SHRI RAMDEOBABA COLLEGE OF ENGINEERING AND MANAGEMENT, NAGPUR
DEPARTMENT OF ELECTRONICS & COMPUTER SCIENCE ENGINEERING
Session: 2024-25

Project Evaluation - I

Project1(ECSP310) VI sem B.Tech (ECS)

Optimization of Antenna Design Using Machine Learning Algorithms

By -
B-43 Rishi Thakre
B-35 Ameya Bahadure
B- 53 Tushar Sanodiya
B- 28 Komal Patle

Project Guide -
Prof. Archana Tiwari

Introduction

An antenna is a device used to transmit and receive electromagnetic waves, such as radio waves, microwaves, and even visible light in some advanced applications. It acts as a transducer, converting electrical signals into electromagnetic waves for transmission and vice versa for reception

IMPORTANCE OF ANTENNAS IN COMMUNICATION SYSTEM

- Signal Transmission & Reception
- Wireless Communication
- Extended Coverage & Better Signal Strength
- High-Speed Data Transfer
- Directionality and Gain
- Essential for GPS, Radar & Space Communication
- Smart Antennas for Modern Networks

OBJECTIVES

- Design a simple microstrip patch antenna using EM Simulator.
- Optimize the antenna for frequency, bandwidth, gain and return loss.
- Generate the dataset for antenna performance parameters to facilitate ML Model training.
- Analyze different machine learning (ML) models to incorporate for antenna design.
- Implement the generated data set on machine learning algorithms to optimize antenna performance and improve key parameters.
- Investigate the predicted output with the results obtained from the EM simulator.

Functions of an Antenna:

- **Signal Transmission:** Converts electrical signals into electromagnetic waves.
- **Signal Reception:** Captures electromagnetic waves and converts them into electrical signals.
- **Directional Control:** Focuses or distributes signals for efficient communication.
- **Impedance Matching:** Ensures maximum power transfer between transmitter and receiver.

Key parameters of antennas:

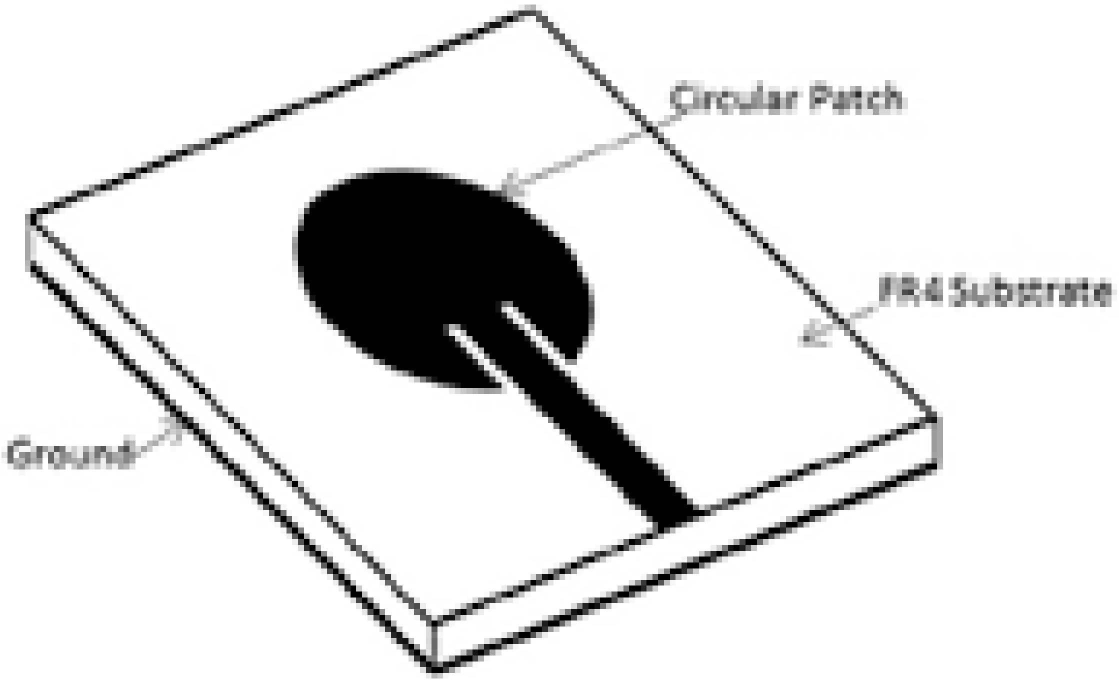
- **Radiation Pattern:** Graphical representation of antenna radiation in space.
- **Bandwidth:** Frequency range over which the antenna operates effectively.
- **Gain:** Measure of how much power is directed in a specific direction.
- **Efficiency:** Ratio of radiated power to input power, indicating performance.

Microstrip Patch Antenna Overview

- **Patch:** Radiating element that emits electromagnetic waves.

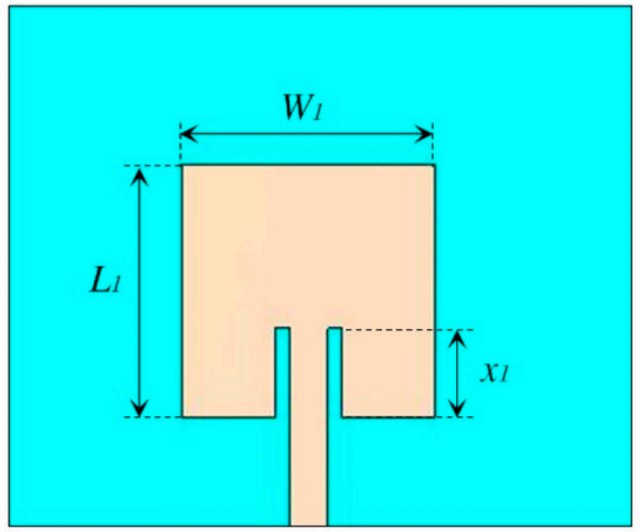
0

- **Substrate:** Dielectric material supporting the patch and feed line.
- **Ground Plane:** Conductive layer below the substrate for signal reflection and stability.

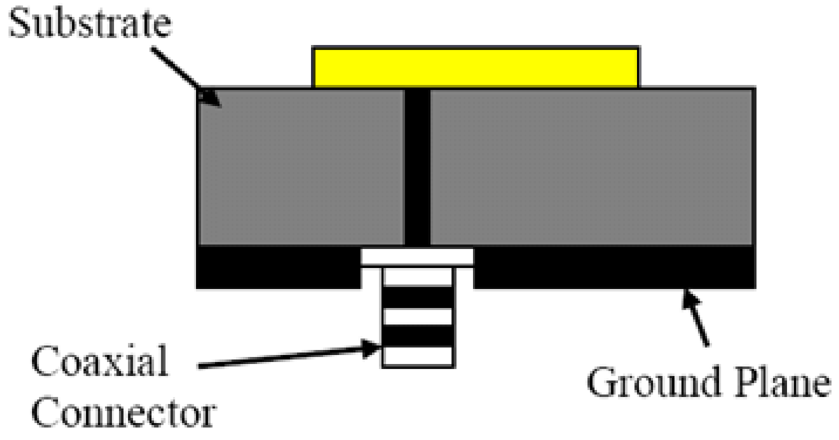


Feeding techniques:

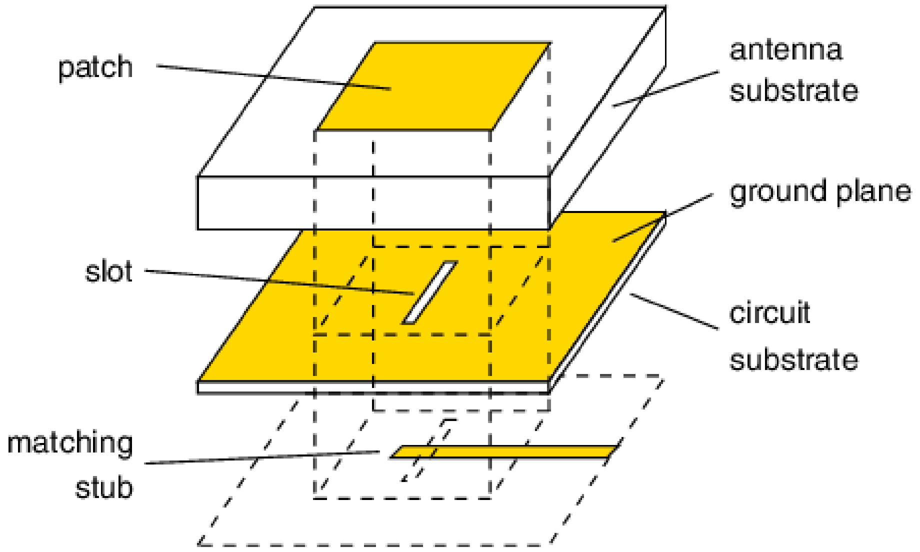
- **Microstrip Line Feed:** A conducting strip directly connected to the patch for easy integration.
- **Coaxial Probe Feed:** A coaxial connector with an inner conductor penetrating the substrate to excite the patch.
- **Aperture Coupled Feed:** Uses a slot in the ground plane to transfer energy, improving bandwidth and isolation.



Microstrip Line Feed



Coaxial Probe Feed



Aperture Coupled Feed

circular patch

- **Compact Size:** Requires less space, ideal for miniaturized devices.
- **Omni-directional Radiation Pattern:** Provides uniform coverage in all directions.
- **Higher Bandwidth:** Offers better bandwidth than a rectangular patch.
- **Easy Integration:** Seamlessly fits into wireless communication systems.

Design Specifications

Target Frequency: 2.45 GHz

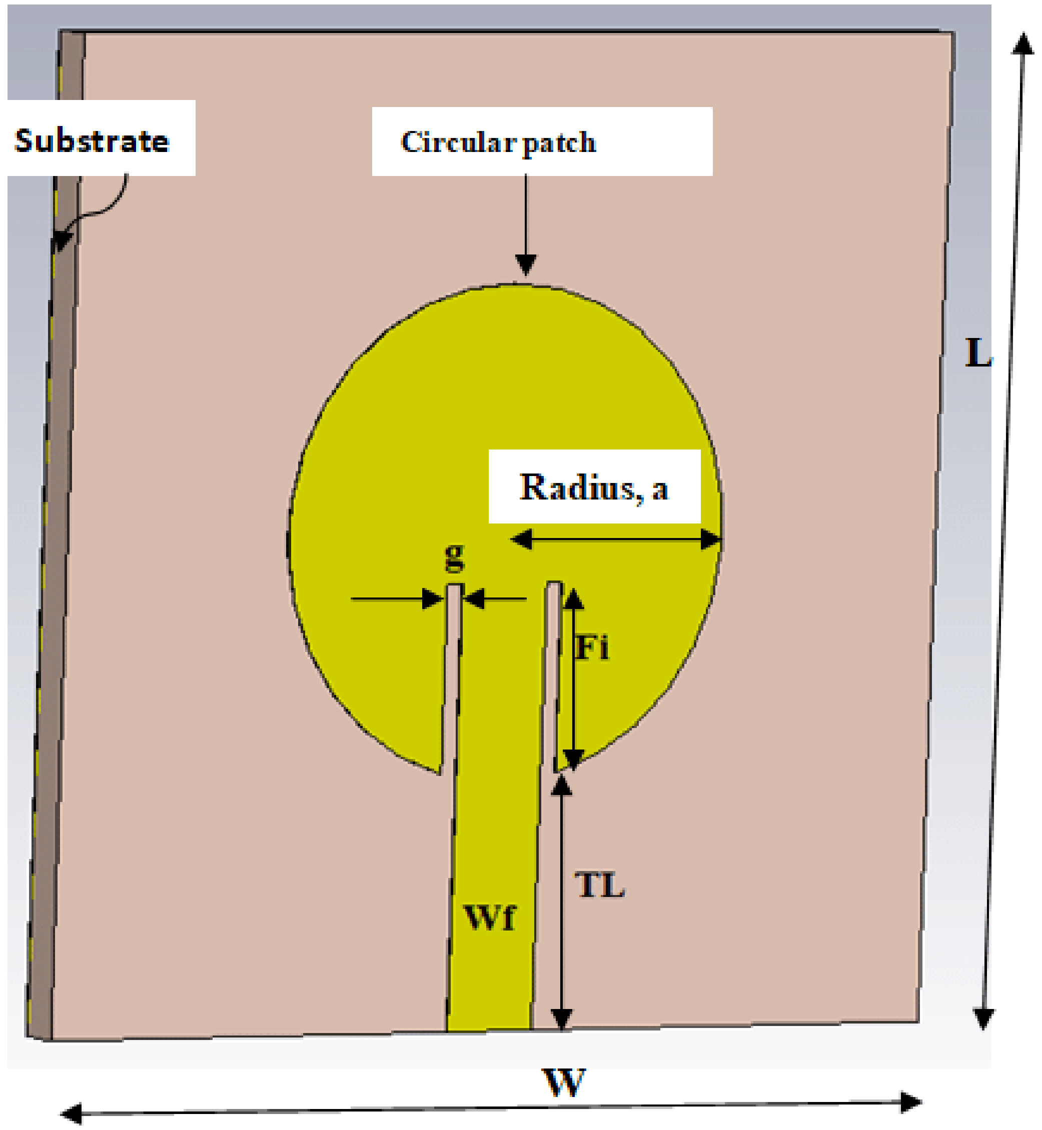
- Selected for Wi-Fi and ISM band applications
- Ensures compatibility with standard wireless communication systems

Ground Plane Size: 50 mm x 50 mm

- Large enough for stable radiation patterns and minimize edge effects
- Ensures consistent antenna performance across different substrates

Substrate Material: FR4 Epoxy

- Low cost and ease of fabrication
- Provides stable mechanical and electrical properties
- Suitable for high-frequency applications

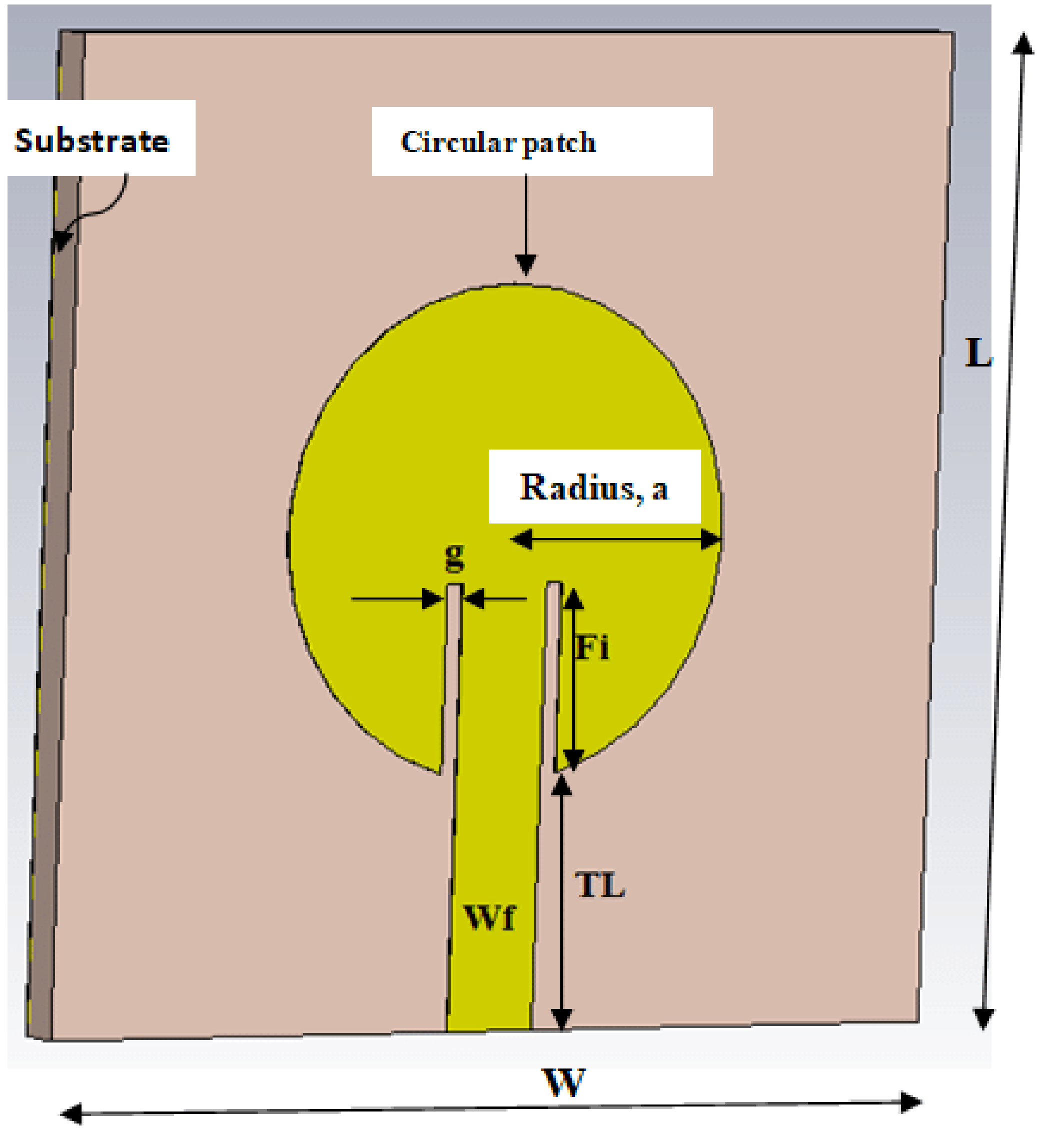


Substrate Thickness: 1.6 mm

- Affects impedance matching and bandwidth
- Optimal thickness ensures better signal integrity and radiation efficiency

Dielectric Constant (εr): 4.4

- Determines the size and resonant frequency of the patch
- Higher dielectric constant results in a smaller antenna size



Feeding Technique: Microstrip Line Feed

- Simple to fabricate and integrate with other planar circuits
- Better impedance matching and minimizes reflection loss
- Ensures uniform current distribution for consistent radiation pattern

DESIGN EQUATIONS

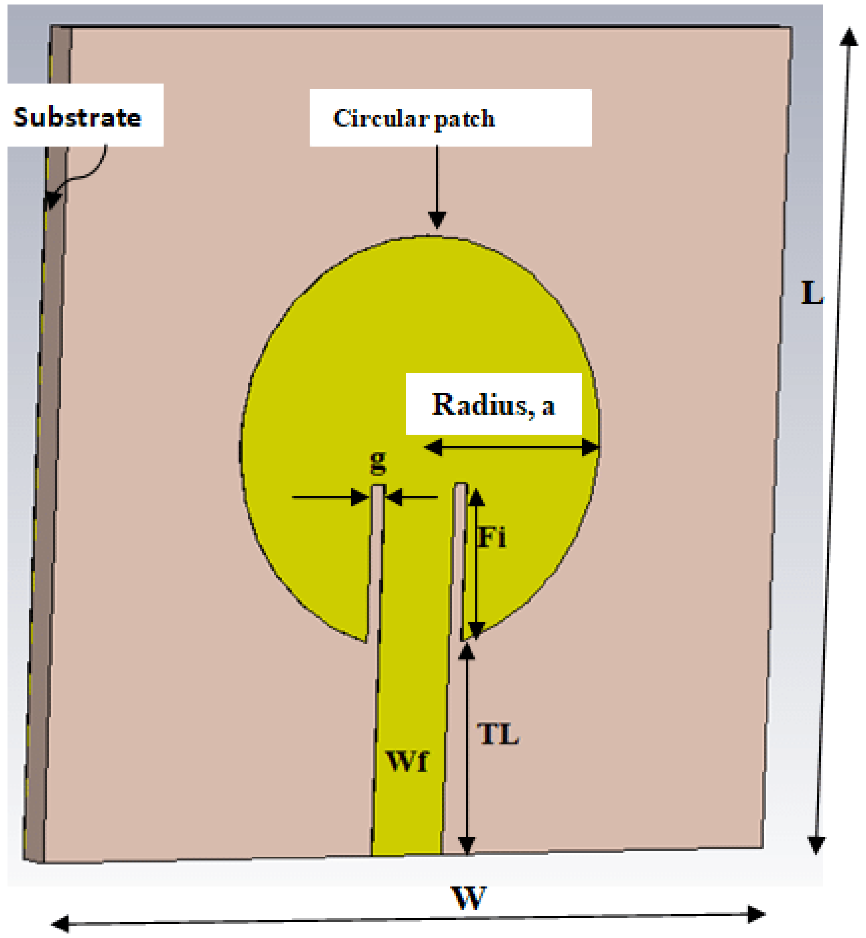
Radius of the Patch (a)

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi a \epsilon_r}\left(\ln \frac{\pi a}{2h} + 1.7726\right)}}$$

Where,

$$F = \frac{8.791 \times 10^9}{f_c \sqrt{\epsilon_r}}$$

- fc = Resonant frequency (Hz)
- ϵr = Relative permittivity of the substrate
- h = Thickness of the substrate



DESIGN EQUATIONS

Effective Dielectric Constant (ε_eff)

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5}$$

Resonant Frequency Fc:

$$f_c = \frac{1.8412 \cdot c}{2\pi a\sqrt{\epsilon_{eff}}}$$

- fc = Resonant frequency (Hz)
- ϵr = Relative permittivity of the substrate
- h = Thickness of the substrate

Effective Wavelength (λg)

$$\lambda_g = \frac{\lambda_0}{\sqrt{\epsilon_{eff}}}$$

- where:
- λ0 is the free-space wavelength
- λg is the guided wavelength inside the substrate

Circular Microstrip Patch Antenna Calculator

Input

Resonant Frequency	f_r	2.45	GHz
Substrate Relative Permittivity	ϵ_r	4.4	
Substrate Height	h	1.6	millimeter

Output

Patch Physical Radius a 16.59776 millimeter

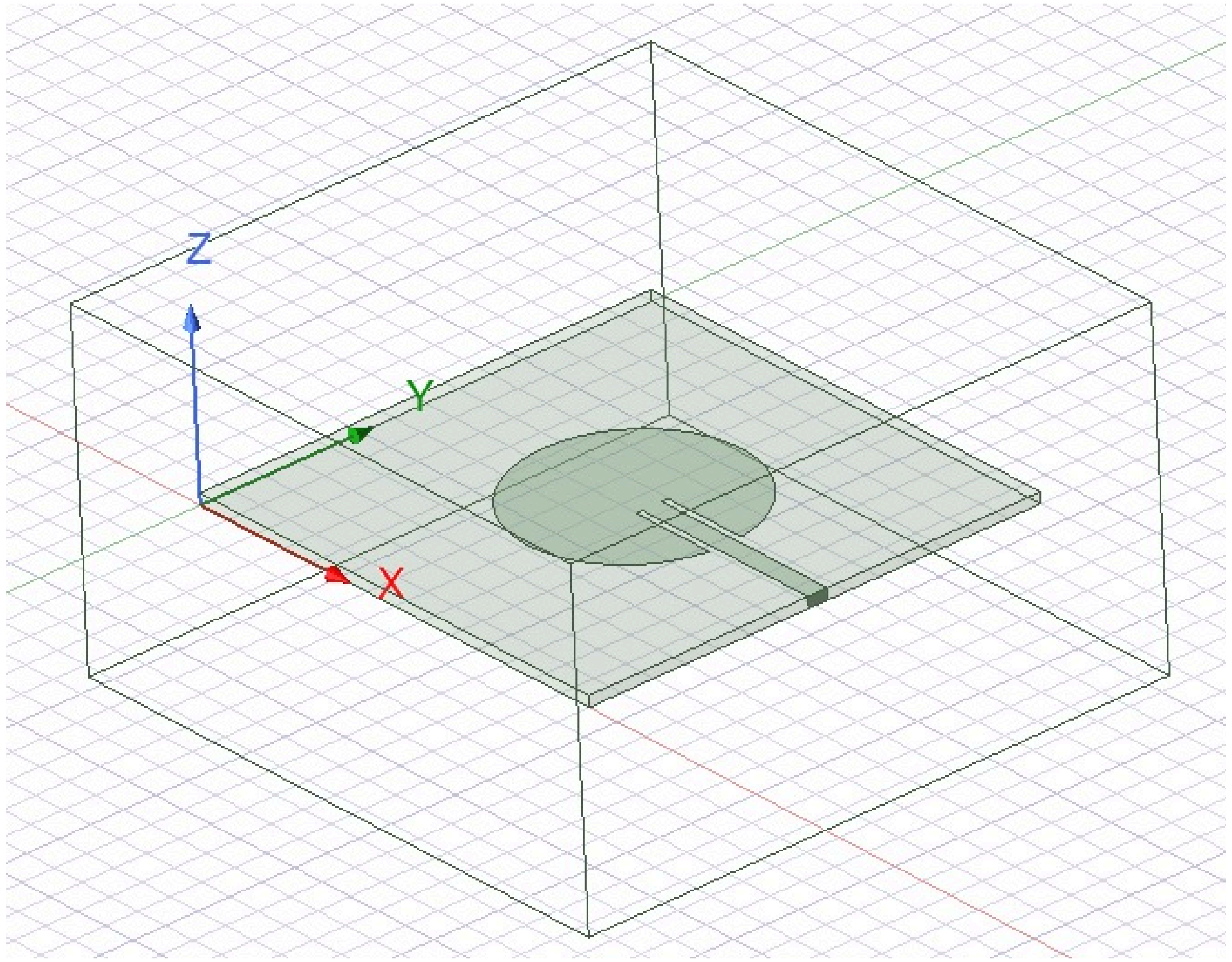
HIGH-FREQUENCY STRUCTURE SIMULATOR

Ansys HFSS (High-Frequency Structure Simulator) is a powerful electromagnetic simulation software used for designing and analyzing antennas. It utilizes the Finite Element Method (FEM) to solve Maxwell's equations, enabling accurate simulation of antenna parameters like return loss, gain, and radiation patterns.

Design in HFSS

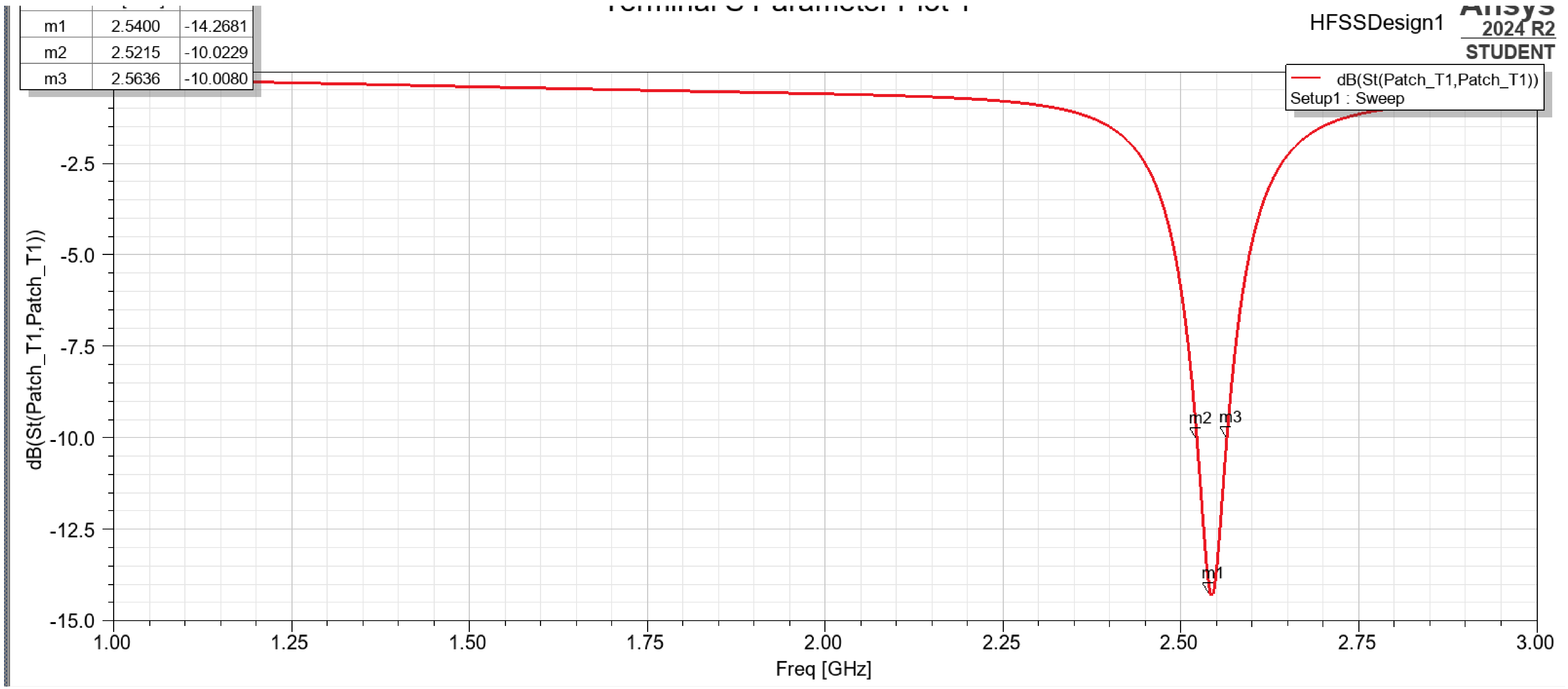
- Create the Ground Plane
- Create the Substrate
- Create the Circular Patch
- Apply Excitation using Microstrip Line Feed
- Define Material Properties
- Set Boundary Conditions

- Finally, Validate And Analyze



RESULT

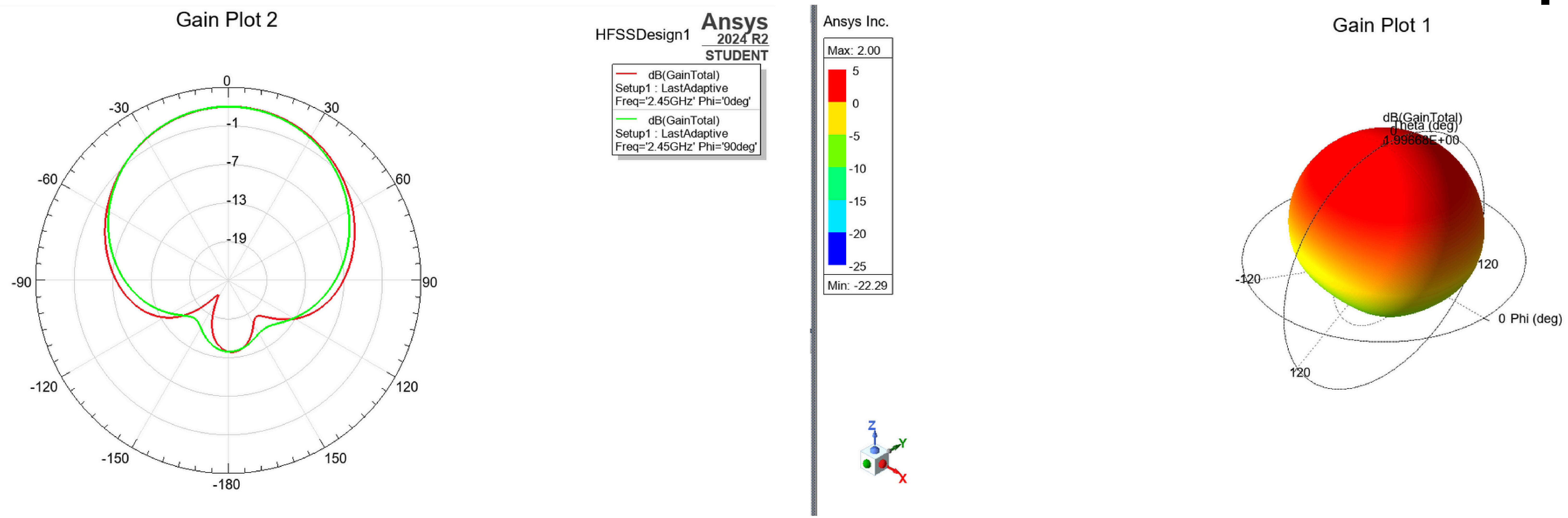
- **Return Loss-**



Observed Results:

The minimum return loss is -14.2681 dB (m1). .**Bandwidth** = 2.5636 - 2.5215 = **42.1 MHz**

- Gain and Radiation Pattern -



- **Observation-**
- **Radiation Pattern-**

1. The 3D gain plot shows a maximum gain of ~2 dB, with radiation concentrated in one direction.
2. The 2D polar plot confirms the main radiation lobe is around 0°, with minimal side lobes.

- **Directionality & Efficiency-**

1. Main lobe is well-defined, ensuring good signal focus.
2. Low side lobes reduce interference and improve efficiency.
3. Weak back lobe minimizes energy loss in the opposite direction.

- **Gain Performance-**

1. Gain of ~2 dB, which is reasonable for a microstrip patch antenna at 2.45 GHz.
2. Some expected losses due to substrate properties and surface waves.

CONCLUSION

- Understood Antenna Basics
- Designed and simulated a circular patch antenna at **2.45 GHz**
- Achieved good return loss, bandwidth, and gain

FUTURE WORK

- Now we are ready for data set generation and apply this dataset on machine learning algorithms.

9. REFERENCES

- Balanis, C. A. Antenna Theory: Analysis and Design. 4th ed., John Wiley & Sons, 2016.

- Singh, O., Bharamagoudra, M. R., Gupta, H., Dwivedi, A. K., Ranjan, P., & Sharma, A. (2022). Microstrip line fed dielectric resonator antenna optimization using machine learning algorithms. Sādhanā, 47, Article 226. Retrieved from https://link.springer.com/article/10.1007/s12046-022-01989-x

- Tiwari, R., Sharma, R., & Dubey, R. (2022). Microstrip Patch Antenna Parameter Optimization Prediction Model using Machine Learning Techniques. International Journal on Recent and Innovation Trends in Computing and Communication, 10(9), 53-58. Retrieved from https://www.researchgate.net/publication/364245259_Microstrip_Patch_Antenna_Parameter_Optimization_Prediction_Model_sing_Machine_Learning_Techniques

- Kurniawati, N., & Zulkifli, F. Y. (2021). Predicting Rectangular Patch Microstrip Antenna Dimension Using Machine Learning. Proceedings of the 2021 International Conference on Artificial Intelligence and Robotics for Industrial Applications (AIRIA), 1-6. Retrieved from https://www.researchgate.net/publication/354436732_Predicting_Rectangular_Patch_Microstrip_Antenna_Dimension_Using_Machine_Learning

- Jankowski-Mihułowicz, P., & Bednarczyk, M. (2020). Designing a compact microstrip antenna using the machine learning approach. Journal of Telecommunications and Information Technology, 3, 45-51. Retrieved from https://www.jtit.pl/jtit/article/view/527

- Kumar, A., & Singh, G. (2021). Efficient modelling of compact microstrip antenna using machine learning. AEU - International Journal of Electronics and Communications, 131, 153612. Retrieved from https://www.sciencedirect.com/science/article/pii/S1434841121001369
- El Misilmani, H. M., & Naous, T. (2019). Machine Learning in Antenna Design: An Overview on Machine Learning Concept and Algorithms. 2019 International Conference on High Performance Computing & Simulation (HPCS).

THANK YOU