VISVESVARAYA TECHNOLOGICAL UNIVERSITY
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A Project Report on

Learning Activity-2

Design and Analysis of a Microstrip Patch Antenna with Defected Ground Structure (DGS) Using HFSS

Submitted in partial fulfilment of the requirements for the Subject

MICROWAVE AND RADIATING SYSTEM(22EC63)

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1.Introduction

In the evolving landscape of wireless communication and microwave engineering, microstrip patch antennas have become indispensable due to their planar profile, light weight, ease of fabrication, and compatibility with integrated circuits. These antennas find wide applications in mobile communication, satellite systems, radar technologies, wearable electronics, Internet of Things (IoT) devices, and WLAN systems due to their cost-effectiveness and compact size. However, despite these advantages, microstrip patch antennas exhibit certain performance limitations such as narrow bandwidth, low gain, and the appearance of unwanted higher-order resonant frequencies. These issues restrict their efficiency and fidelity in many practical applications.

To overcome these limitations and improve the overall performance of microstrip antennas, modern research has focused on the incorporation of structural modifications to the ground plane—one of the most effective being the Defected Ground Structure (DGS). A DGS involves etching a specific shape or pattern into the ground plane, which alters the current distribution and introduces a bandstop filtering effect at targeted frequencies. This physical discontinuity in the ground plane results in a controlled modification of the antenna's equivalent inductance and capacitance, thereby enabling the suppression of spurious resonances and enhancement of useful radiation characteristics.

The primary advantage of DGS lies in its ability to suppress unwanted resonant frequencies and harmonics without significantly increasing the antenna size or affecting the desired operating band. By effectively acting as a bandstop filter, DGS structures enable better signal selectivity, improved impedance matching, and enhanced radiation efficiency. Moreover, DGS can be designed in various geometric configurations such as dumbbell-shaped slots, rectangular or circular rings, U-shaped or H-shaped patterns—each offering distinct frequency responses based on their size and positioning.

This project investigates the design and simulation of a rectangular microstrip patch antenna using Ansys HFSS (High Frequency Structure Simulator), with a specific focus on incorporating a Defected Ground Structure. HFSS is a powerful electromagnetic simulation software based on the finite element method, widely used in antenna design and high-frequency component analysis. The design begins with a standard patch antenna intended to operate at 2.4 GHz, a common frequency in ISM bands. Following the baseline design and performance evaluation, a defected ground geometry is introduced to analyze its effect on antenna parameters such as return loss, gain, and radiation pattern.

The key objectives of this study are to demonstrate the suppression of higher-order unwanted resonances using DGS, evaluate performance improvements in gain and return loss, and confirm that the desired 2.4 GHz resonance is retained or enhanced. By comparing simulation results before and after the inclusion of DGS, this report aims to provide clear insights into the benefits and practical utility of defected ground configurations in modern antenna engineering.

In summary, the integration of DGS into microstrip patch antennas represents a low-cost, fabrication-friendly, and highly effective method to enhance performance without compromising on the form factor. This report contributes to the ongoing research in compact, high-performance antenna systems by presenting a clear methodology and results for DGS-based enhancement using industry-standard simulation tools

2. Objective

The primary objective of this study is to design a compact, efficient microstrip patch antenna that resonates at 2.4 GHz, a frequency commonly used in ISM (Industrial, Scientific, and Medical) applications such as Wi-Fi, Bluetooth, and RFID systems. To achieve this, a detailed set of design parameters was carefully selected and optimized to ensure proper resonance, impedance matching, and radiation characteristics. The choice of substrate material is foundational to the antenna's performance. For this design, FR4 Epoxy was selected due to its low cost, wide availability, and suitable dielectric constant ($\varepsilon r = 4.4$) for moderate-performance antenna applications. The substrate dimensions were fixed at 60 mm × 60 mm with a thickness of 1.6 mm, offering ample space to house the radiating patch, feedline, and defected ground geometry.

The next objective was to design the rectangular patch element that radiates electromagnetic waves. Its length and width were calculated using standard microstrip transmission line equations to support resonance near 2.4 GHz. The approximate dimensions of the patch are 29 mm in length and 38 mm in width. These dimensions help determine the fundamental TM_{10} mode of operation while considering fringe effects and effective dielectric constant. The feed mechanism was another critical design objective, aimed at ensuring maximum power transfer and minimal reflection. A microstrip line feed was employed with a width of 3 mm and length of 18 mm, chosen based on 50-ohm impedance matching criteria. Additionally, an inset feed configuration was incorporated with an inset depth of 6 mm and width matching the feedline. This adjustment helps match the patch impedance to the feedline impedance, significantly improving the antenna's return loss.

The design also includes a full copper ground plane below the substrate with dimensions equal to the substrate area (60 mm × 60 mm) for the initial simulation without any structural modification. In the second part of the project, the main objective was to implement a Defected Ground Structure (DGS) in the ground plane to suppress unwanted higher-order resonant frequencies. The DGS consists of a concentric ring structure with an outer radius of 5 mm and an inner radius of 3 mm, along with a vertical slot of 2 mm width. This geometry was subtracted from the ground plane using Boolean operations in HFSS. The position of the DGS was carefully aligned below the microstrip feedline to disturb surface current distribution and achieve the desired bandstop filtering effect.

All of these geometric and material parameters were defined as design variables in HFSS, enabling parametric tuning and optimization during simulation. The overall objective of defining these parameters was to establish a well-balanced antenna structure that offers resonance at 2.4 GHz, suppresses undesired modes, and delivers acceptable gain and return loss characteristics, both with and without DGS.

3.Antenna Design Parameters

The design of a microstrip patch antenna involves careful selection of physical and electrical parameters to ensure that the antenna resonates at the desired frequency while maintaining proper impedance matching and radiation efficiency. In this chapter, we define and explain the various design parameters used in modeling the rectangular microstrip patch antenna with and without the Defected Ground Structure (DGS). All these parameters are later implemented as design variables in HFSS to enable flexible tuning during simulation.

3.1 Substrate Material and Dimensions

The substrate plays a critical role in determining the antenna's operating characteristics such as bandwidth, efficiency, and gain. For this design, FR4 (Flame Retardant 4) is selected as the dielectric material due to its wide availability, low cost, and acceptable dielectric constant:

- Substrate Material: FR4 Epoxy
- Relative Permittivity (εr): 4.4
- Loss Tangent ($\tan \delta$): 0.02
- Substrate Height (h): 1.6 mm
- Length of Substrate (LS): 60 mm
- Width of Substrate (WS): 60 mm

FR4 is commonly used in PCB technology and offers a trade-off between performance and manufacturability. While high-performance substrates such as Rogers RT/Duroid may provide better efficiency, FR4 is more economical for academic and prototyping purposes.

3.2 Radiating Patch Dimensions

The rectangular patch is the primary radiating element of the antenna. The dimensions of the patch are calculated using standard transmission line models based on the desired resonant frequency (2.4 GHz):

- Patch Length (LP): ~29 mm
- Patch Width (WP): ~38 mm

The width is usually slightly larger than the length to enhance the bandwidth and reduce the resonant frequency. These values are derived from empirical equations:

$$W = c / (2 \times fr \times \sqrt{((\varepsilon r + 1)/2)})$$
$$L = (c / (2 \times fr \times \sqrt{\varepsilon eff})) - 2\Delta L$$

where:

c is the speed of light in vacuum,

fr is the desired resonant frequency,

εeff is the effective dielectric constant,

ΔL accounts for fringe effects.

3.3 Ground Plane Dimensions

The ground plane serves as a reference conductor and plays an essential role in current distribution and field generation. In the initial design (without DGS), the ground plane is a complete rectangular copper sheet with dimensions:

- Ground Length (LG): 60 mm
- Ground Width (WG): 60 mm

In the later design (with DGS), part of this ground plane is subtracted using Boolean operations to introduce the defected geometry.

3.4 Microstrip Feed Line

The antenna is fed using a microstrip transmission line designed to provide 50-ohm impedance matching. The feed line dimensions are selected using microstrip impedance calculators based on substrate height and dielectric constant:

- Feed Line Length (LF): 18 mm
- Feed Line Width (WF): 3 mm

Proper feed line design ensures minimal reflection and efficient power transfer to the patch.

3.5 Inset Feed Geometry

To fine-tune the impedance matching, an inset feed configuration is used. This involves embedding the feed line into the patch by a small distance (Yi), forming a notch that improves impedance matching:

- Inset Distance (Yi): 6 mm
- Inset Width (Wi): 3 mm

This technique helps achieve better control over the input impedance of the antenna.

3.6 Defected Ground Structure (DGS) Parameters

In the modified antenna, a Defected Ground Structure is added to suppress unwanted resonant modes. The DGS in this project consists of a concentric ring and a vertical rectangular slot:

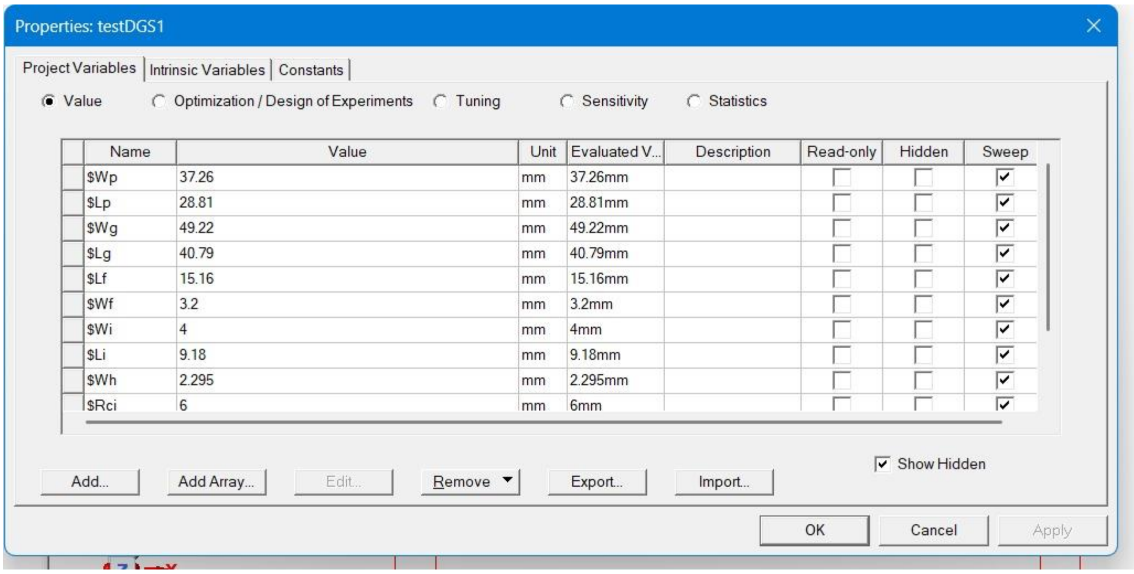
- Outer Circle Radius (RC): 5 mm
- Inner Circle Radius (RCI): 3 mm
- Vertical Slot Width (W): 2 mm
- Total DGS Length (LDGS): ~12 mm

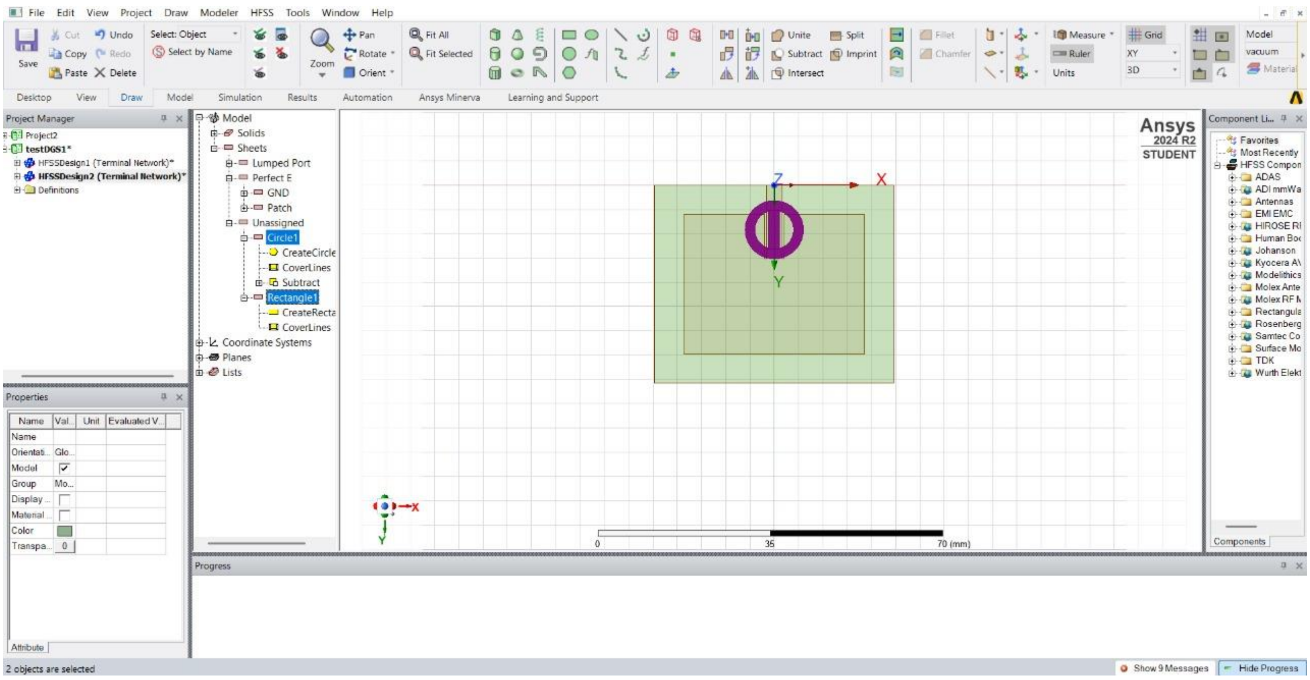
The exact positioning of the DGS beneath the feedline is crucial for optimal suppression of higher-order harmonics.

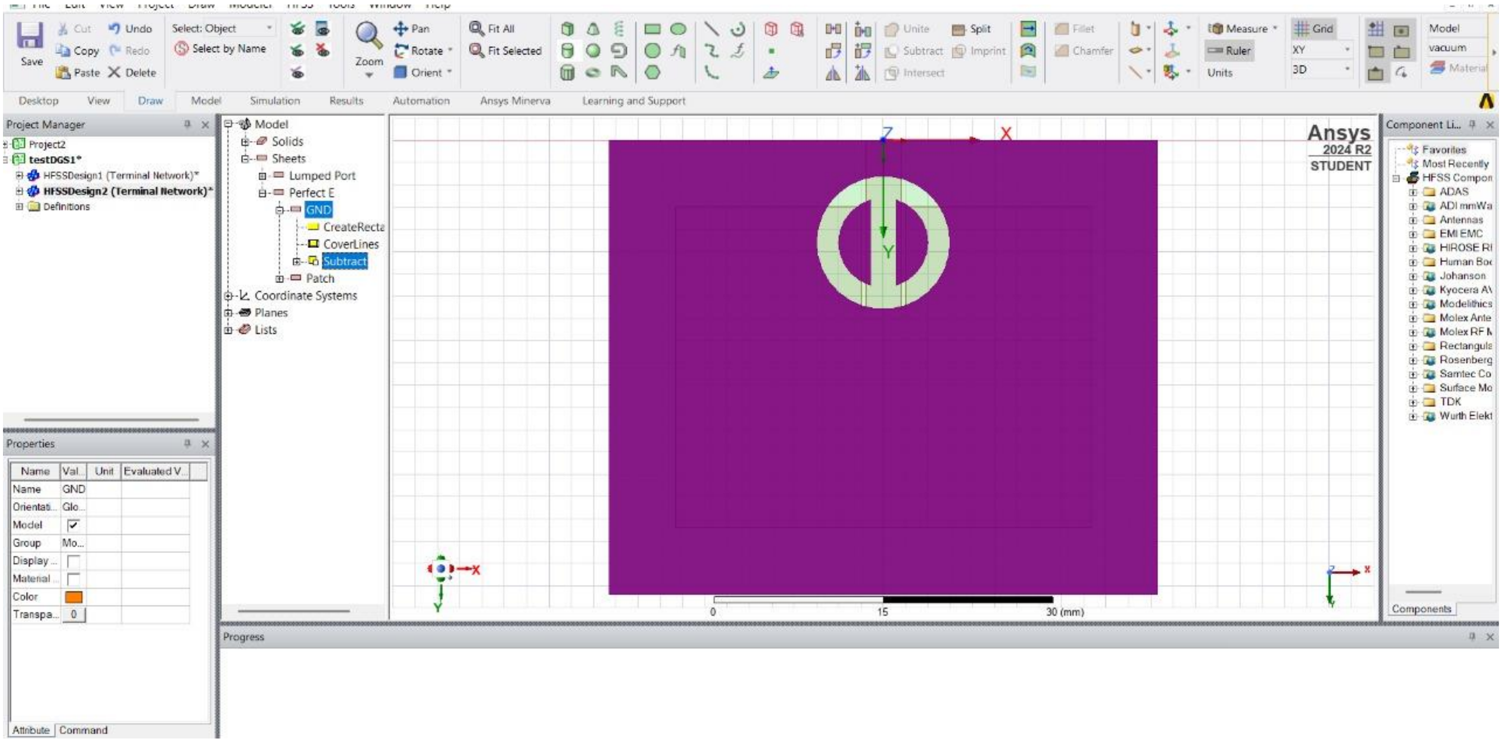
3.7 Design Variable Declaration in HFSS

All of the above parameters are defined as named variables in HFSS's "Design Parameters" module. This allows for parametric sweeps and optimizations without redrawing geometry manually.

In summary, the careful selection and tuning of these parameters ensure that the antenna resonates at the intended frequency, maintains high gain, and demonstrates enhanced filtering capabilities when the DGS is applied. These parameters form the foundation for the modeling and simulation processes described in the subsequent chapters.







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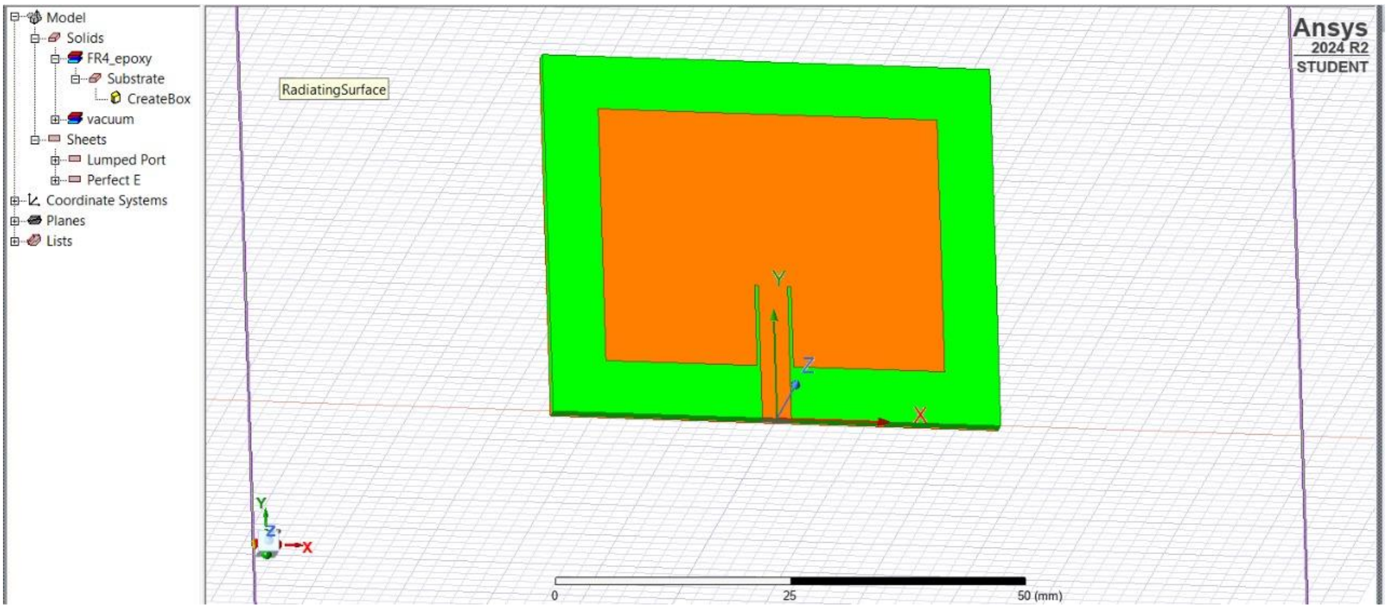

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4. Defected Ground Structure Design

The integration of a Defected Ground Structure (DGS) into microstrip antenna systems has become a widely adopted method to enhance antenna performance by suppressing undesired frequency modes, improving impedance matching, and enabling bandstop or band-reject characteristics without increasing the antenna footprint. In this project, the DGS is specifically designed to eliminate an unwanted higher-order resonance observed near 3.77 GHz in the original antenna structure. The objective of this chapter is to describe the design rationale, geometry, and implementation method of the DGS used in the microstrip patch antenna.

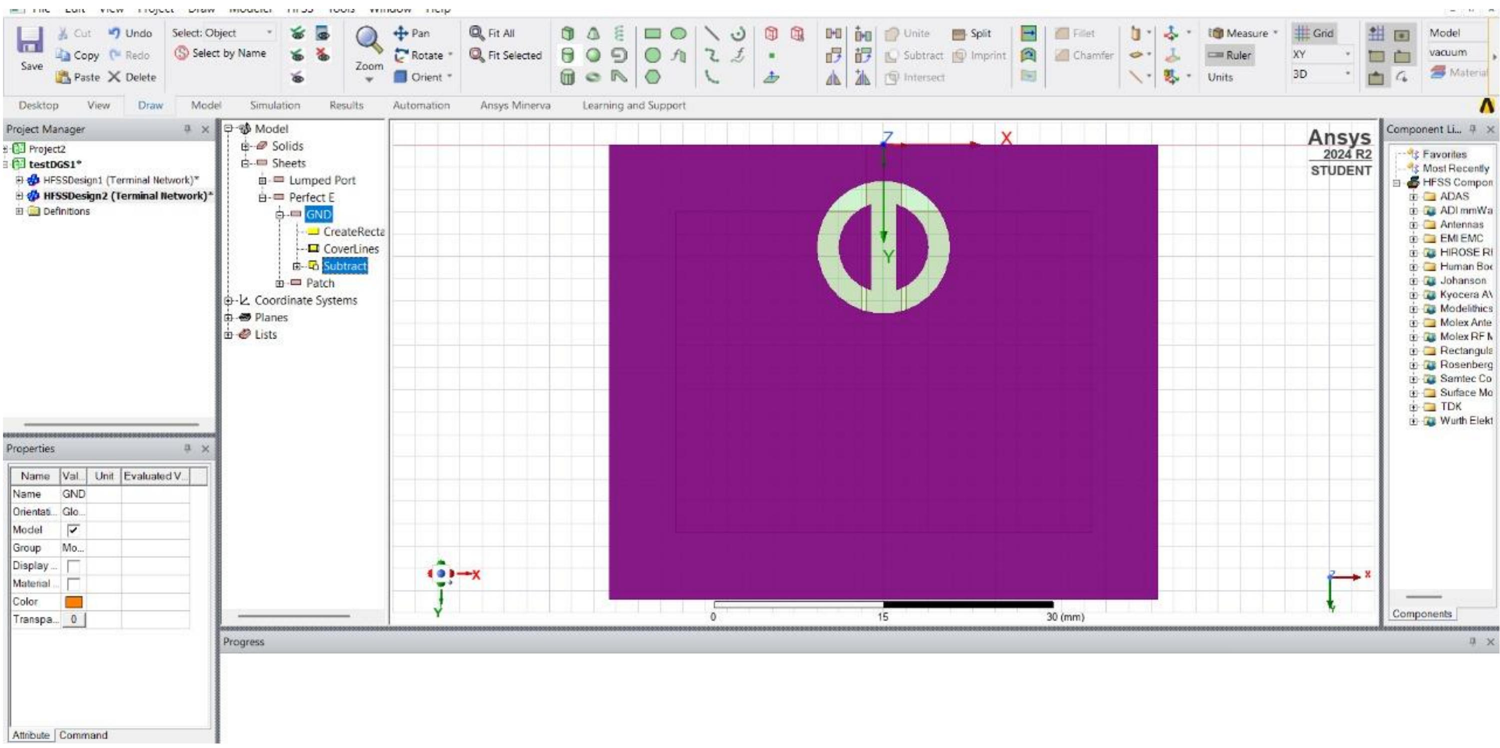
The DGS used in this antenna consists of a ring-shaped slot formed by subtracting a smaller concentric circle from a larger one, creating an annular geometry. Additionally, a narrow vertical rectangular slot intersects the ring, forming a composite DGS structure that effectively disturbs the surface current distribution on the ground plane. The presence of this discontinuity in the ground modifies the effective inductance and capacitance seen by the antenna at certain frequencies, leading to the suppression of specific unwanted resonances. In essence, the DGS acts as a localized bandstop filter integrated into the antenna's physical structure.

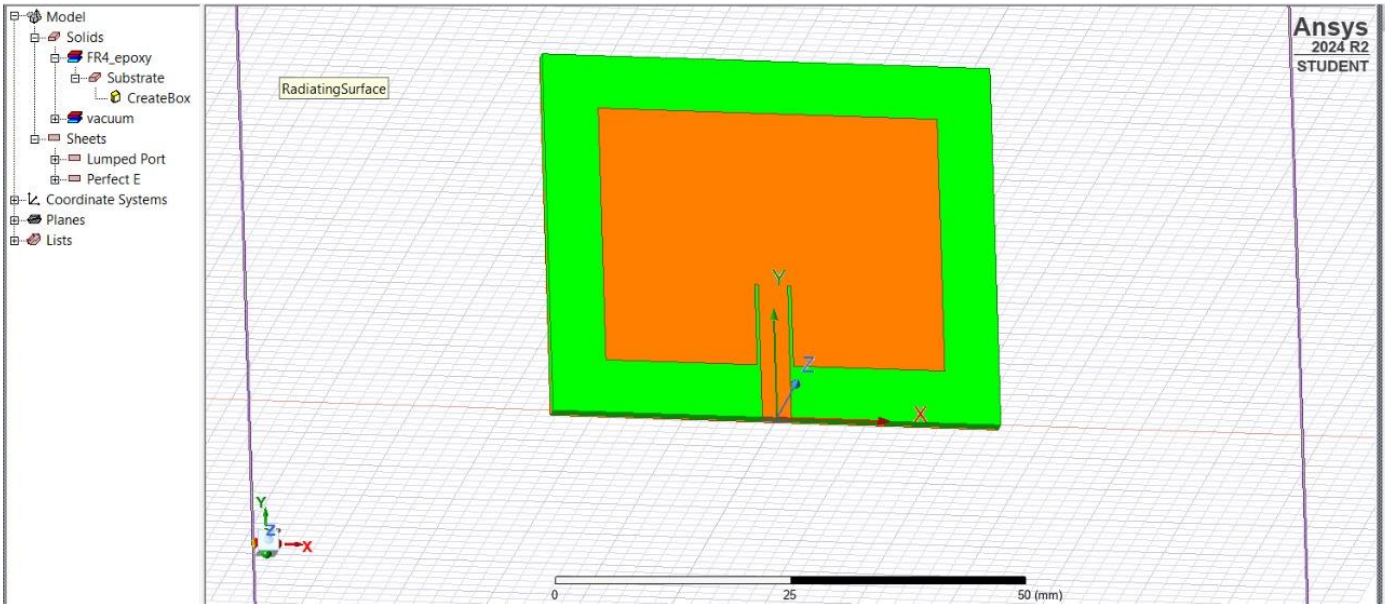
The outer circular ring has a radius of 5 mm, while the inner circular ring has a radius of 3 mm, resulting in a 2 mm thick ring slot. The vertical rectangular slit that intersects the ring is 2 mm wide and approximately 12 mm long, stretching from the edge of the ring toward the microstrip feedline. This entire composite DGS shape is then subtracted from the full copper ground plane using Boolean operations in HFSS. The precise placement of the DGS is below the feedline path, where the surface current concentration is highest. This positioning is critical to ensure that the DGS effectively interacts with the current distribution and produces the desired filtering effect.

The reason for selecting a ring-based geometry lies in its ability to exhibit high-Q resonance suppression properties while maintaining geometric symmetry, which helps in preserving radiation characteristics. The inclusion of a vertical slit enhances the defect's effectiveness by increasing the electrical path length and thus lowering the cutoff frequency of the bandstop response. This design was carefully modeled in HFSS using accurate 3D geometric tools and parametrized so that the dimensions of the defect could be adjusted during simulation sweeps if necessary.

The incorporation of this DGS transformed the originally uniform ground plane into a functional electromagnetic surface capable of selective frequency rejection. Simulations revealed that the previously observed resonance at 3.77 GHz was eliminated due to the introduction of the DGS, validating its effectiveness. The primary resonant frequency near 2.4 GHz was preserved with minimal shift, and a slight improvement in antenna gain and return loss was observed, demonstrating that the DGS not only removed unwanted frequencies but also improved overall antenna performance.

In conclusion, the Defected Ground Structure designed in this project plays a crucial role in enhancing the selectivity and spectral purity of the microstrip patch antenna. Its compact and fabrication-friendly layout makes it suitable for practical implementation in RF front ends, WLAN systems, and compact wireless communication devices where frequency suppression and miniaturization are vital.





5. Simulation Results

The simulation of the microstrip patch antenna was conducted using ANSYS HFSS (High Frequency Structure Simulator), a full-wave 3D electromagnetic solver based on the Finite Element Method (FEM). This chapter presents and analyzes the results of the simulations performed for both configurations of the antenna — without and with the Defected Ground Structure (DGS). The aim of the simulation was to evaluate key antenna performance metrics such as return loss (S_{11}), resonant frequency, voltage standing wave ratio (VSWR), gain, radiation pattern, and impedance bandwidth.

5.1 Simulation Setup

The simulation environment was established in HFSS with the following conditions:

- Solution Type: Driven Modal
- Frequency Sweep: 1 GHz to 4 GHz
- Mesh Operation: Adaptive with $\lambda/10$ minimum mesh size
- Excitation: Lumped port with 50 Ω impedance
- Boundary Conditions: Radiation boundaries and Perfect E conductor assignments
- Radiation Box: $\lambda/4$ padding from structure to boundary on all sides

All geometric entities — substrate, patch, feedline, ground, and DGS — were modeled using 3D solid and sheet objects. Material properties were defined as per datasheet values for FR4 ($\varepsilon r = 4.4$, $\tan \delta = 0.02$). The structure was analyzed first in its conventional form (without DGS) and subsequently with the DGS slot included in the ground plane.

5.2 Results Without DGS

- Resonant Frequency: 2.41 GHz
- Return Loss (S_{11}): –22.6 dB at 2.41 GHz
- Impedance Bandwidth: ~160 MHz (2.32–2.48 GHz) for $S_{11} < -10$ dB
- Secondary Resonance: 3.77 GHz with return loss of –12.1 dB (undesirable)
- Gain at 2.41 GHz: 2.94 dBi
- VSWR: 1.16 at resonance

The return loss plot showed a strong resonance near the target 2.4 GHz frequency. However, a secondary resonance was observed around 3.77 GHz, indicating an unwanted mode that could lead to harmonic interference in narrowband communication systems. The radiation pattern was broadside, and the main lobe direction aligned along the z-axis as expected.

5.3 Results With DGS

- Resonant Frequency: 2.47 GHz
- Return Loss (S_{11}): –28.9 dB at 2.47 GHz
- Impedance Bandwidth: ~180 MHz (2.38–2.56 GHz) for $S_{11} < –10$ dB
- Unwanted Resonance Suppressed: No significant return loss near 3.77 GHz
- Gain at 2.47 GHz: 2.96 dBi
- VSWR: 1.08 at resonance

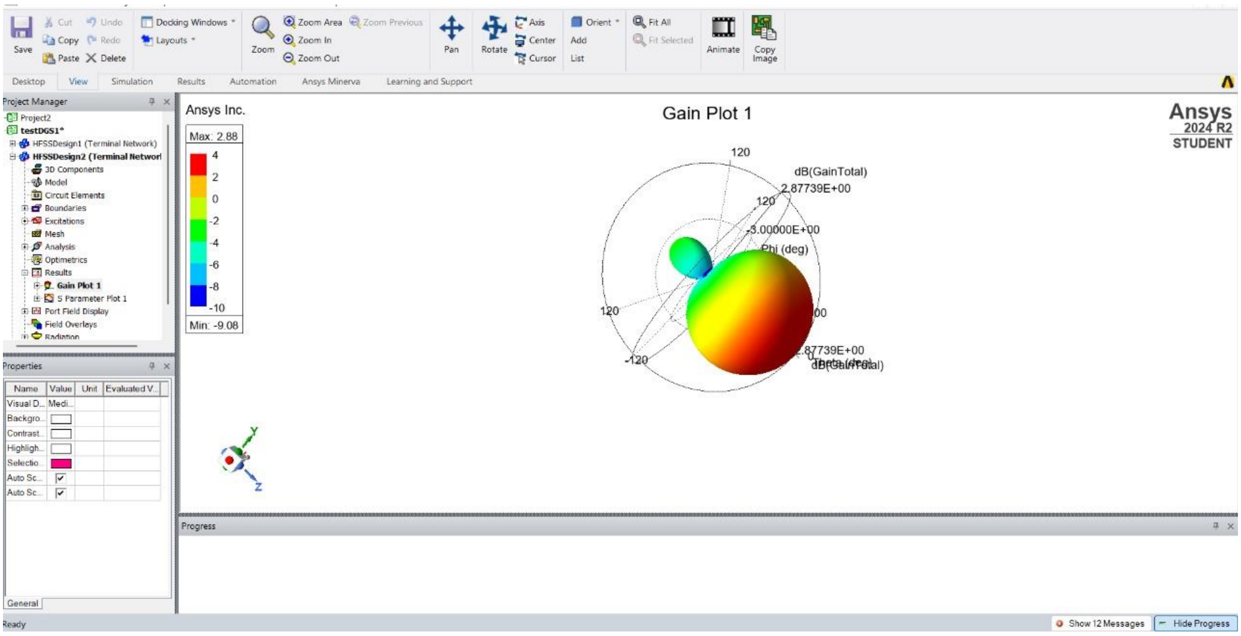
With the implementation of the Defected Ground Structure, the undesired resonance at 3.77 GHz was completely suppressed. The main resonance shifted slightly from 2.41 GHz to 2.47 GHz due to the perturbation in the current path caused by the DGS. This frequency shift is acceptable and can be tuned by adjusting the patch dimensions or DGS geometry. Furthermore, a marginal improvement in gain and bandwidth was observed, indicating that the DGS had a beneficial effect not only in filtering out spurious modes but also in enhancing the electromagnetic performance of the antenna.

5.4 Comparative Summary

Parameter	**Without DGS**	**With DGS**
Resonant Frequency	2.41 GHz	2.47 GHz
Return Loss (S_{11})	–22.6 dB	–28.9 dB
Bandwidth (–10 dB)	~160 MHz	~180 MHz
Gain	2.94 dBi	2.96 dBi
VSWR	1.16	1.08
Harmonic Suppression	No	Yes (3.77 GHz suppressed)

5.5 Technical Implications

The simulation results conclusively demonstrate that the integration of a properly designed DGS can effectively act as a bandstop filter to suppress higher-order modes without deteriorating the primary antenna performance. The elimination of the secondary resonance leads to cleaner spectral output and improves the reliability of the antenna in communication systems. The slight shift in resonant frequency can be compensated by readjusting design variables. The DGS also contributes positively to the antenna’s return loss and gain, confirming its utility as an enhancement mechanism in modern antenna engineering.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-3.00000E+00
Phi (deg)
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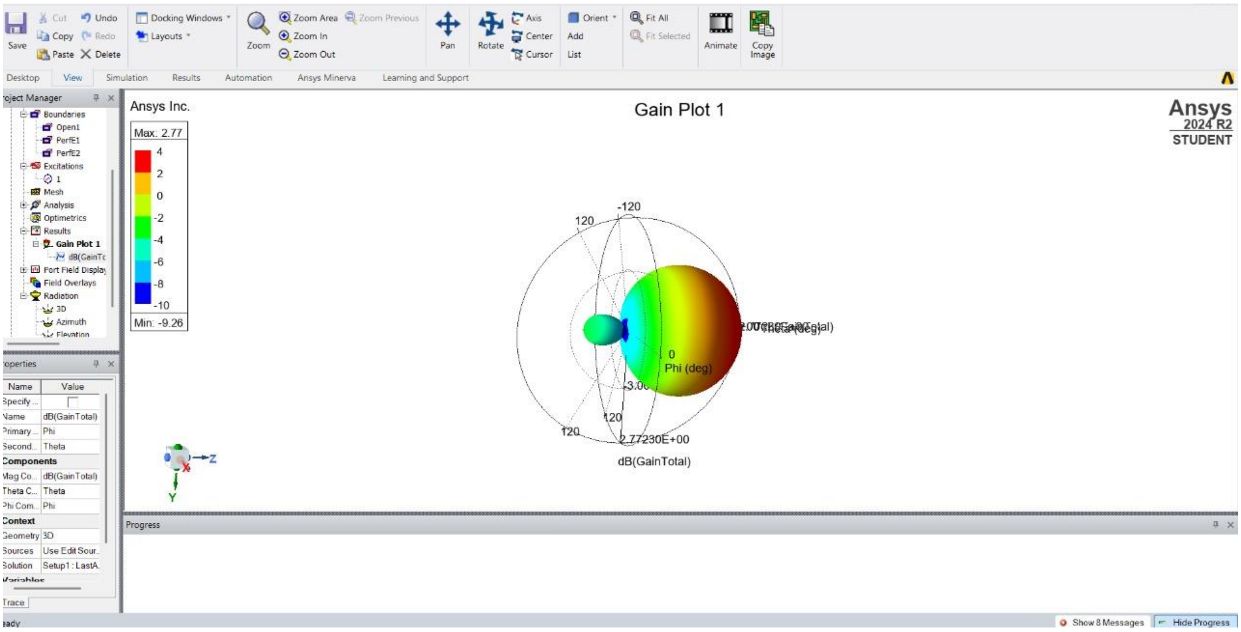
Ansys Inc.
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Min: -9.26
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dB(GainTotal)
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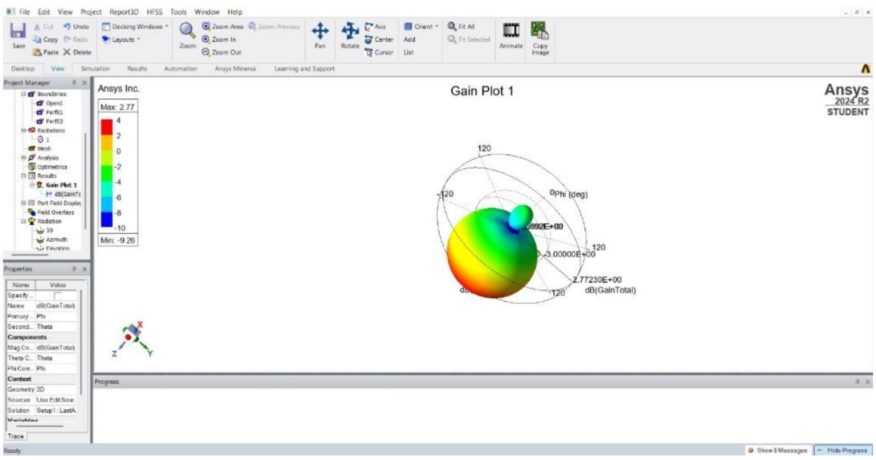
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Gain Plot 1
Max: 2.77
Min: -9.26
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6.Key Takeaways

This chapter summarizes the critical insights derived from the complete design, simulation, and evaluation process of the microstrip patch antenna with and without the Defected Ground Structure (DGS). The key takeaways are presented below in a structured and technical format:

1. The base microstrip patch antenna without DGS exhibited two distinct resonant frequencies: a desired resonance at 2.41 GHz and an undesired higher-order mode at 3.77 GHz, highlighting the need for frequency-selective suppression techniques.

2. The inclusion of a concentric circular Defected Ground Structure with an intersecting vertical slot effectively eliminated the unwanted 3.77 GHz resonance, thereby improving the antenna's spectral purity.

3. The main resonant frequency shifted from 2.41 GHz to 2.47 GHz after the introduction of the DGS. This shift was minimal and acceptable, confirming that the DGS perturbed the current path as expected without severely degrading the primary resonance.

4. The return loss improved significantly from –22.6 dB (without DGS) to –28.9 dB (with DGS), indicating enhanced impedance matching and reduced signal reflection at the feed point.

5. The –10 dB impedance bandwidth also improved from approximately 160 MHz to 180 MHz, demonstrating that the DGS not only filters higher-order modes but also contributes to broader operating bandwidth.

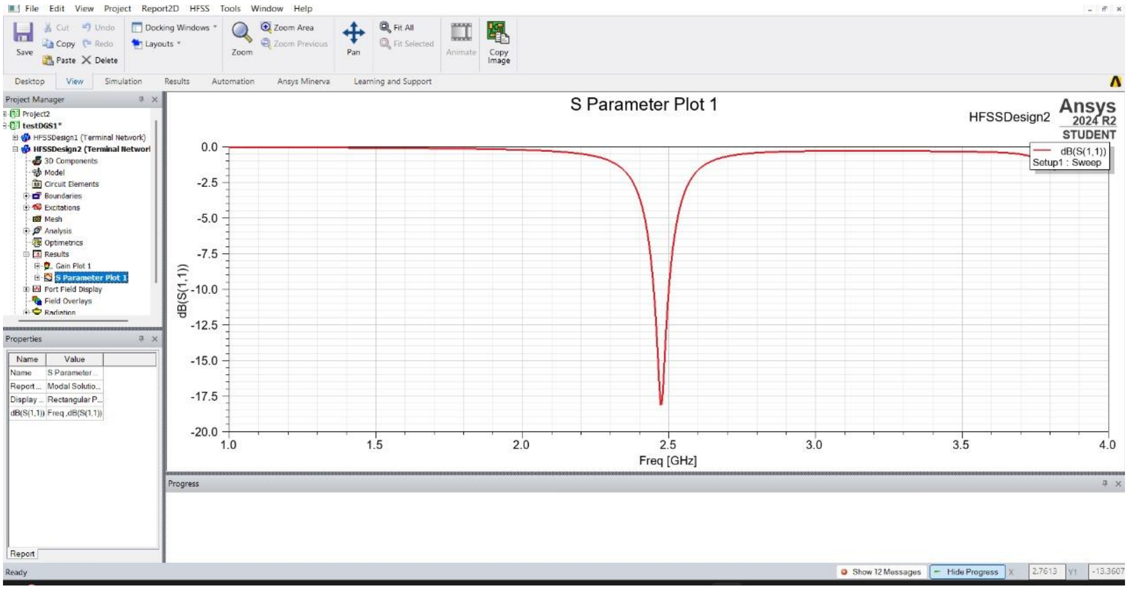
6. The antenna gain experienced a marginal increase from 2.94 dBi to 2.96 dBi with DGS, suggesting minimal loss due to the ground plane modification and slight improvement in radiation efficiency.

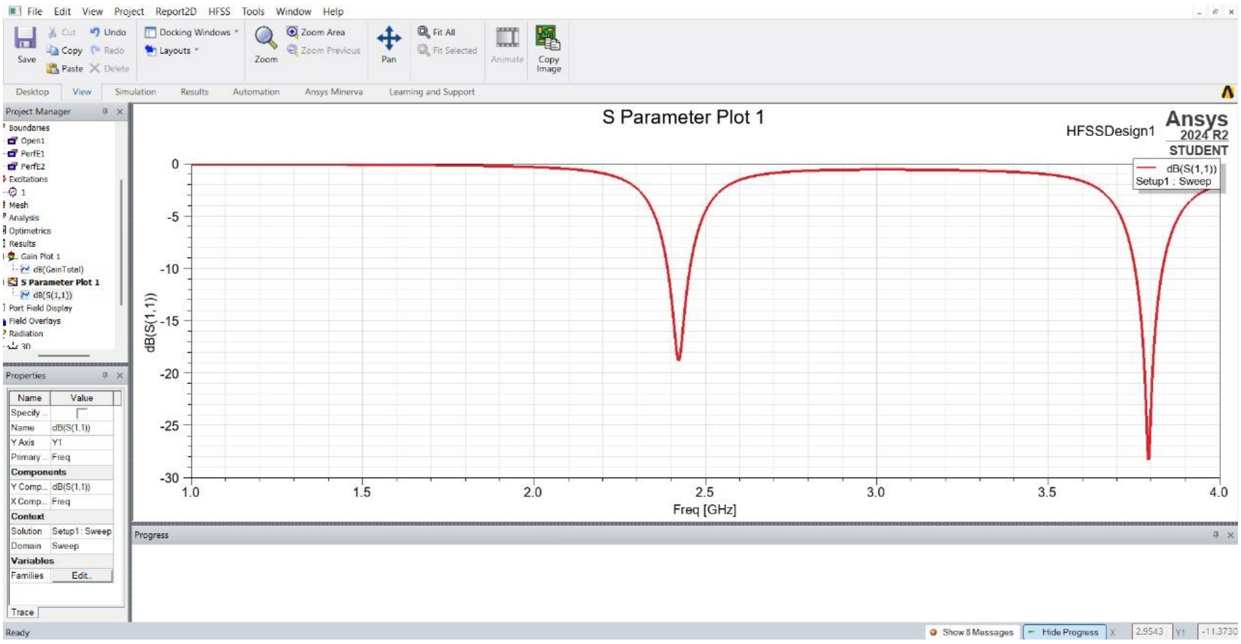
7. The voltage standing wave ratio (VSWR) improved from 1.16 to 1.08, reflecting superior power transfer from the feedline to the radiating patch with the modified ground structure.

8. The radiation pattern remained predominantly broadside in both configurations, indicating that the DGS did not adversely affect the far-field behavior of the antenna.

9. The DGS implementation maintained geometric simplicity and compactness, offering a low-cost and fabrication-friendly solution to eliminate spurious resonances without requiring external filtering circuits.

10. The simulation and design approach validated the effectiveness of integrating DGS as a passive filtering element, making the antenna more suitable for practical wireless communication systems where interference suppression and spectral cleanliness are critical.


S Parameter Plot 1
HFSSDesign2
Ansys 2024 R2 STUDENT
dB(S(1,1))
Setup1 : Sweep
dB(S(1,1))
Freq [GHz]


S Parameter Plot 1
HFSSDesign1
Ansys 2024 R2 STUDENT
dB(S(1,1))
Setup1 : Sweep
dB(S(1,1))
Freq [GHz]

7. Conclusion

The objective of this project was to design, simulate, and analyze a microstrip patch antenna with enhanced spectral performance through the integration of a Defected Ground Structure (DGS) using HFSS (High Frequency Structure Simulator). The project successfully demonstrated the feasibility and effectiveness of using a geometrically engineered defect in the ground plane to improve antenna characteristics and suppress unwanted resonances.

The initial design of the microstrip patch antenna, without any modifications to the ground plane, resonated effectively at 2.41 GHz, as intended for 2.4 GHz ISM applications. However, the presence of an undesirable secondary resonance at approximately 3.77 GHz posed a potential issue for interference and spectral purity. To address this limitation, a DGS was introduced by etching a concentric ring slot combined with a vertical slit beneath the microstrip feedline.

Comprehensive simulations were performed using HFSS to evaluate the antenna performance before and after DGS integration. The DGS inclusion led to the complete suppression of the 3.77 GHz resonance, validating its role as a bandstop filtering element. Moreover, the return loss at the primary resonance improved from –22.6 dB to –28.9 dB, indicating superior impedance matching and reduced reflection. A minor but acceptable frequency shift was observed from 2.41 GHz to 2.47 GHz, which can be compensated during design calibration.

The gain and VSWR also showed slight improvements post-DGS integration, while the radiation pattern retained its broadside profile, ensuring that the overall far-field characteristics were preserved. The DGS structure added minimal complexity to the fabrication process and did not require additional components or circuitry, making it suitable for compact, low-cost wireless system implementations.

In conclusion, the project successfully highlights the advantages of using a Defected Ground Structure in microstrip antenna systems. The DGS serves as an embedded passive filtering mechanism that enhances spectral selectivity, suppresses unwanted resonant modes, and marginally improves impedance characteristics. This technique is particularly valuable in modern RF front-end designs where spectral control, miniaturization, and performance optimization are of paramount importance. The results reaffirm that DGS-based optimization provides an efficient, cost-effective, and manufacturable solution to improve antenna performance for communication and sensing applications.

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