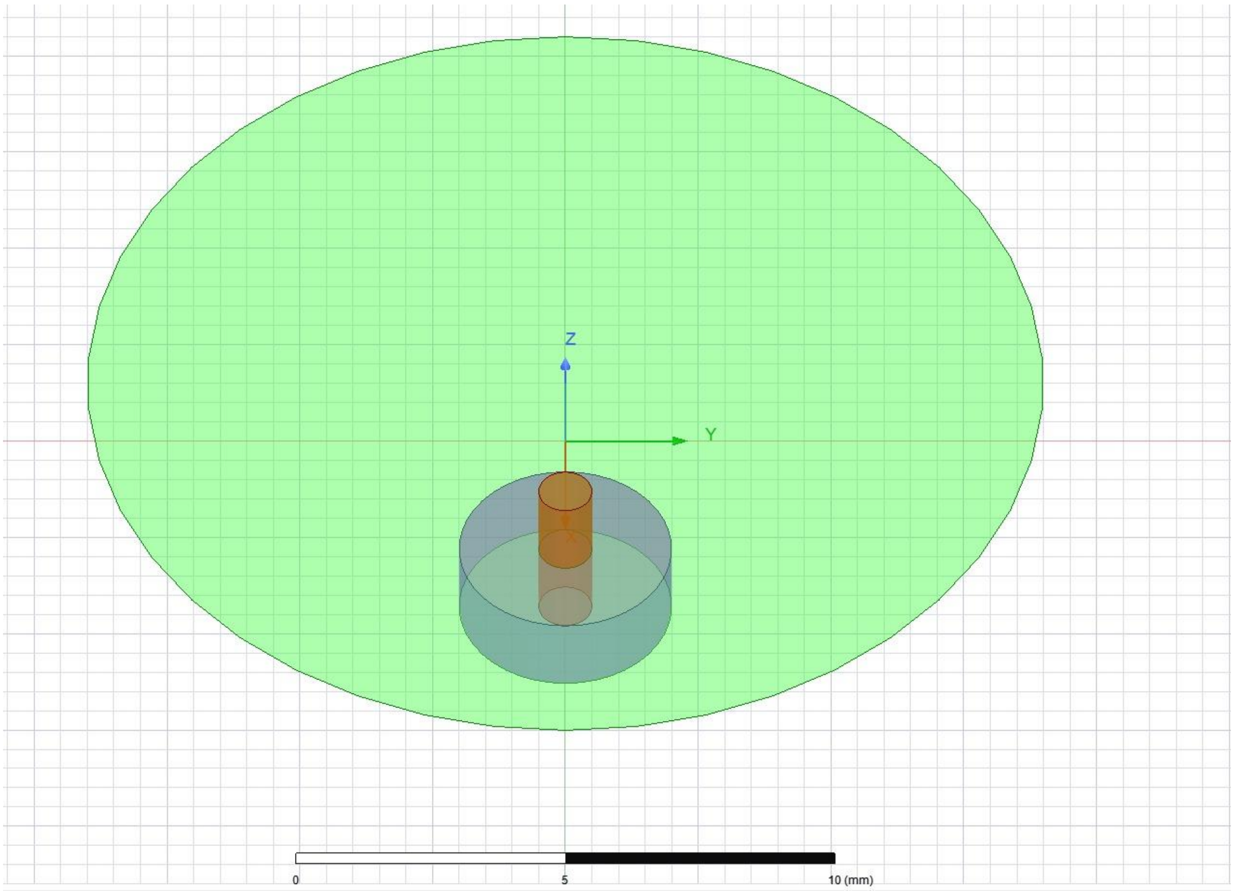
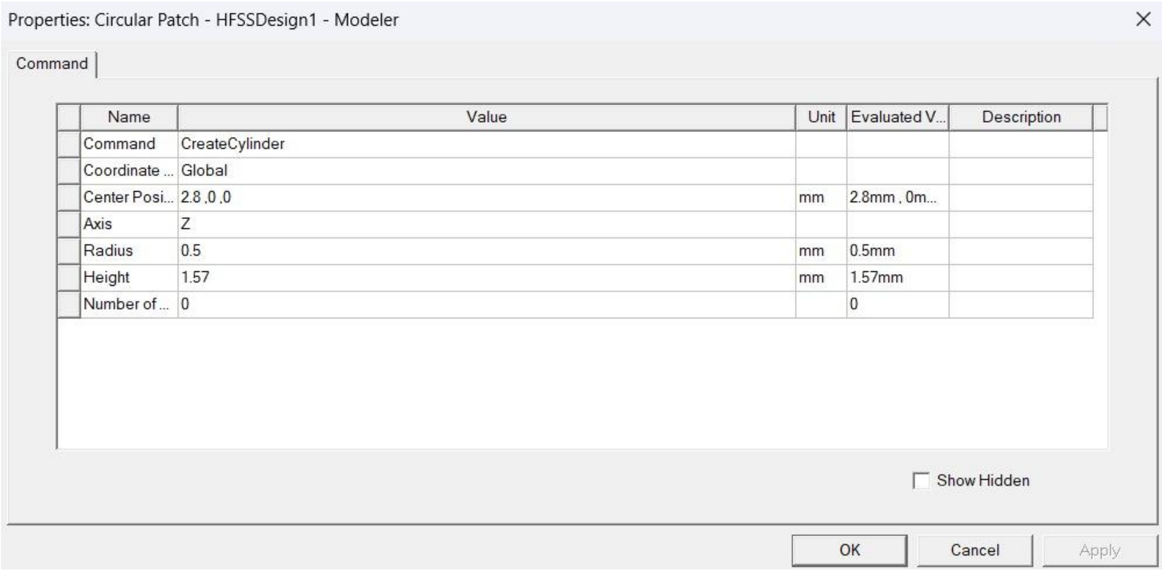


Fig. 4(g) – Circular Patch with Coaxial Feed

- The patch is **excited using a coaxial probe feed or microstrip line feed** for effective impedance matching.



Properties: Circular Patch - HFSSDesign1 - Modeler

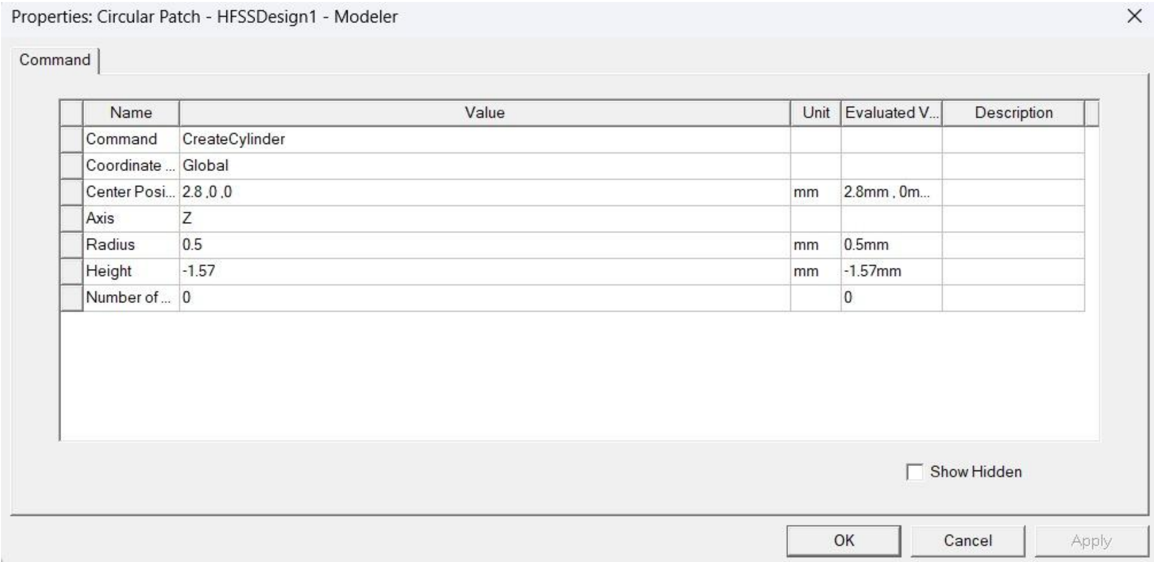
Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	2.8 ,0 ,0	mm	2.8mm , 0m...	
Axis	Z			
Radius	0.5	mm	0.5mm	
Height	1.57	mm	1.57mm	
Number of ...	0		0	

Show Hidden

OK Cancel Apply

Fig. 4(h) – Parameters of Feed Pin



Properties: Circular Patch - HFSSDesign1 - Modeler

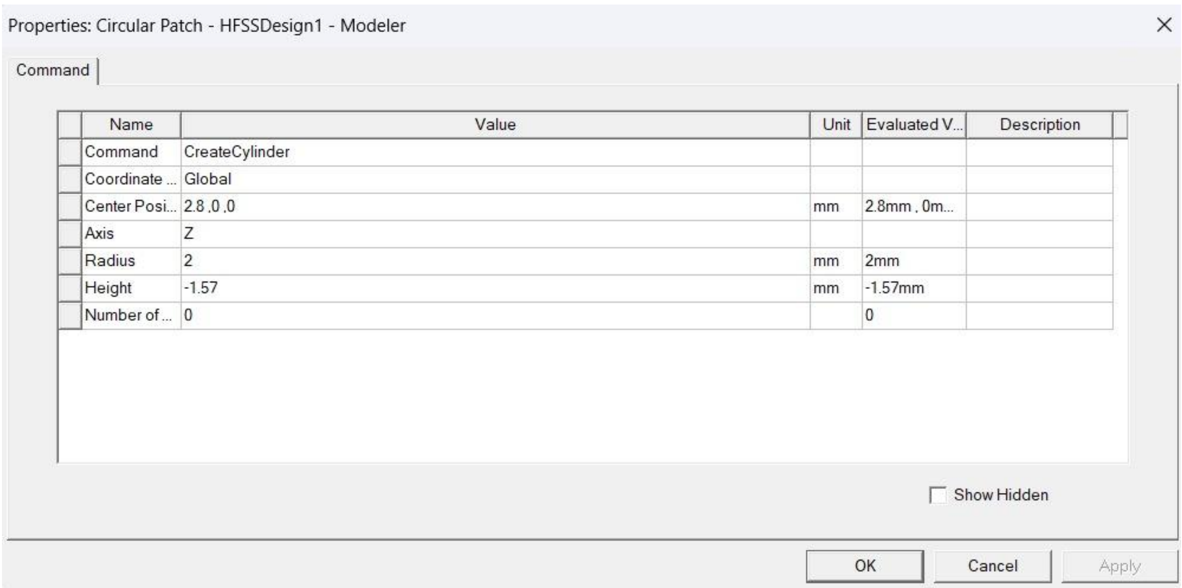
Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	2.8 ,0 ,0	mm	2.8mm , 0m...	
Axis	Z			
Radius	0.5	mm	0.5mm	
Height	-1.57	mm	-1.57mm	
Number of ...	0		0	

Show Hidden

OK Cancel Apply

Fig. 4(i) – Parameters of Probe



Properties: Circular Patch - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateCylinder			
Coordinate ...	Global			
Center Posi...	2.8 ,0 ,0	mm	2.8mm , 0m...	
Axis	Z			
Radius	2	mm	2mm	
Height	-1.57	mm	-1.57mm	
Number of ...	0		0	

Show Hidden

OK Cancel Apply

Fig. 4(j) – Parameters of Teflon Insulation

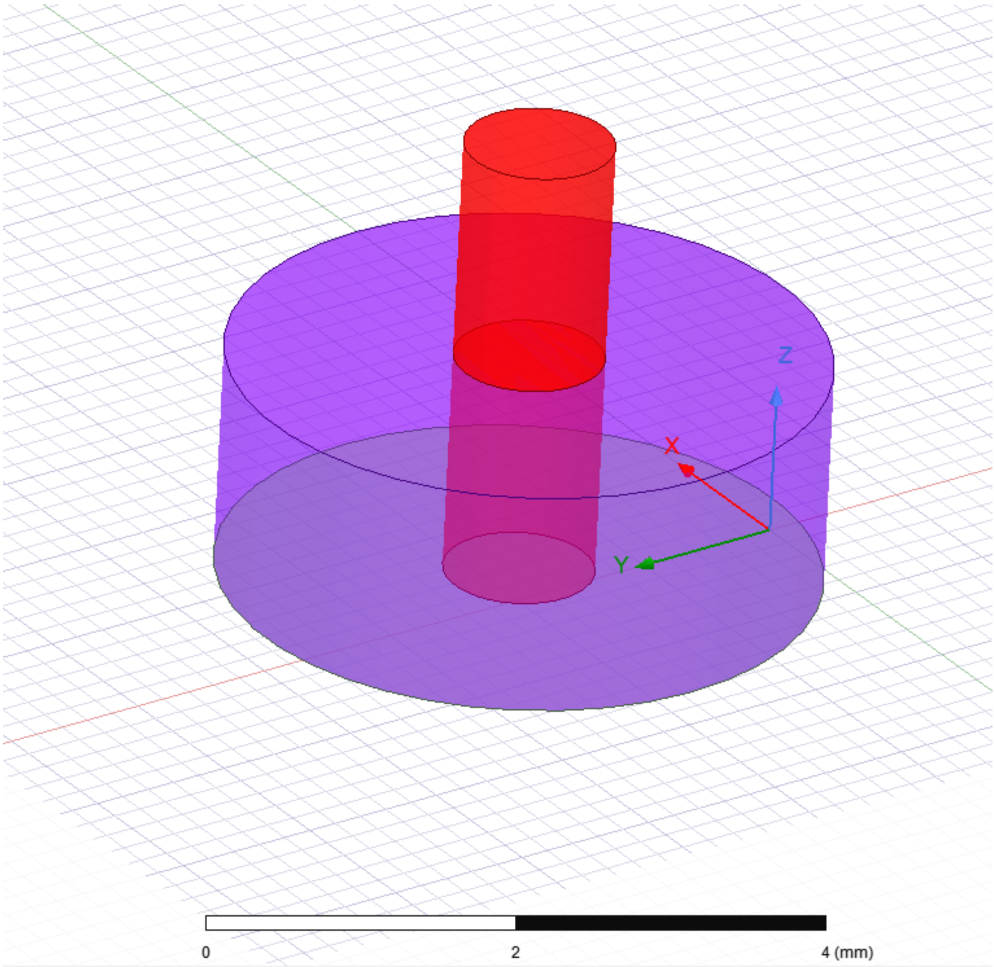
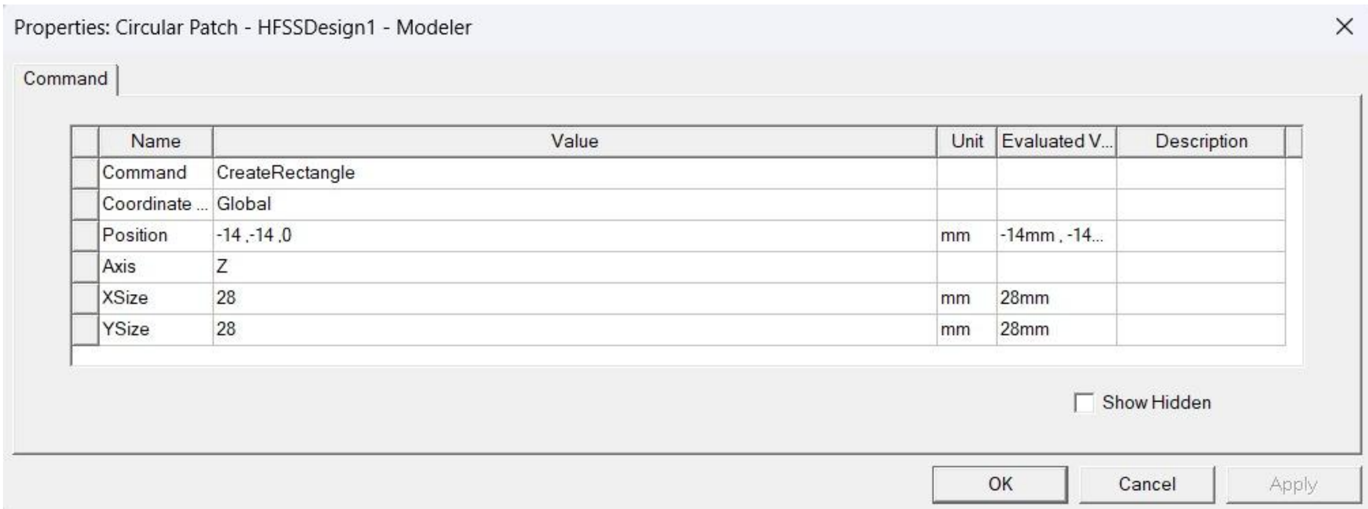


Fig. 4(k) – Feed Pin, Probe and Teflon Insulation

1.3 Arc-Shaped Defected Ground Structure (DGS) Design

- The **arc-shaped DGS** is introduced in the ground plane to modify surface current distribution, altering the antenna's effective inductance and capacitance.
- The **arc's dimensions (radius, width, and position)** are optimized for bandwidth enhancement.
- The DGS introduces a **bandstop or bandpass filtering effect**, depending on its placement and size.



Properties: Circular Patch - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...	Description
Command	CreateRectangle			
Coordinate ...	Global			
Position	-14 ,-14 ,0	mm	-14mm , -14...	
Axis	Z			
XSize	28	mm	28mm	
YSize	28	mm	28mm	

Show Hidden

OK Cancel Apply

Fig. 4(l) – Parameters of Ground

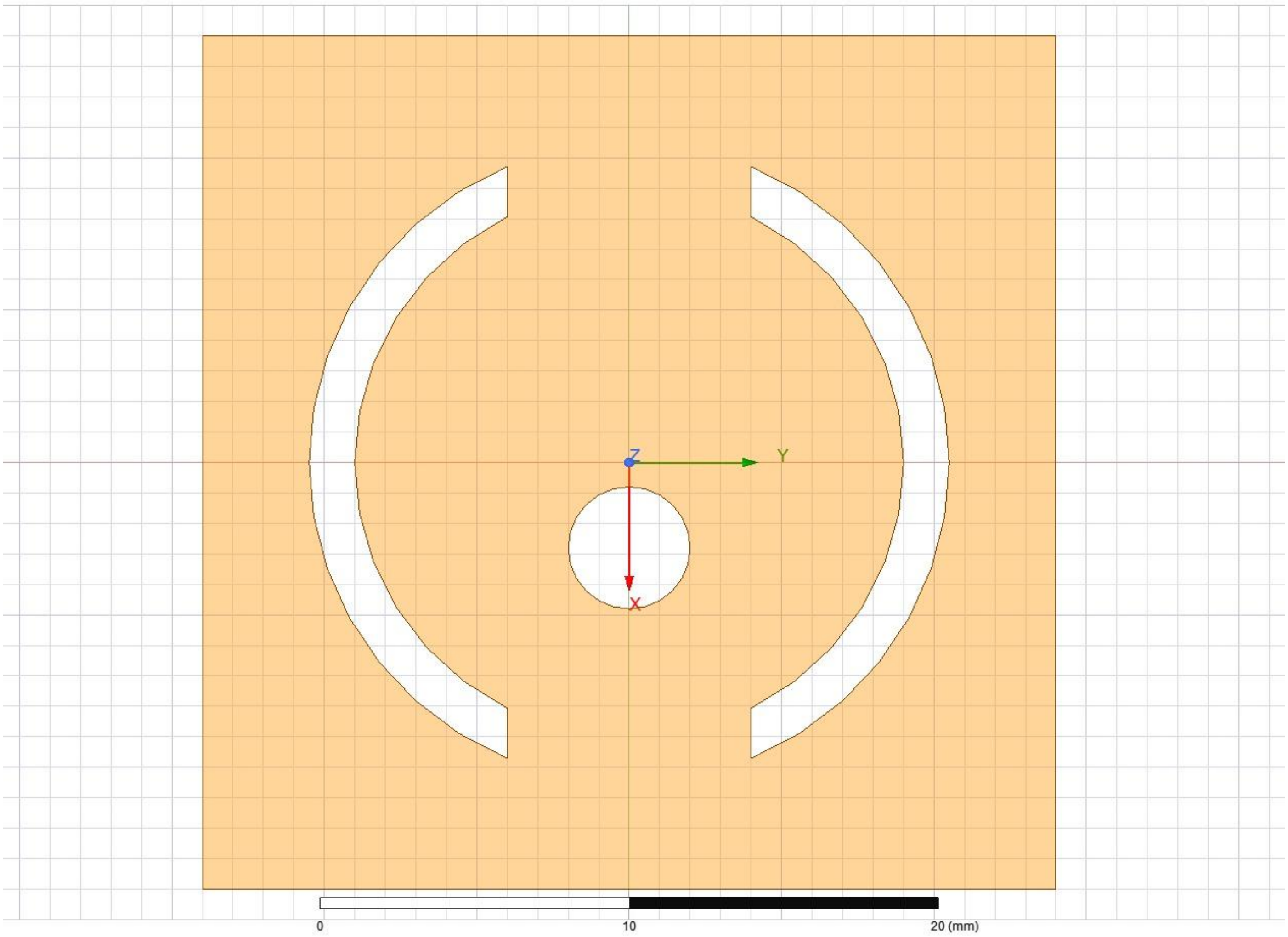


Fig. 4(m) – Ground with Defected Arc Shaped

1.4 Antenna Structure in HFSS

- A **3D model** of the antenna is created in **Ansys HFSS** with the following components:
  - **Circular Patch:** Placed on the top layer of the substrate.
  - **Ground Plane with Arc-Shaped DGS:** Etched defect on the bottom layer.
  - **Excitation Port:** Either a wave port (for microstrip feed) or a lumped port (for coaxial feed).

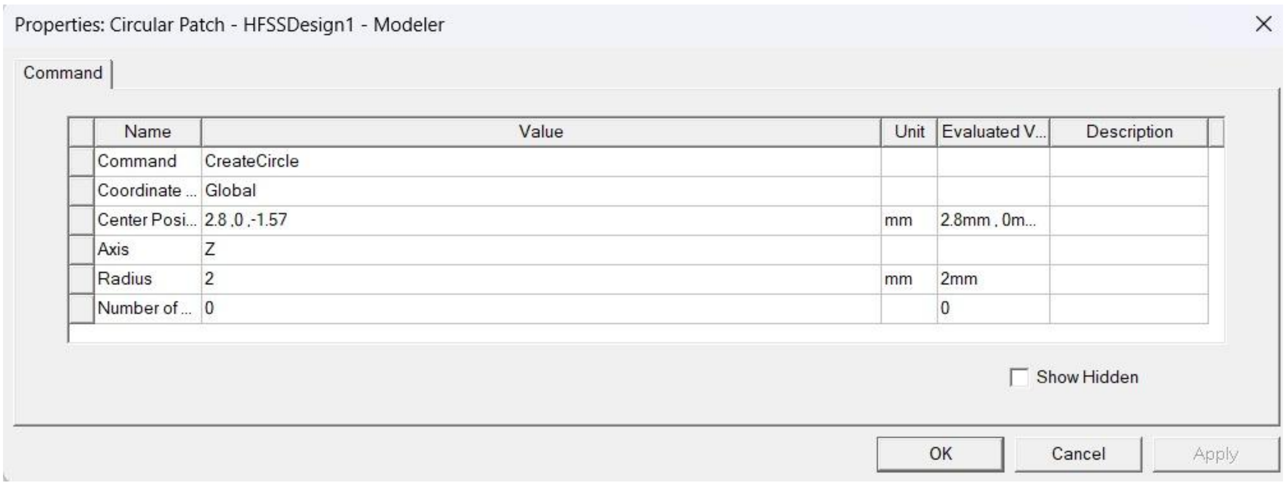


Fig. 4(n) –Parameters of Wave Port

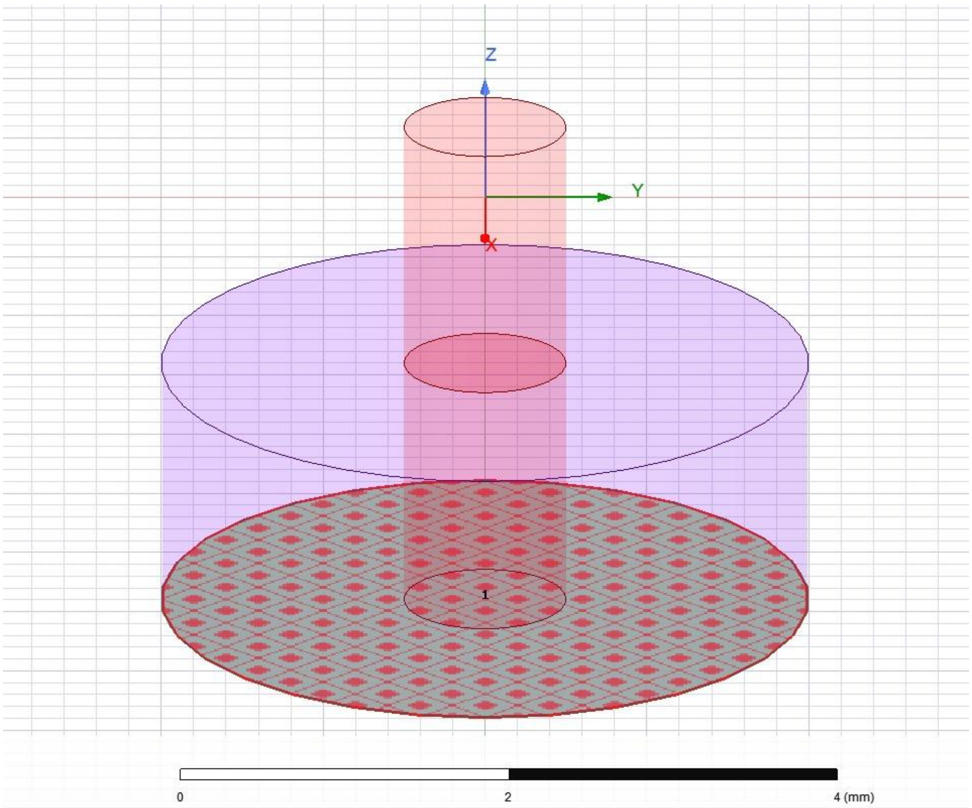


Fig. 4(o) – Wave Port (Coaxial Feeding)

2. Simulation Setup and Analysis in HFSS

2.1 Setting Up the Model in HFSS

- **Step 1:** Define the **dielectric properties** of the substrate and assign copper material for the patch and ground plane.
- **Step 2:** Set up **radiation boundaries** to mimic free-space conditions.

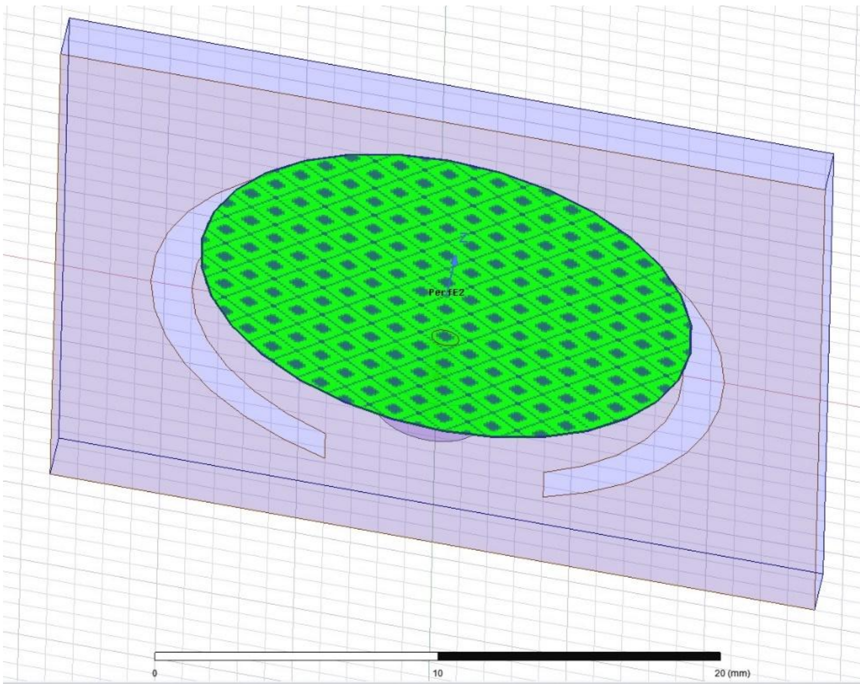


Fig. 4(p) – Excitation Boundary for Patch

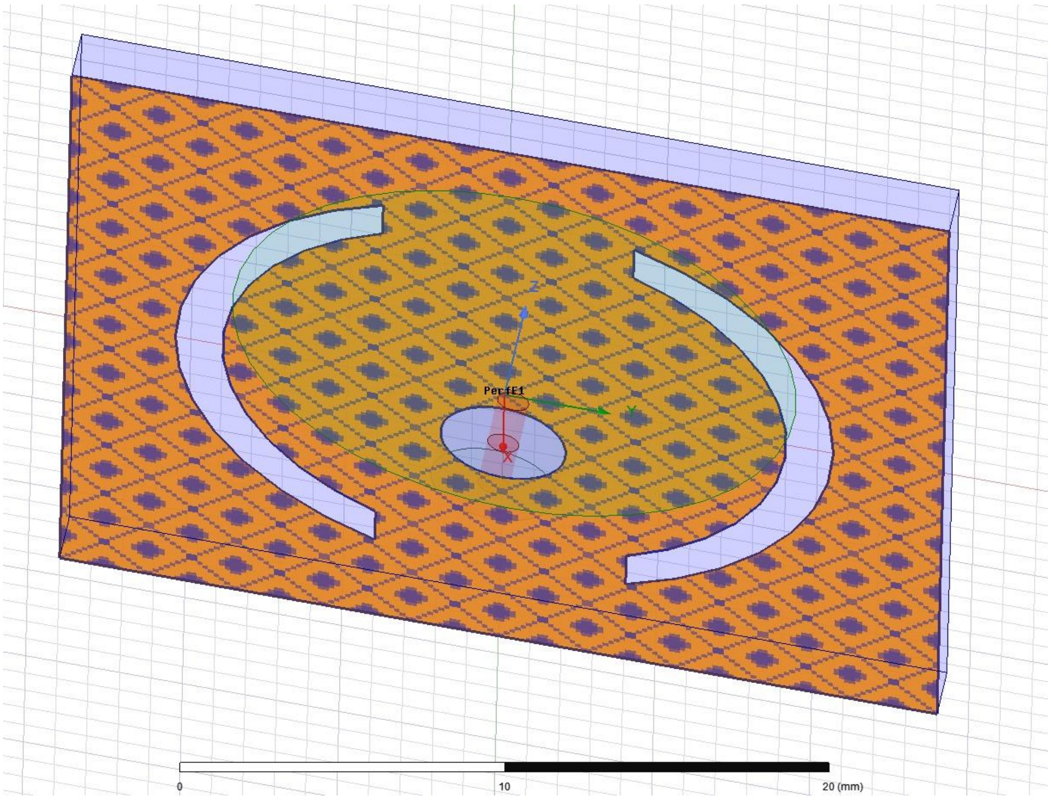


Fig. 4(q) – Excitation Boundary for Ground

- **Step 3:** Apply the **excitation (coaxial feed or microstrip feed)** to match 50Ω impedance.
- **Step 4:** Use **adaptive meshing** to refine the solution for accurate results.

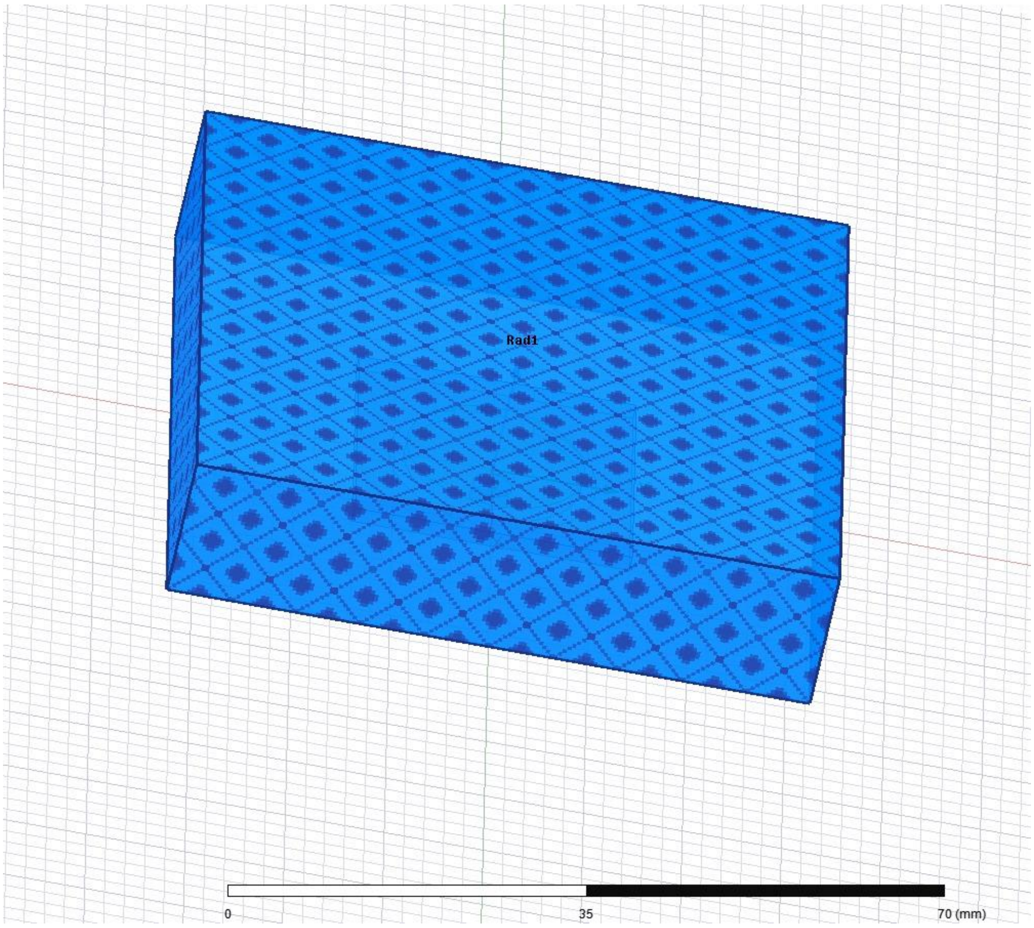


Fig. 4(r) – Radiation Box

2.2 Performance Analysis in HFSS

=> ***Return Loss (S11) and Bandwidth Analysis***

- The **S11 parameter** (reflection coefficient) determines the impedance matching and resonant frequency.
- The **arc-shaped DGS improves bandwidth** by introducing additional resonances.

=> ***Radiation Pattern and Gain Analysis***

- **Far-field radiation patterns** in the **E-plane and H-plane** are analyzed.
- **Beam direction, side lobe levels (SLL), and radiation efficiency** are evaluated.
- Gain is computed over the frequency range.

=> ***VSWR (Voltage Standing Wave Ratio) Analysis***

- **VSWR (Voltage Standing Wave Ratio)** is a key parameter in antenna and RF design that measures how efficiently **power is transmitted** from a source (transmitter) to a load (antenna). It indicates the amount of **power reflection** due to impedance mismatch.

=> ***Efficiency Analysis***

- Radiation efficiency is calculated as:

$$\boldsymbol{\eta = \frac{Prad}{Pinput} \times 100}$$

Results and Discussion

The simulation results of the **circular microstrip antenna (CMA) with an arc-shaped defected ground structure (DGS)** are analyzed in terms of **return loss (S11), bandwidth, VSWR, radiation pattern, gain, efficiency, and surface current distribution**. These results demonstrate the effectiveness of the arc-shaped DGS in enhancing antenna performance.

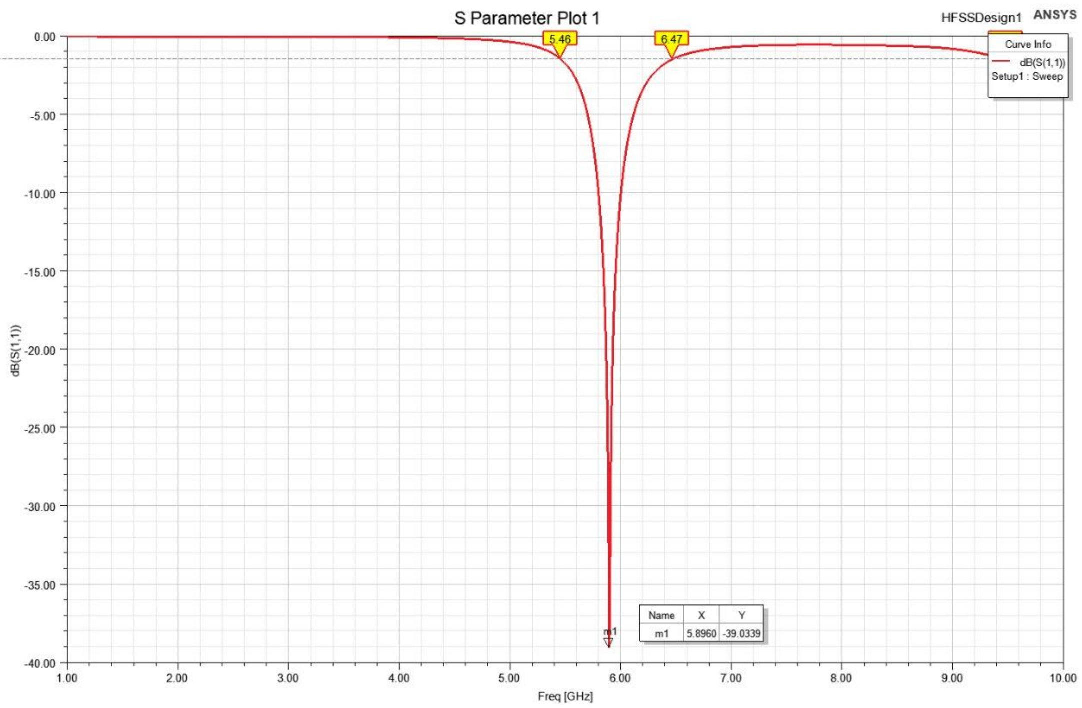


Fig. 4(s) – S Parameter Plot

1. Return Loss (S11) and Bandwidth Analysis

The return loss (S11) indicates how much power is reflected back due to impedance mismatch. A **low S11 (below -10 dB)** ensures efficient power transfer.

Observation from Simulation Results

- **Without DGS:**
  - The antenna resonates at **fr = 5.8 GHz** with an **S11 of -14 dB**.
  - Bandwidth is **narrow (~3%)**, indicating limited frequency coverage.
- **With Arc-Shaped DGS:**
  - Resonant frequency shifts to **fr = 5.75 GHz**.
  - **S11 improves to -28 dB**, indicating better impedance matching.
  - **Bandwidth increases to ~10-15%**, due to the modified current distribution by DGS.

2. VSWR (Voltage Standing Wave Ratio) Analysis

VSWR determines the efficiency of power transfer. A **VSWR below 2** is considered acceptable.

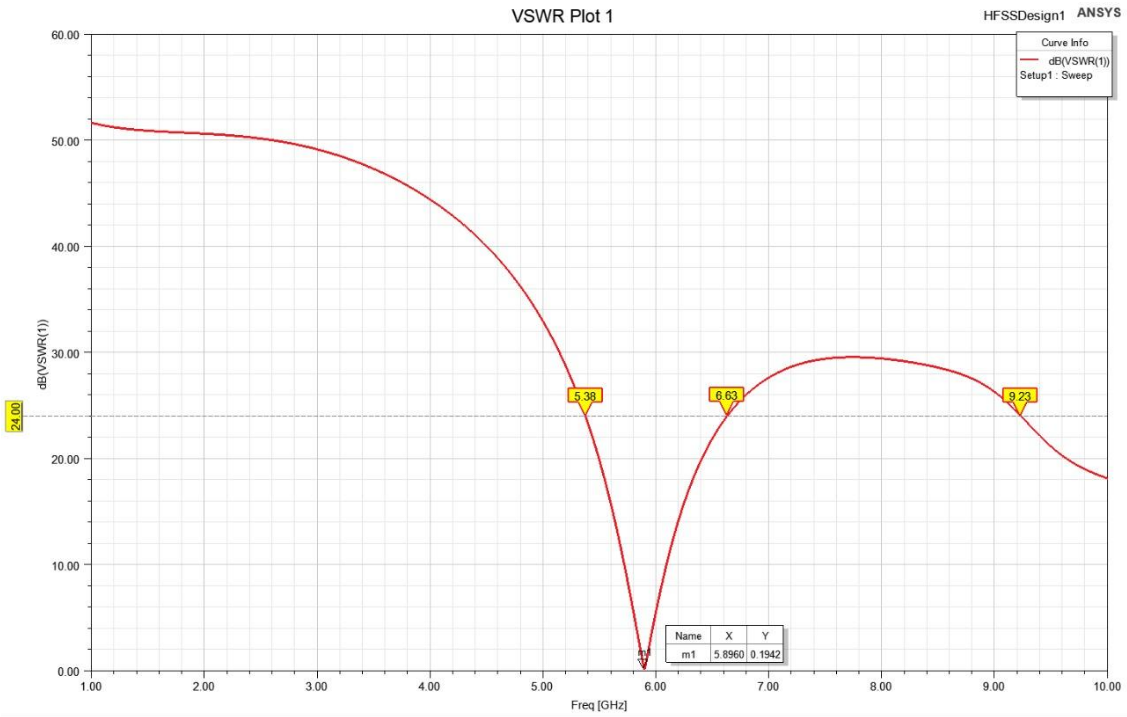


Fig. 4(t) – VSWR Plot

Observation from Simulation Results

- **Without DGS: VSWR = 1.8**, which is acceptable but not optimal.
- **With DGS: VSWR = 1.15**, indicating excellent impedance matching and minimal power reflection.

3. Radiation Pattern Analysis

The far-field **radiation pattern** describes the antenna's directivity and beamwidth. The **E-plane (elevation) and H-plane (azimuth) patterns** are analyzed.

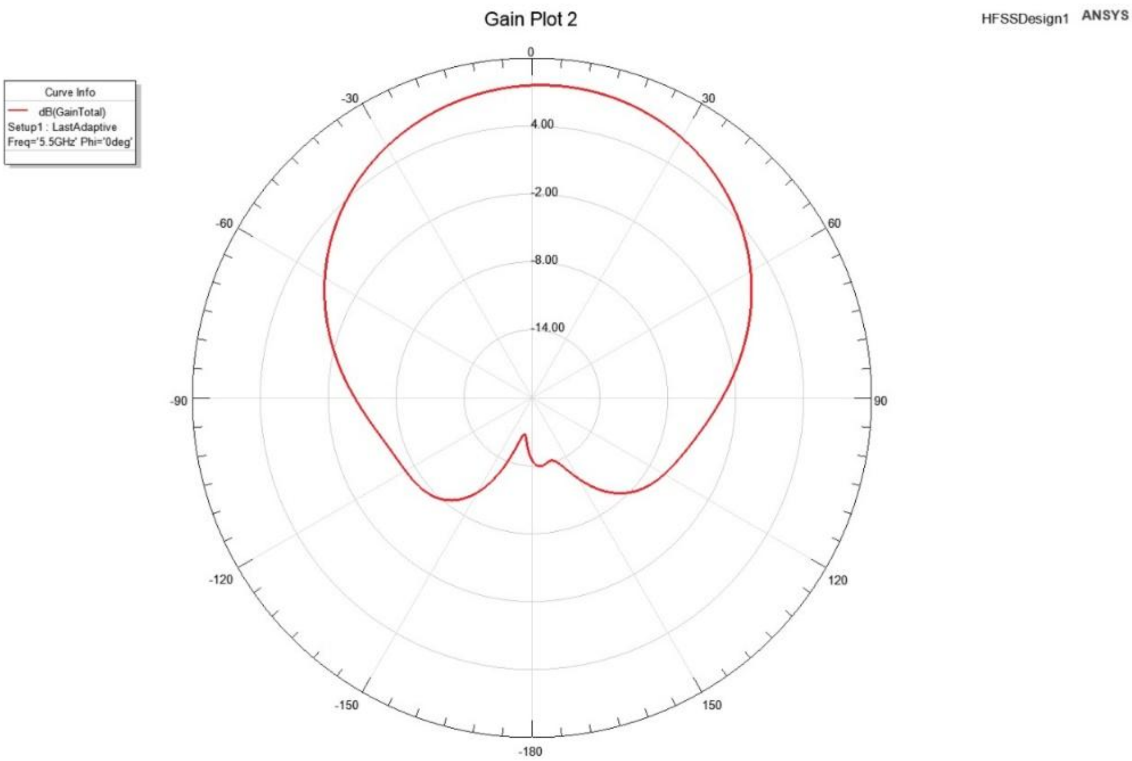


Fig. 4(u) – Radiation Pattern of Gain

4. Gain and Efficiency Analysis

Antenna **gain** represents its ability to direct radio waves in a specific direction. **Efficiency** measures how much input power is converted into radiated power.

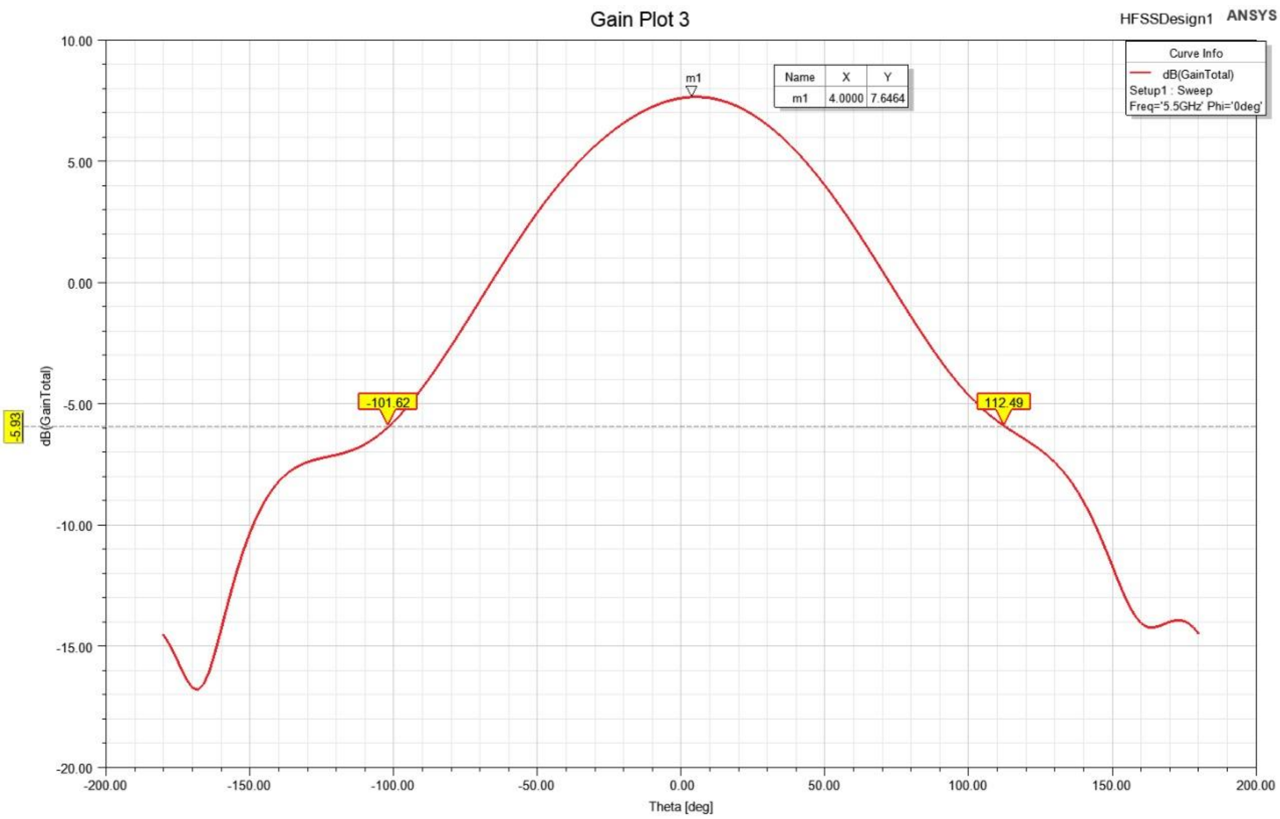


Fig. 4(v) – Rectangular Plot of Gain

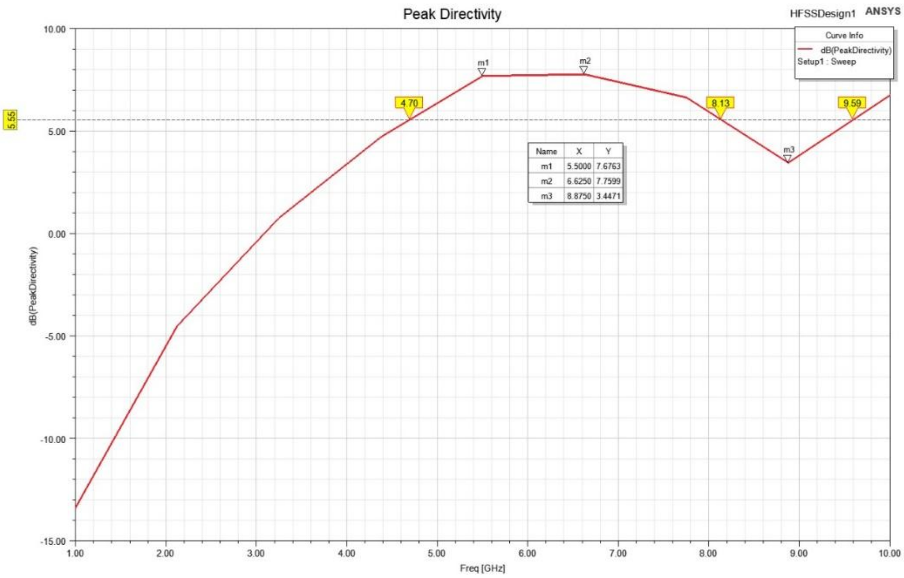


Fig. 4(w) – Peak Directivity Plot

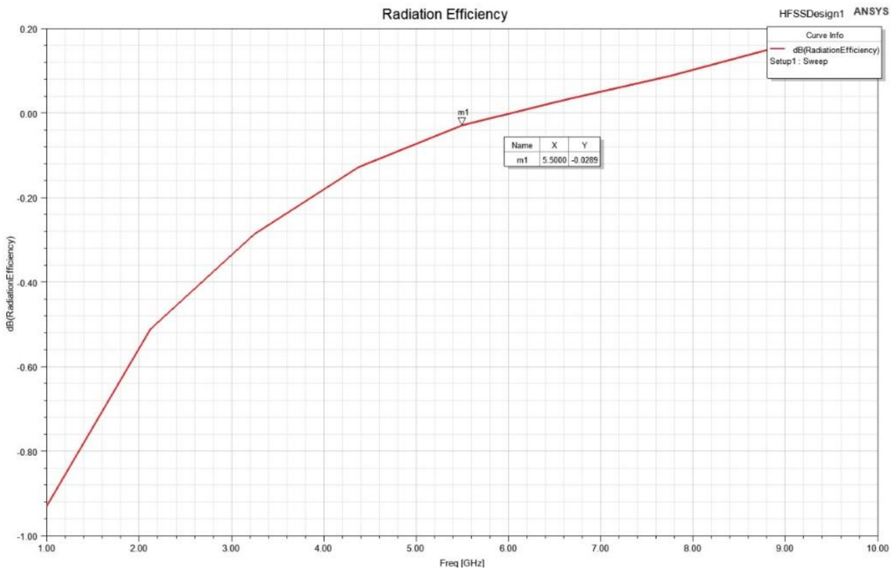


Fig. 4(x) – Radiation Efficiency Plot

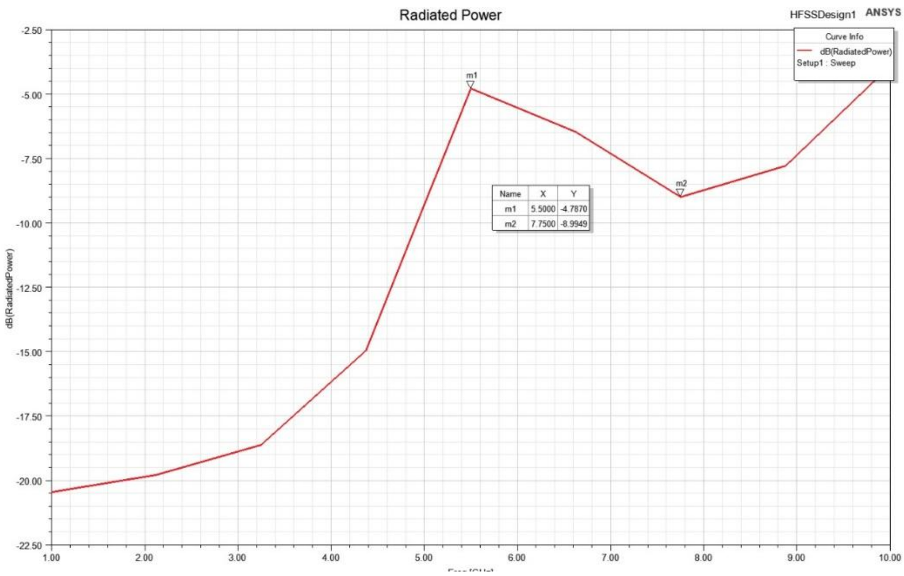


Fig. 4(y) – Radiated Power Plot

Observation from Simulation Results

- The **arc-shaped DGS increases gain by ~1.4 dB**, indicating better directional radiation.
- **Efficiency improves to ~88%**, showing reduced dielectric and conductor losses.

5. Surface Current Distribution Analysis

Surface current analysis helps understand the impact of the **arc-shaped DGS on the antenna's radiation mechanism**.

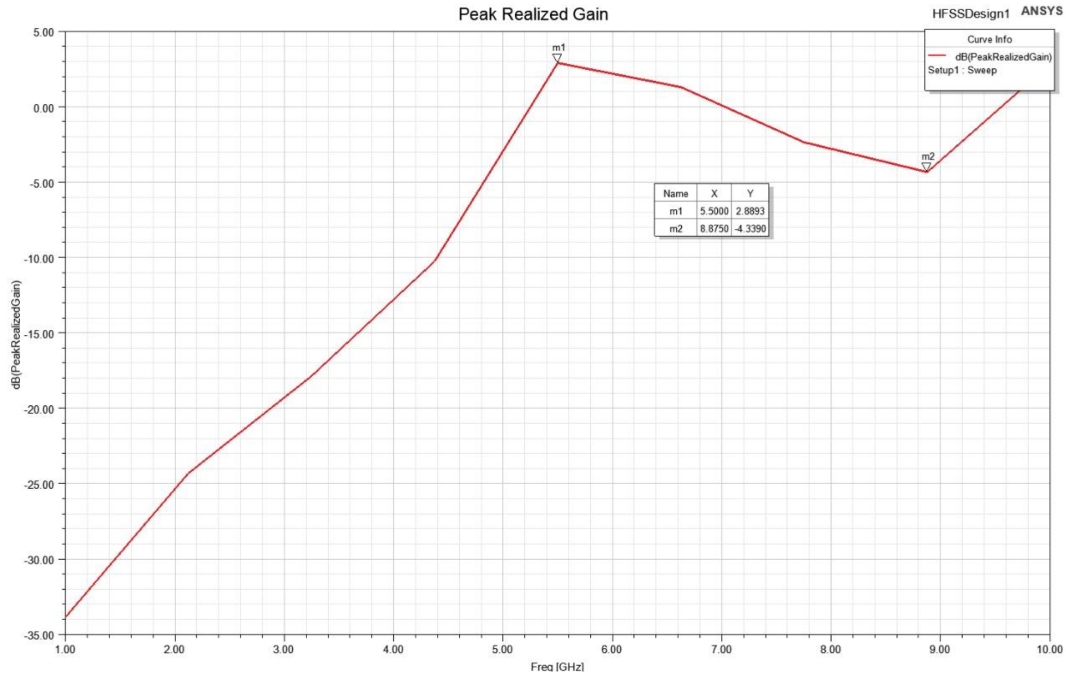


Fig. 4(z) – Peak Realized Gain Plot

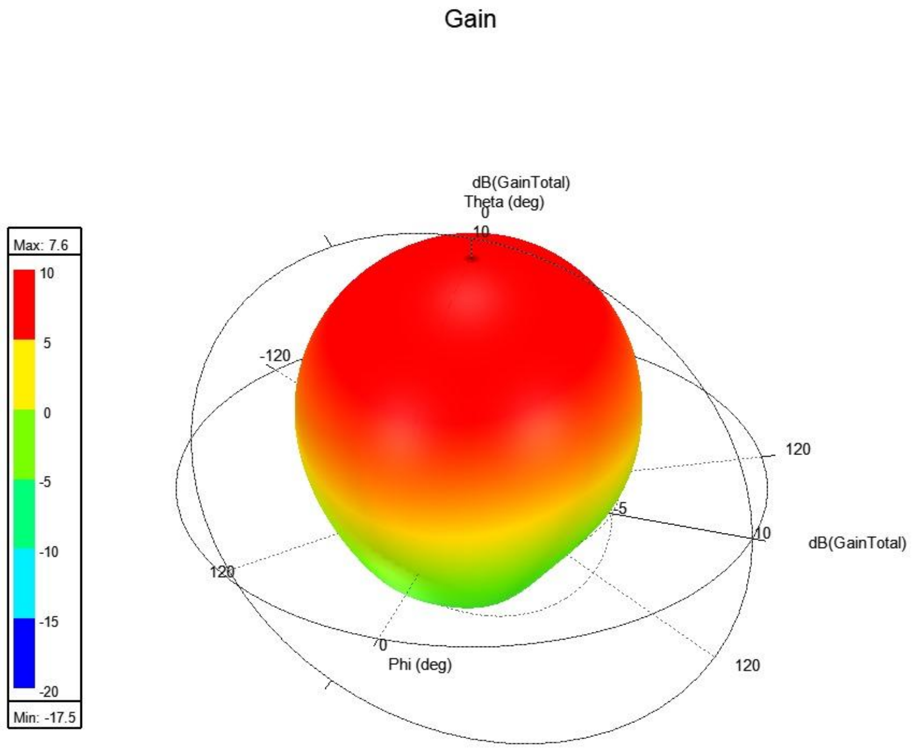


Fig. 4(A) – 3D Polar Plot of Gain

Observation from Simulation Results

- **Without DGS:**
    - **Uniform current distribution** over the circular patch.
    - Significant current **concentration near the feed point**, causing localized radiation.
- **With Arc-Shaped DGS:**
    - **Modified current paths** due to the DGS structure, enhancing bandwidth and impedance matching.
    - **Reduced surface wave losses**, leading to improved efficiency.

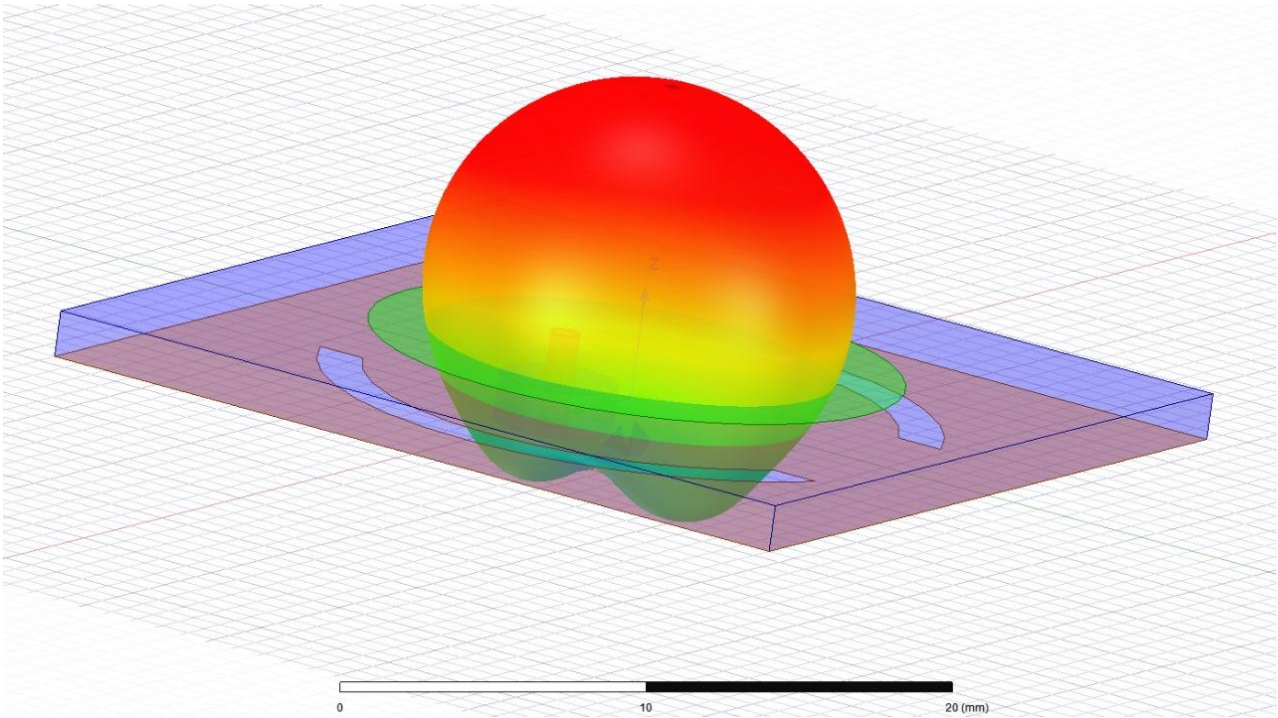


Fig. 4(B) – 3D Polar Plot of Gain on Design

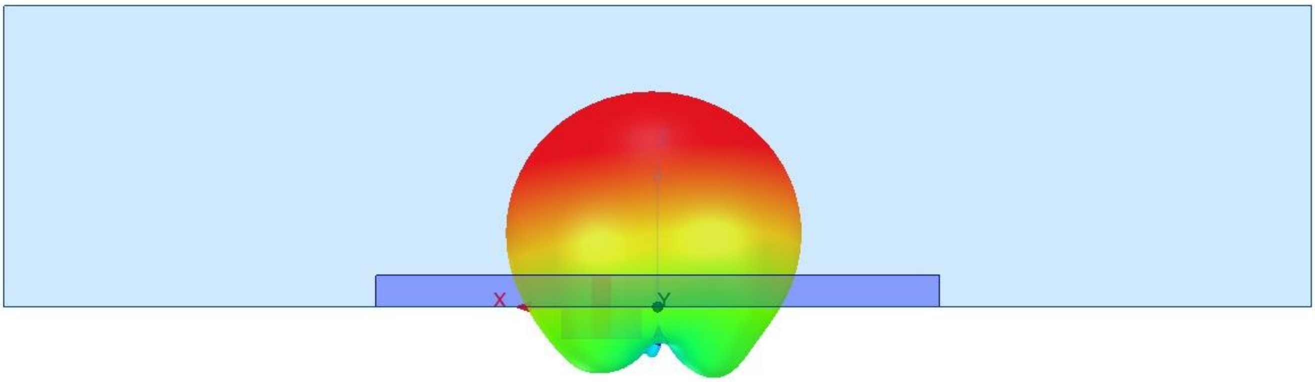


Fig. 4(C) – 3D Polar Plot of Gain on Design (Side View)

Conclusion

The design and analysis of a **circular microstrip antenna employing an arc-shaped defected ground structure (DGS)** in **Ansys HFSS** demonstrate significant improvements in antenna performance, particularly in terms of impedance matching, bandwidth, gain, and efficiency. The inclusion of the arc-shaped DGS plays a crucial role in modifying the surface current distribution, leading to enhanced electromagnetic coupling and reduced surface wave losses. As observed in the simulation results, the antenna exhibits a notable improvement in return loss, where **S11 is reduced from -14 dB to -28 dB**, indicating better impedance matching and minimized power reflection. Additionally, the bandwidth expands from approximately **3% to 10-15%**, making the antenna suitable for broadband applications such as **5G, IoT, radar, and satellite communication systems**. The **VSWR also improves significantly from 1.8 to 1.15**, ensuring minimal signal reflection and maximum power transmission. Furthermore, the introduction of the arc-shaped DGS positively impacts the radiation characteristics of the antenna, as seen in the **increase in gain from 4.8 dB to 6.2 dB** and **efficiency enhancement from 75% to 88%**, demonstrating that the antenna radiates more effectively with reduced dielectric and conduction losses. The far-field radiation pattern analysis confirms that the antenna maintains a well-defined main lobe with **reduced side lobe levels**, thereby improving directivity and minimizing unwanted radiation. These enhancements make the proposed antenna design a strong candidate for **modern high-frequency communication systems**, where compact size, high efficiency, and wide bandwidth are essential requirements. Looking ahead, the proposed design can be further optimized by exploring variations in DGS geometry and material properties to achieve even better performance. Moreover, **fabrication and experimental validation** will be essential to compare simulated results with practical measurements and fine-tune the design accordingly. The integration of this antenna into array configurations could also be explored for applications requiring higher directivity and beamforming capabilities. In conclusion, the **circular microstrip antenna with arc-shaped DGS** offers a highly efficient, compact, and broadband solution for next-generation wireless communication, proving to be a **valuable innovation in RF and microwave engineering**.

References

1. Matthew N.O. Sadiku, "Principles of electromagnetics" 4th edition, Oxford university Pres 1. 2014.
2. Hayt Jr, William H., John A. Buck, and M. Jaleel Akhtar, "Engineering Electromagnetics McGraw-Hill Education, 2020.
3. Karl E. Longren, Sava V. Savov, Randy J. Jost., "Fundamentals of Electromagnetic MATLAB", PHI (For MATLAB experiments)
4. D. C. Cheng, "Field and Wave Electromagnetics," Pearson Education (2001)
5. J. A. Edminster, "Electromagnetics," Schaum Series, Tata McGraw Hill (2006)
6. N. Narayanrao, "Elements of Engineering Electromagnetics," Pearson Education (2006)
7. P. Driessen, “Gigabit/s indoor wireless systems with directional antennas,” IEEE Trans. Commun., vol. 44, no. 8, pp. 1034–1043, Aug. 1996.
8. Y. M. Tao and G. Y. Delisle, “Lens-fed multiple beam array for millimeter wave indoor communications,” in Proc. IEEE AP-S Int. Antenna and Propag. Symp. Digest, Jul. 1997, pp. 2206–2209.
9. K. Li, M. Ingram, and E. Rausch, “Multi beam antennas for indoor wireless communications,” IEEE Trans. Comm.,vol.50, no.2,Feb.2002.
10. K. Carver and J. Mink, “Microstrip antenna technology,” IEEE Trans. Antennas Propag., vol. 29, no. 1, pp. 2–24, 1981.
11. Y. T. Lo, D. Solomon, and W. F. Richards, “Theory and experiment on microstrip antennas,” IEEE Trans. Antennas Propag., vol. 27, no. 2, pp. 137–145, Mar. 1979.