# SRM VALLIAMMAI ENGINEERING COLLEGE

(An Autonomous Institution)
SRM Nagar, Kattankulathur –603203

## Department of Electronics and Communication Engineering

## 1906810-PROJECT WORK-PHASE II

# OPTIMIZATION OF PLANAR ANTENNAS USING MACHINE LEARNING

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B.E ECE-IV Year/VIII Semester

# PRESENTATION OUTLINE

- Introduction
- Literature Review
  * Summary of Literature Review
- Problem Statement
- Objectives
- Methodology
- Designs and Results
- ML Implementation
- Applications
- Conclusion
- Work Plan
- References

# SUSTAINABLE DEVELOPMENT GOALS

**SDG NO** : 9

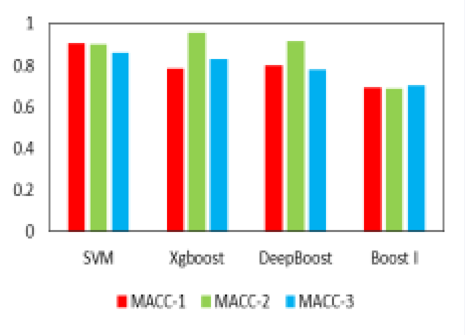
**Title** : Industry, Innovation and Infrastructure

**Justification**: Optimizing planar antennas using machine learning enhances wireless communication efficiency , supporting advancements in 5G , IOT and satellite systems .This fosters innovation ,strengthens digital infrastructure and accelerates industrial growth.

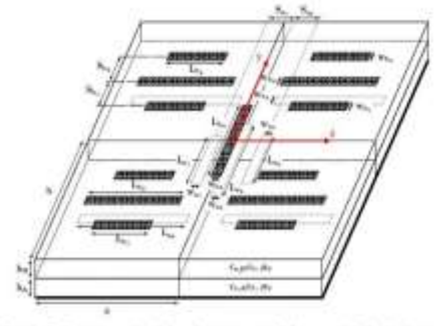
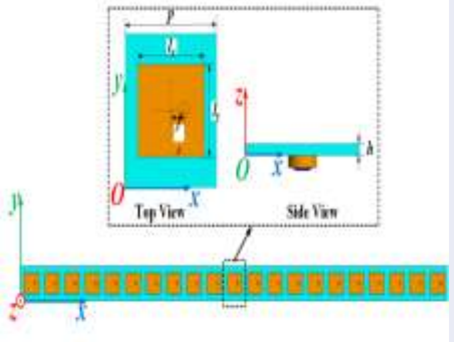
# INTRODUCTION

- It is widely used in modern communication systems due to their compact size, lightweight structure, and ease of fabrication.
- However, optimizing their performance parameters like gain, bandwidth, and efficiency is challenging due to complex design constraints.
- Machine learning offers a powerful approach to optimize planar antennas by predicting performance metrics, reducing simulation time, and improving design accuracy.
- ML models can learn from previous simulations and optimize antenna parameters effectively.
- Integrating ML with antenna design can significantly enhance the development of high-performance antennas for applications in 5G, Multiband Antennas and satellite communications.

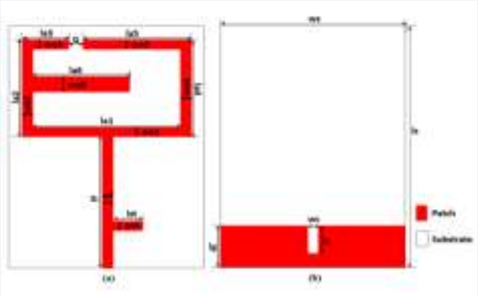
# LITERATURE REVIEW

| S.No. | Paper details | Contribution by author | Inference | Structure |
|---|---|---|---|---|
| 1. | Christodoulou, C., Rohwer, J. and Abdallah, C., "The use of machine learning in smart antennas". IEEE Antennas and Propagation Society Symposium, 2004. | • Application of ML in Smart Antennas<br>• Development of LS-SVM for DOA<br>• Adaptation to Environmental Changes<br>• Real-time Problem Solving | • Increased Fault Tolerance<br>• Enhanced DOA Estimation<br>• Real-time Optimization<br>• Advancement in Smart Antenna Technology<br>• Broader Applicability |  |
| 2. | T. Turki, "An empirical study of machine learning algorithms for cancer identification," IEEE 15th International Conference on Networking, Sensing and Control (ICNSC), pp.1-5,2018. | • Application of Machine Learning Algorithms<br>• Performance Evaluation<br>• Data-Driven Insights | • Improved estimation<br>• Application in design<br>• Resource optimization |  |

# LITERATURE REVIEW

| S.No. | Paper details | Contribution by author | Inference | Structure |
|---|---|---|---|---|
| 3. | D. R. Prado, J. A. Lopez-Fern ´ andez, M. Arrebola and G. Goussetis, ´ “Efficient Shaped-Beam Reflectarray Design Using Machine Learning Techniques,” 15th European Radar Conference (EuRAD), pp. 525– 528, Madrid, 2018. | • Application of SVMs in Reflect array Design<br>• Acceleration of Design Process<br>• Modeling of Reflection Coefficient Matrix<br>• Discretization of Angle of Incidence<br>• Mitigation of Overfitting | • Substantial Improvement in Efficiency<br>• Reduction in Design Time<br>• Enhanced Design Accuracy<br>• Potential for Broader Application<br>• Improvement in Cost-Effectiveness |  Fig. 1. Reflectarray unit cell based on two sets of four parallel dipoles in two different layers |
| 4. | Gan, L., Jiang, W., Chen, Q., Li, X., Zhou, Z. and Gong, S., "Method to Estimate Antenna Mode Radar Cross Section of Large-Scale Array Antennas". IEEE Transactions on Antennas and Propagation, 69(10), pp.7029-7034, 2021. | • New Estimation Method<br>• Improvement of SPMM<br>• Efficiency<br>• Accuracy<br>• Validation | • Improved estimation<br>• Application in design<br>• Resource optimization |  |

# LITERATURE REVIEW

| S.No. | Paper details | Contribution by author | Inference | Structure |
|---|---|---|---|---|
| 5. | Mohammad Reza Ghaderi and Nasrin Am, "Application of Machine Learning Techniques in Phased Array Antenna" Synthesis: A Comprehensive Mini Review, Journal of Communications, vol. 18, no. 10, October *2023* | • Identification of Key ML Techniques<br>• Insight into Practical Applications<br>• Highlighting Challenges and Future Directions<br>• Comparison with Conventional Methods | • Efficiency of ML in PAA Design<br>• Adaptability of ML<br>• Insight into Practical Applications<br>• Highlighting Challenges and Future Directions |  |
| 6. | Mohamedi. waly, Mohsen Bakouri, Jamel Smida , Bakheet Awad Alresheedi, Tariq Mohammed Alqahtani, Khalid a. Alonzi, and amor Smida "Optimization of a Compact Wearable LoRa Patch Antenna for Vital Sign Monitoring in WBAN Medical Applications Using Machine Learning" , vol 12,June 2024 | • Design of a Compact Wearable Antenna<br>• Application of Machine Learning<br>• Focus on Medical Applications<br>• Performance Evaluation | • Effectiveness of Machine Learning<br>• Enhanced Medical Monitoring |  |

# SUMMARY OF LITERATURE REVIEW

**Advancements in Antenna Technology**:

- Enhanced performance through machine learning.
- Innovative design solutions improve bandwidth, reduce costs, and maintain compactness.

**Machine Learning aspects:**

- Successful use of SVMs in antenna design and cancer identification.
- Significant improvements in efficiency, accuracy, and cost-effectiveness.

**Broader Implications**:

- Potential for broader applications in engineering and healthcare.
- Emphasis on the need for larger datasets for improved prediction accuracy in ML-driven antenna design.

# PROBLEM STATEMENT

Several Challenges that need to be addressed.

- Limited availability of quality data for training.
- complexity of integrating antenna design with machine learning techniques.
- High computational cost
- Difficulty in interpreting the results generated by machine learning models.

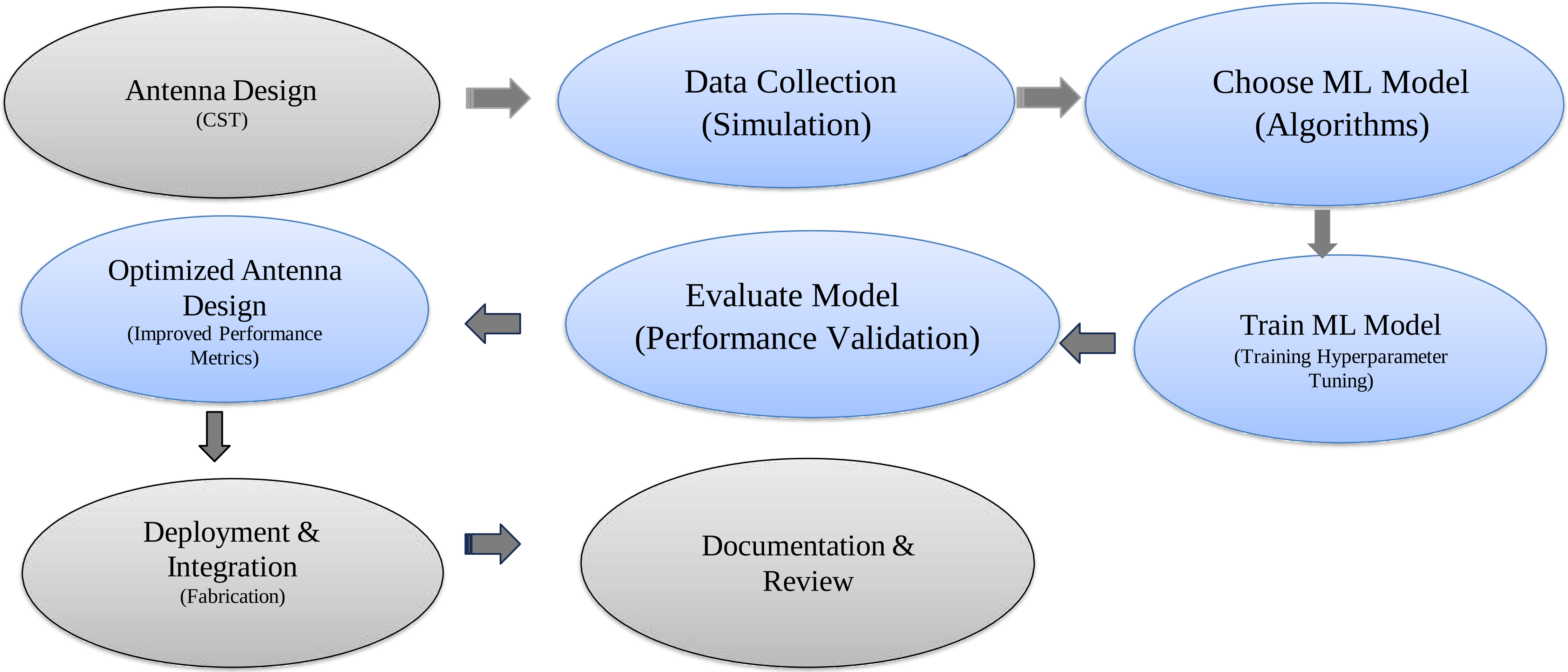
Here are some ways to improve the process of antenna optimization using machine learning algorithms

- Data Augmentation
- Feature engineering
- Ensemble Methods

# OBJECTIVES

- Optimize planar antennas using machine learning to enhance performance based on specific criteria.
- Identifies optimal design parameters to improve performance.
- Accelerates design process with high accuracy and minimal error.
- Reduces reliance on extensive simulations.
- Automates design exploration and predicts outcomes.
- Guides the process toward optimal solutions efficiently.
- Results in faster, more innovative antenna designs meeting desired specifications.

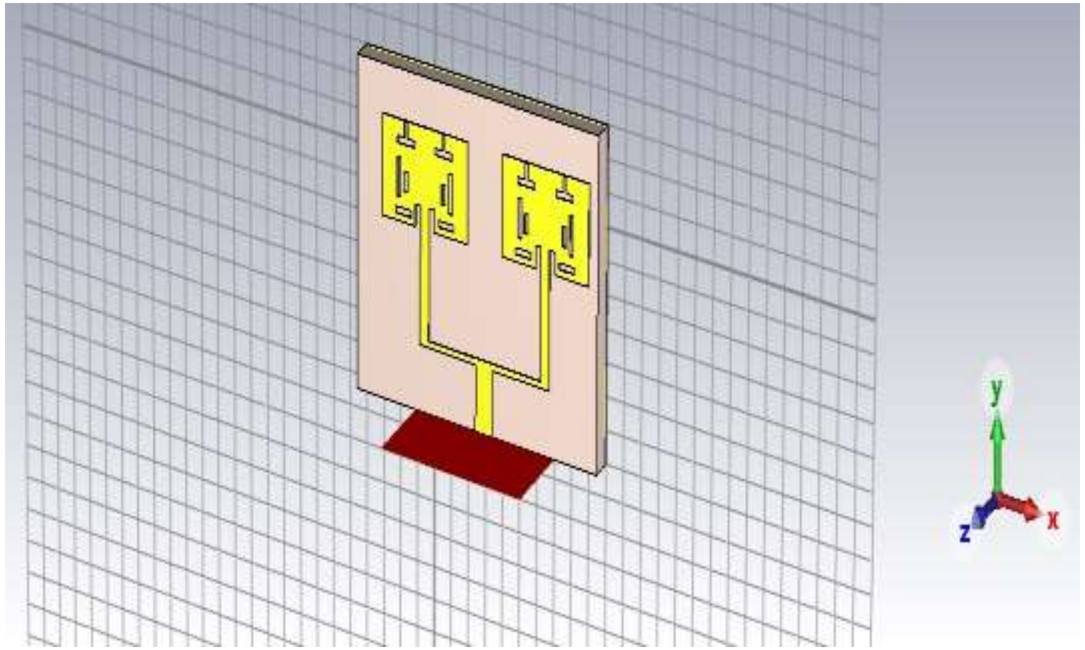
# METHODOLOGY



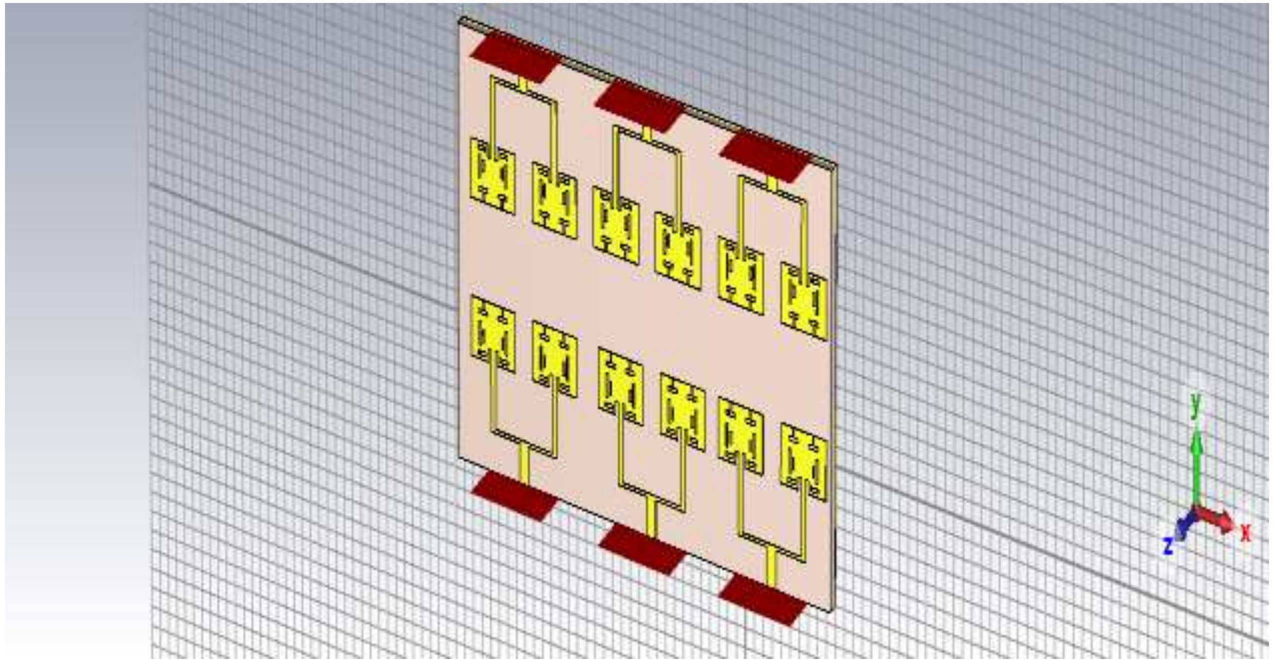
# PROPOSED SYSTEM

- Integrates machine learning (ML) techniques to optimize the design and performance of MIMO antennas used in 5G mm Wave applications.
- Machine learning algorithms like Random Forest, K-Nearest Neighbors (KNN), and Support Vector Machines (SVM) are used to identify patterns in the data, optimize antenna parameters, and make predictions for antenna performance under different conditions.
- This data-driven approach provides faster and more accurate optimization, improving the overall efficiency of the antenna design process.

# ANTENNA DESIGN

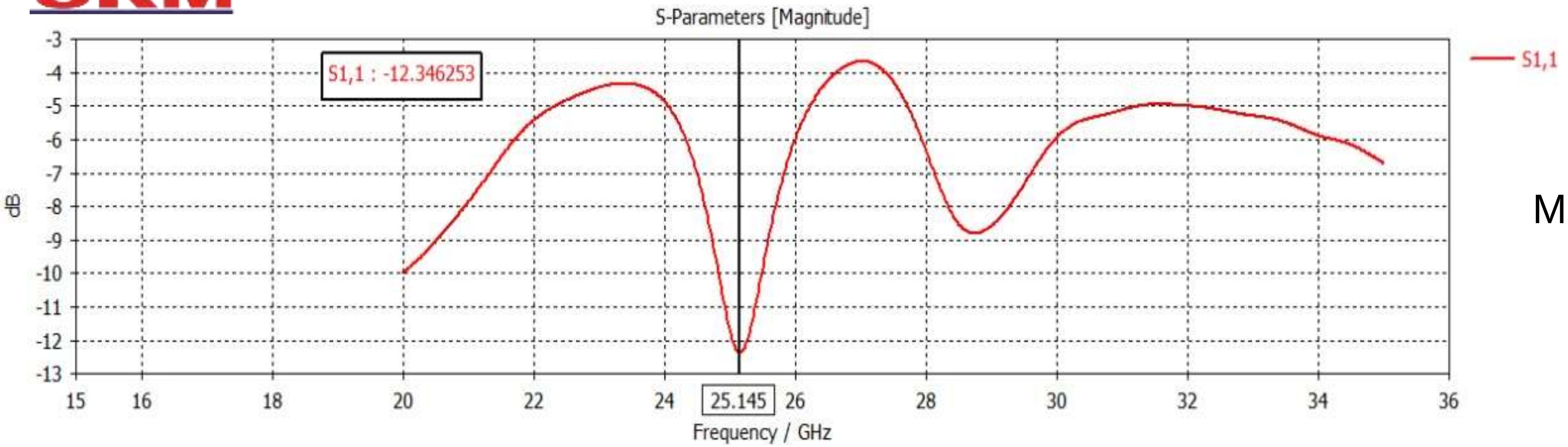



1(a) ARRAY

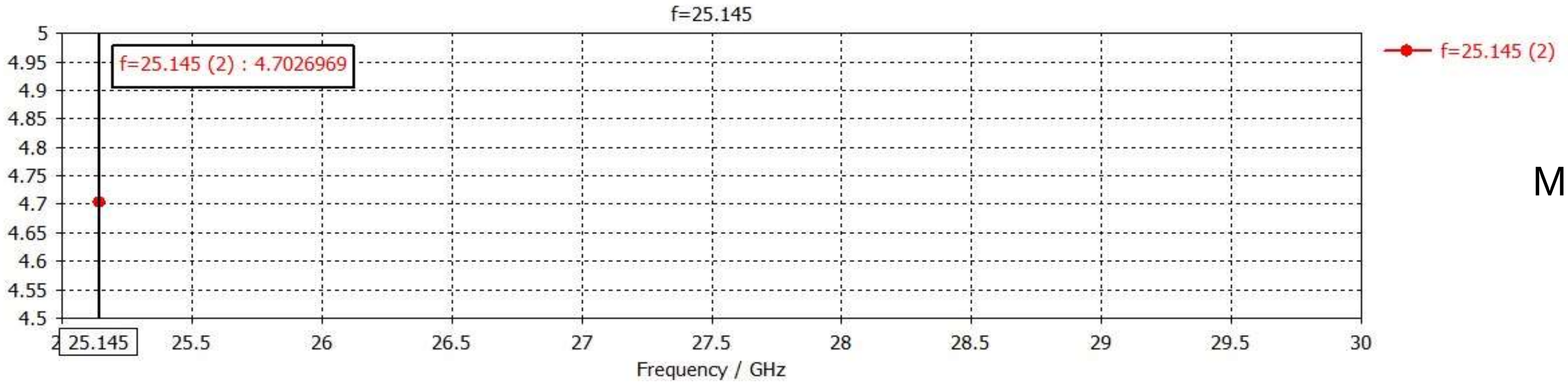



1(b) MIMO

# RESULT

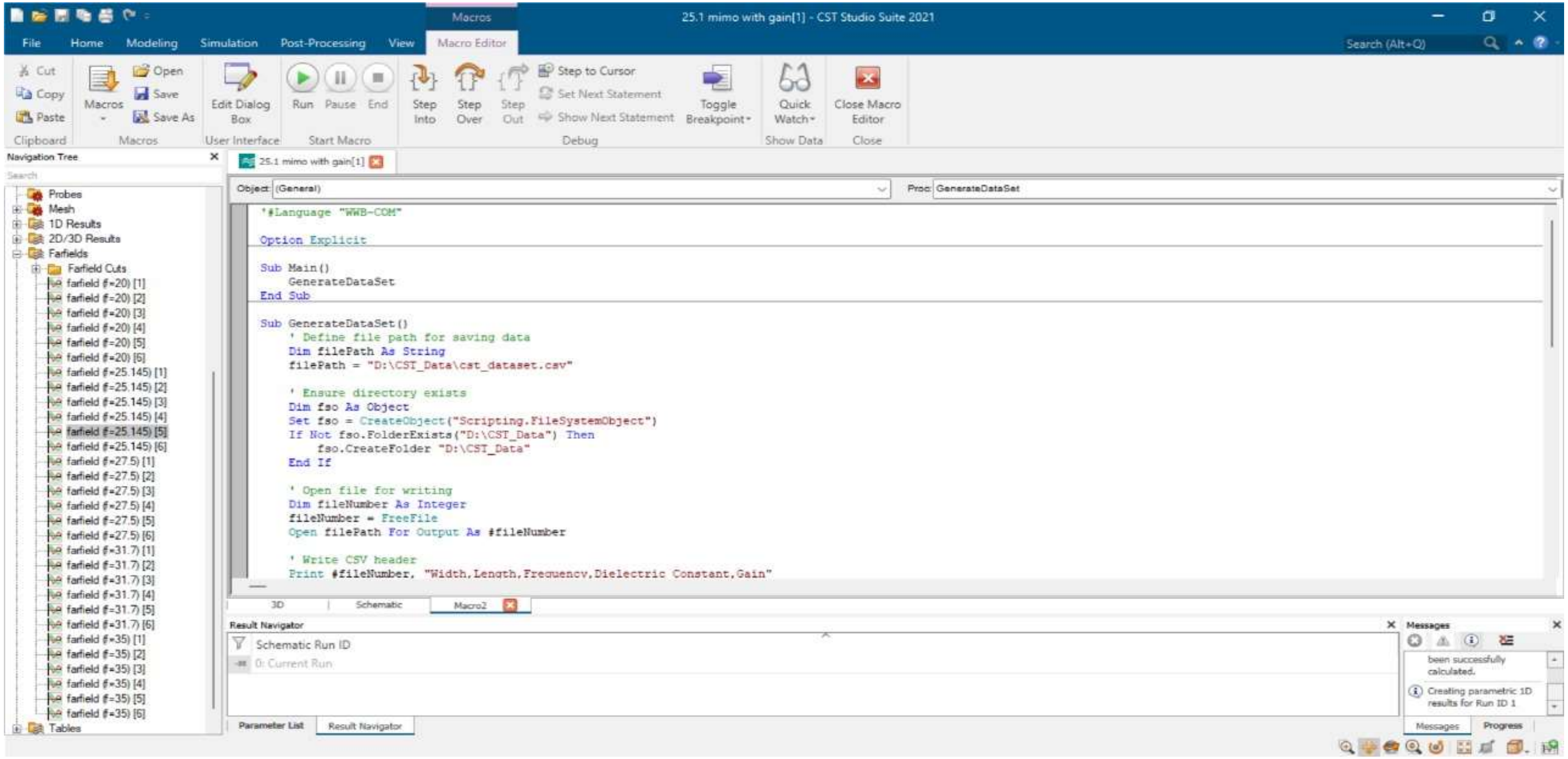



MIMO S-PARAMETER

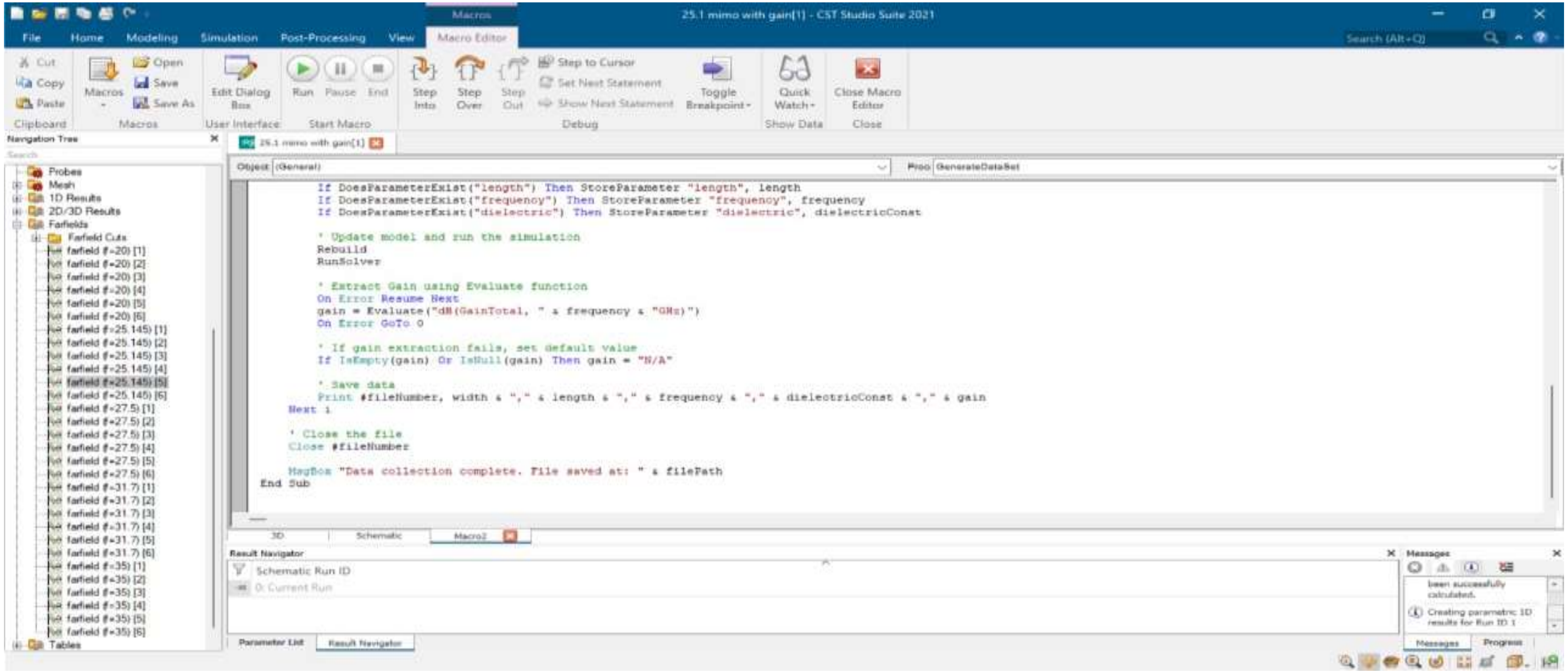



MIMO GAIN

# SCRIPT


25.1 mimo with gain[1] - CST Studio Suite 2021
Object: (General)
Proc: GenerateDataSet
'#Language "WWB-COM"
Option Explicit
Sub Main()
GenerateDataSet
End Sub
Sub GenerateDataSet()
' Define file path for saving data
Dim filePath As String
filePath = "D:\CST_Data\cst_dataset.csv"
' Ensure directory exists
Dim fso As Object
Set fso = CreateObject("Scripting.FileSystemObject")
If Not fso.FolderExists("D:\CST_Data") Then
fso.CreateFolder "D:\CST_Data"
End If
' Open file for writing
Dim fileNumber As Integer
fileNumber = FreeFile
Open filePath For Output As #fileNumber
' Write CSV header
Print #fileNumber, "Width,Length,Frequency,Dielectric Constant,Gain"

# SCRIPT


25.1 mimo with gain[1] - CST Studio Suite 2021
If DoesParameterExist("length") Then StoreParameter "length", length
If DoesParameterExist("frequency") Then StoreParameter "frequency", frequency
If DoesParameterExist("dielectric") Then StoreParameter "dielectric", dielectricConst
' Update model and run the simulation
Rebuild
RunSolver
' Extract Gain using Evaluate function
On Error Resume Next
gain = Evaluate("dB(GainTotal, " & frequency & "GHz)")
On Error GoTo 0
' If gain extraction fails, set default value
If IsEmpty(gain) Or IsNull(gain) Then gain = "N/A"
' Save data
Print #fileNumber, width & "," & length & "," & frequency & "," & dielectricConst & "," & gain
Next i
' Close the file
Close #fileNumber
MsgBox "Data collection complete. File saved at: " & filePath
End Sub

# MACHINE LEARNING IMPLEMENTATION

```
import numpy as np
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn import metrics
from sklearn.metrics import mean_absolute_error
from xgboost import XGBRegressor,XGBModel
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.preprocessing import MinMaxScaler
from matplotlib import pyplot
import pandas as pd
import numpy as np
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import LabelEncoder, StandardScaler
from sklearn.impute import SimpleImputer
from sklearn.ensemble import RandomForestRegressor
from sklearn.neighbors import KNeighborsRegressor
from sklearn.svm import SVR
from sklearn.metrics import mean_absolute_error, mean_squared_error, r2_score


import warnings
warnings.filterwarnings("ignore")
```

# MACHINE LEARNING IMPLEMENTATION

```
dataframe=pd.read_csv("synthetic_antenna_data.csv")

print("--------------------------------------------")
print()
print("Data Selection")
print("Samples of our input data")
print(dataframe.head(5))
print("--------------------------------------------")
print()

dataframe.describe()
```

```
#checking  missing values
print("--------------------------------------------")
print()
print("Before Handling Missing Values")
print()
print(dataframe.isnull().sum())
print("--------------------------------------------")
print()

print("--------------------------------------------")
print("After handling missing values")
print()
dataframe_2=dataframe.fillna(0)
print(dataframe_2.isnull().sum())
print()
print("--------------------------------------------")
```

## MACHINE LEARNING IMPLEMENTATION

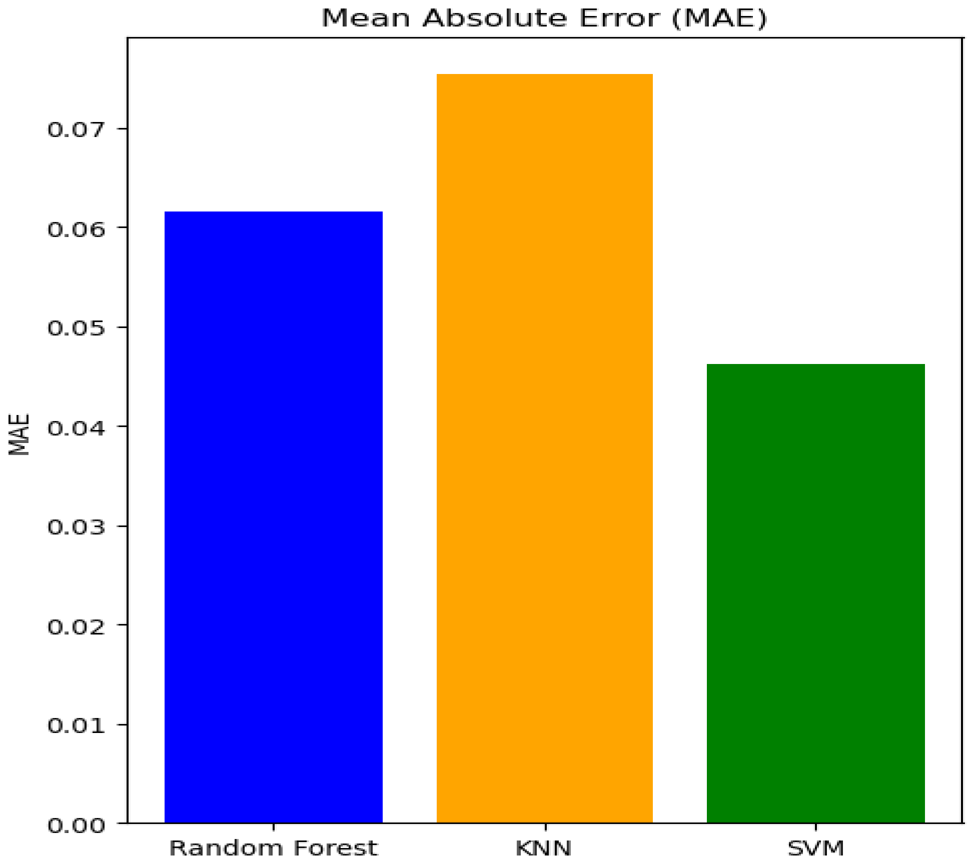
```python
# Step 3: Split the dataset into features (X) and target (y)
x = df.drop('predicted_gain', axis=1)  # Features: All columns except 'gain'
y = df['predicted_gain']  # Target: The antenna gain

# Split data into training and testing sets (80% train, 20% test)
X_train, X_test, y_train, y_test = train_test_split(x, y, test_size=0.2, random_state=42)


# # Step 4: Feature Scaling (Optional)
scaler = StandardScaler()
X_train = scaler.fit_transform(X_train)
X_test = scaler.transform(X_test)

# Step 5: Regression Models

# 1. Random Forest Regression
rf_model = RandomForestRegressor(n_estimators=100, random_state=42)
rf_model.fit(X_train, y_train)
y_pred_rf = rf_model.predict(X_test)

# 2. K-Nearest Neighbors (KNN) Regression
knn_model = KNeighborsRegressor(n_neighbors=5)
knn_model.fit(X_train, y_train)
y_pred_knn = knn_model.predict(X_test)

# 3. Support Vector Machine (SVM) Regression
svm_model = SVR(kernel='linear')
svm_model.fit(X_train, y_train)
y_pred_svm = svm_model.predict(X_test)
```

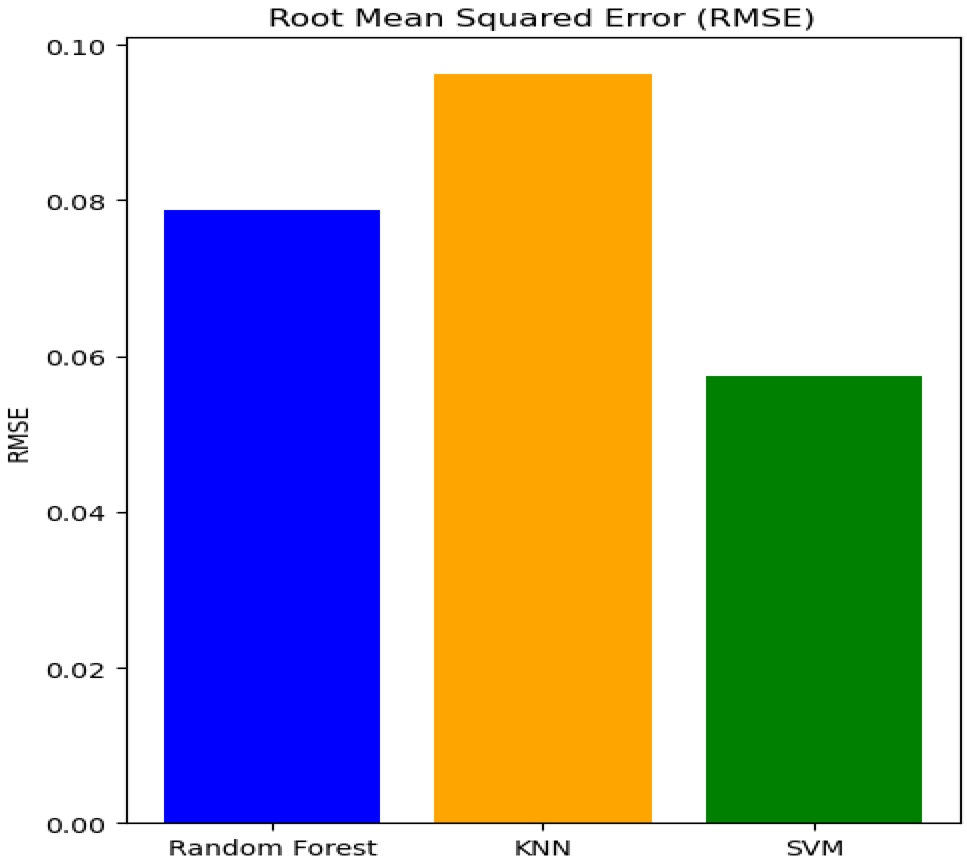
# MACHINE LEARNING IMPLEMENTATION

```python
# Function to evaluate performance metrics for regression models
def regression_performance_metrics(y_true, y_pred):
    mae = mean_absolute_error(y_true, y_pred)
    rmse = mean_squared_error(y_true, y_pred, squared=False)  # RMSE = sqrt(MSE)
    r2 = r2_score(y_true, y_pred)
    print(f"MAE (Mean Absolute Error): {mae:.4f}")
    print(f"RMSE (Root Mean Squared Error): {rmse:.4f}")
    print(f"R² (R-squared): {r2:.4f}")

    # Additional regression performance metrics
    print(f"Train Accuracy (R² on training data): {r2_score(y_train, rf_model.predict(X_train)):.4f}")
    print(f"Test Accuracy (R² on test data): {r2:.4f}")
```

```
Random Forest Regression Performance:
MAE (Mean Absolute Error): 0.0615
RMSE (Root Mean Squared Error): 0.0787
R² (R-squared): 0.8971
Train Accuracy (R² on training data): 0.9834
Test Accuracy (R² on test data): 0.8971

KNN Regression Performance:
MAE (Mean Absolute Error): 0.0754
RMSE (Root Mean Squared Error): 0.0961
R² (R-squared): 0.8464
Train Accuracy (R² on training data): 0.9834
Test Accuracy (R² on test data): 0.8464

SVM Regression Performance:
MAE (Mean Absolute Error): 0.0462
RMSE (Root Mean Squared Error): 0.0574
R² (R-squared): 0.9453
Train Accuracy (R² on training data): 0.9834
Test Accuracy (R² on test data): 0.9453
```

# MACHINE LEARNING IMPLEMENTATION



# MACHINE LEARNING IMPLEMENTATION

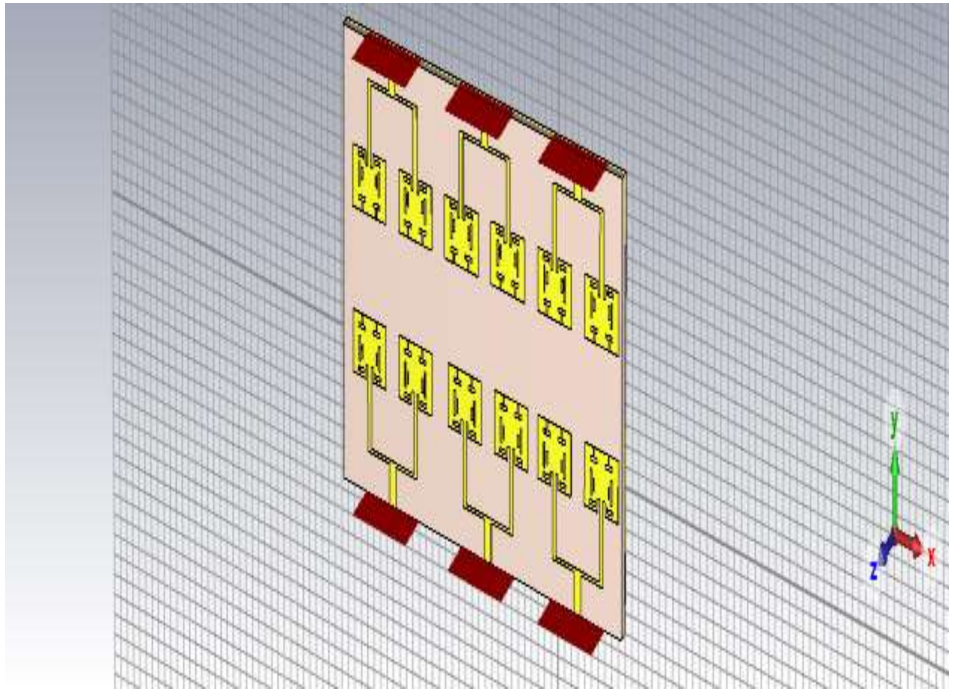
```
def calculate_snr(y_true, y_pred):
    noise = np.subtract(y_true, y_pred)  # Residuals (errors)
    signal = np.mean(y_true)  # Signal is the mean of the true values
    snr = signal / np.std(noise)  # SNR = Signal/Noise
    print(f"SNR (Signal-to-Noise Ratio): {snr:.4f}")
```

```
Random Forest SNR:
SNR (Signal-to-Noise Ratio): 55.4268

KNN SNR:
SNR (Signal-to-Noise Ratio): 46.0946

SVM SNR:
SNR (Signal-to-Noise Ratio): 76.2476
```

# MACHINE LEARNING IMPLEMENTATION

```python
import pandas as pd
import joblib

# Load the pre-trained pipeline (which includes both StandardScaler and SVR)
svm_pipeline = joblib.load("C:\\Users\\rogin\\OneDrive\\Desktop\\Project_27.02.2025\\Sourcecode\\svm_model.pkl")  # Ensure this is your pipeline file

# Load the dataset from CSV (make sure it has the same features as used during training)
df = pd.read_csv("synthetic_antenna_data.csv")  # Replace with your actual file name

# Drop the 'predicted_gain' column if it exists to avoid conflicts
if 'predicted_gain' in df.columns:
    df = df.drop(columns=['predicted_gain'])

# Convert DataFrame to NumPy array to avoid feature names warning
X = df.values

# Predict the gain using the loaded pipeline (the scaler step is applied internally)
predicted_gain = svm_pipeline.predict(X)

# Add the predicted gain back to the DataFrame
df['predicted_gain_new'] = predicted_gain

# Save the results to a new CSV file
df.to_csv("final_svm_gain.csv", index=False)

# Display the first row of the DataFrame
print(df.head(1))
```

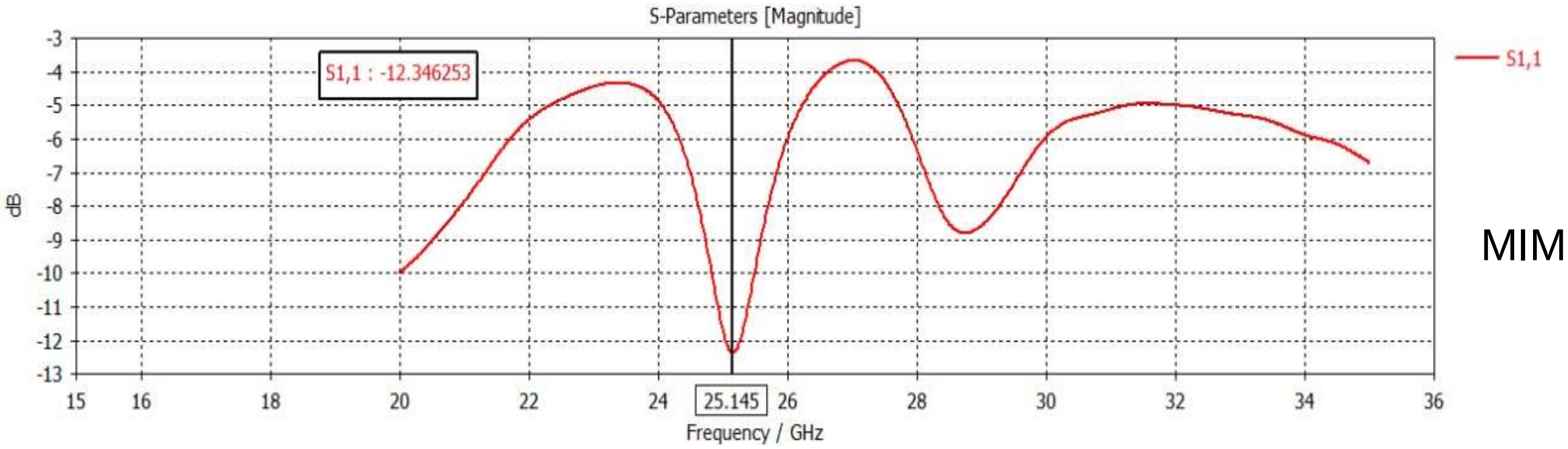
# DESIGN AND DIMENSIONS OF THE ANTENNA



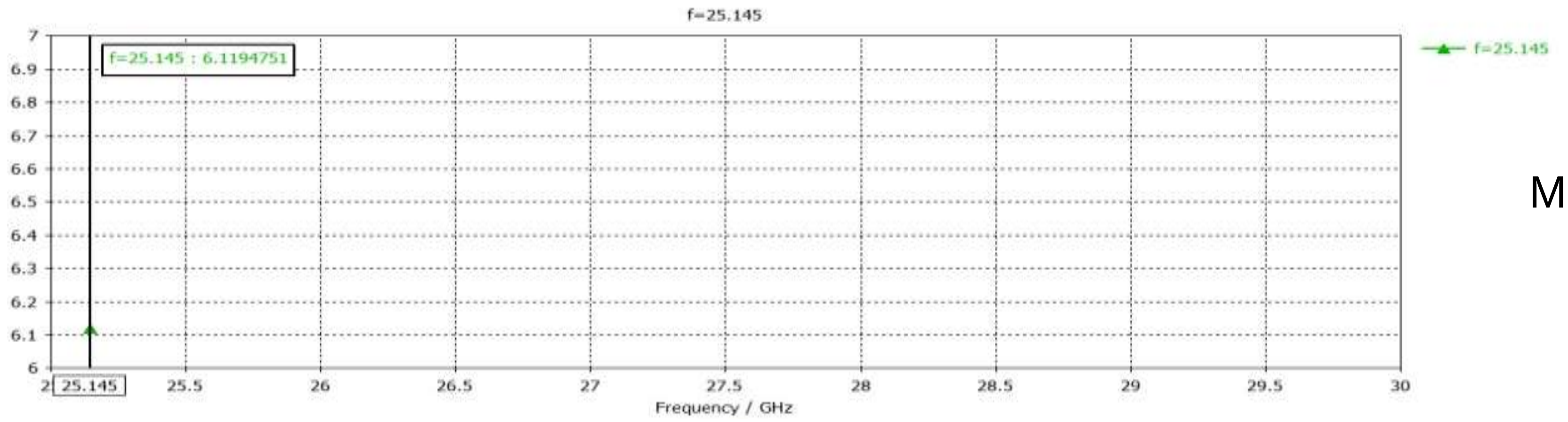

MIMO DESIGN

| SPECIFICATION | DIMENSIONS(mm) |
|---|---|
| Length X Width of Substrate | 3.025 X 5 |
| Thickness of the Substrate | 0.035 |
| Length X Width of Ground | 5.5 X 6 |
| Substrate material | FR-4(Lossy) |
| Ground material | copper |

# RESULT




MIMO S- PARAMETER




MIMO GAIN

# COMPARISON

| PARAMETERS | MICROSTRIP ANTENNA | MIMO ANTENNA PAPER 1 | MIMO ANTENNA PAPER 2 | OUR MIMO ANTENNA |
|---|---|---|---|---|
| BANDWIDTH | 0.658 GHz | 0.578 GHz | 0.548 GHz | 0.693 GHz |
| FREQUENCY RANGE | 21 to 30 GHz | 21 to 30 GHz | 21 to 30 GHz | 21 to 30 GHz |
| RESONANT FREQUENCY | 25 GHz | 25 GHz | 25 GHz | 25.1 GHz |
| SUBSTRATE MATERIAL | Rogers RT5880 | Rogers RT5880 | Rogers RT5880 | FR-4 (Lossy) |
| THICKNESS OF SUBSTRATE | 0.030 mm | 0.034 mm | 0.027 mm | 0.035 mm |

# COMPARISON

| PARAMETERS | MICROSTRIP ANTENNA | MIMO ANTENNA PAPER 1 | MIMO ANTENNA PAPER 2 | OUR MIMO ANTENNA |
|---|---|---|---|---|
| VSWR | 1.02 | 1.27 | 1.01 | 1.63 |
| GAIN | 5.7 dB | 5.2 dB | 5.8 dB | 6.1 dB |
| NUMBER OF DATASETS | 150 | 200 | 250 | 500 |
| ALGORITHMS USED | Polynomial regression | Decision tree regression, XGB regression, Nonparametric regression | Decision tree regression, XGB regression, Random forest regression | Random forest regression , KNN regression, SVM regression |

# APPLICATIONS

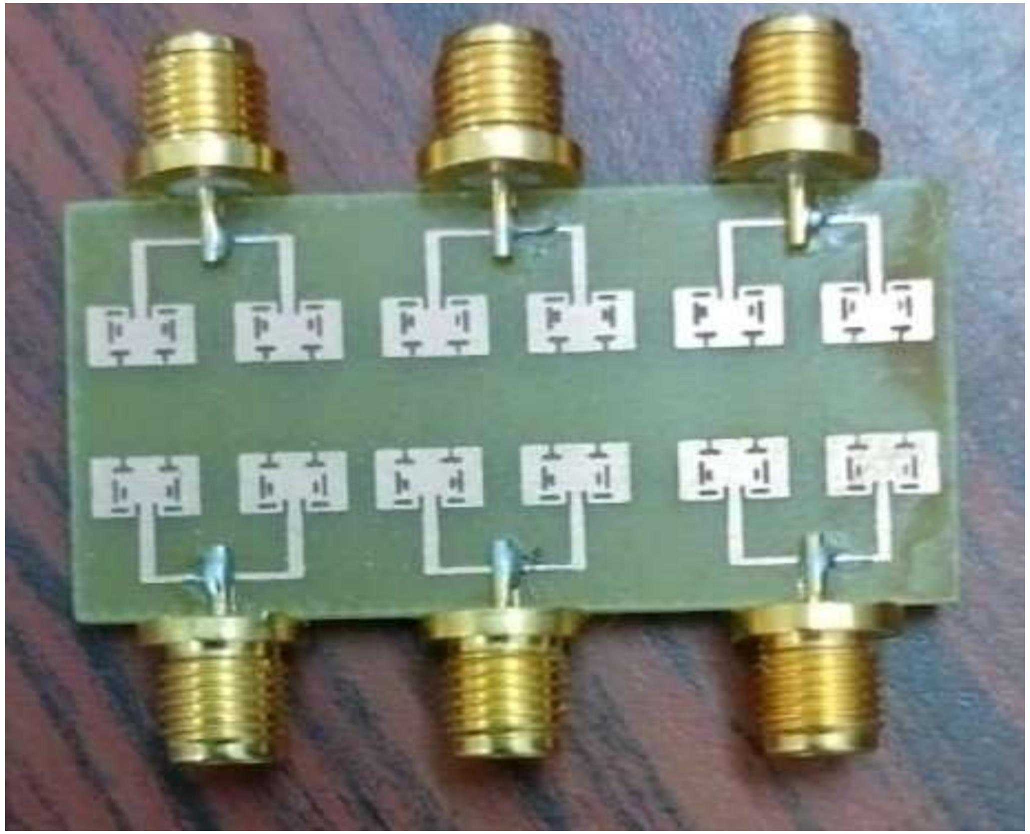
- Antenna Design Optimization
  - ➢ Miniaturization
  - ➢ Multiband Antennas
  - ➢ Pattern Synthesis
- Adaptive Beamforming
- Military surveillance radar and airborne radars.
- Remote Sensing and Space Applications
- They support multiple-input multiple-output (MIMO) systems, which enhance data rates and signal reliability.
- Drones and UAVs use patch antenna arrays for long-range communication and navigation.
- Patch antennas are utilized in wireless body area networks (WBAN).

# CONCLUSION

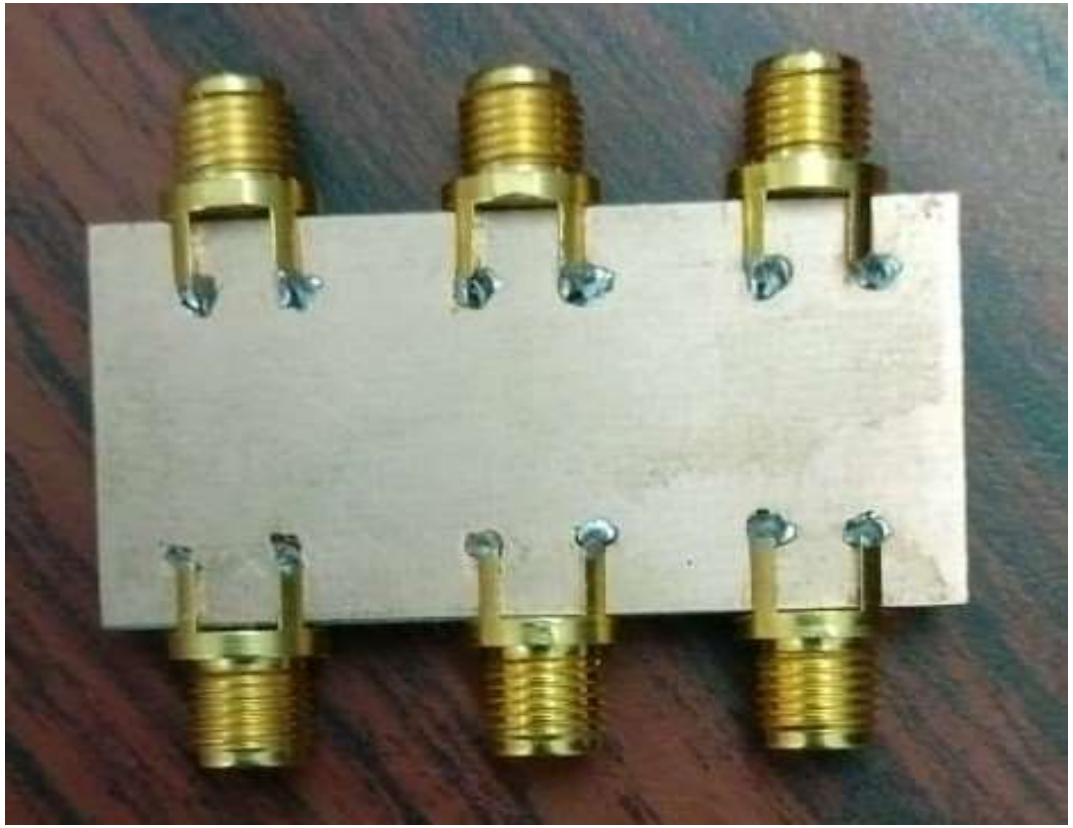
- Enhanced performance metrics: gain, bandwidth, radiation patterns.
- ML techniques reduce design time and computational resources.
- Adaptable to various design constraints and objectives.
- Enables exploration of innovative and unconventional antenna designs.
- Improve model accuracy and explore sophisticated algorithms.
- Integrate ML with other optimization techniques for further advancements performance.

| | |
|---|---|
| S Parameter (dB) | 25.1 |
| VSWR | 1.63 |
| Bandwidth (GHz) | 0.693 |
| Gain without ML Optimization (dB) | 4.7 |
| Gain with ML Optimization (dB) | 6.1 |
| ML Accuracy (%) | 98 |

# FABRICATION OF ANTENNA



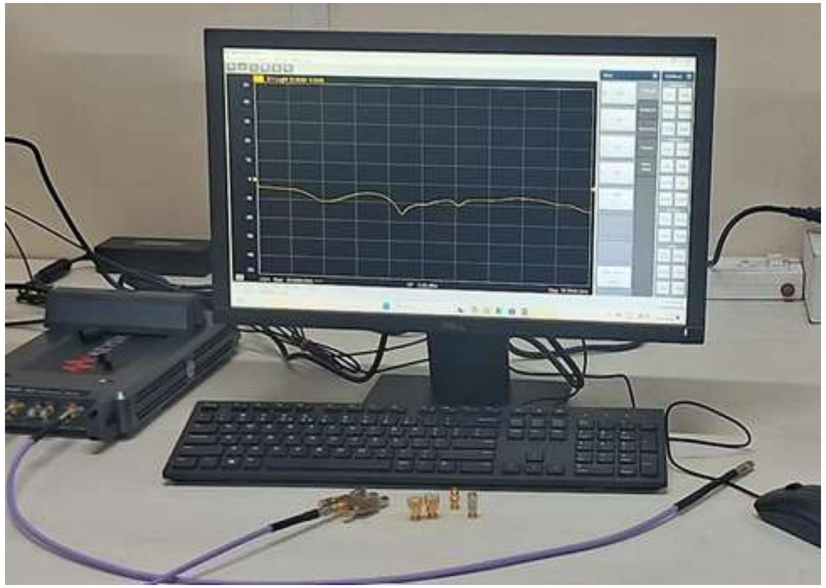
FRONT VIEW

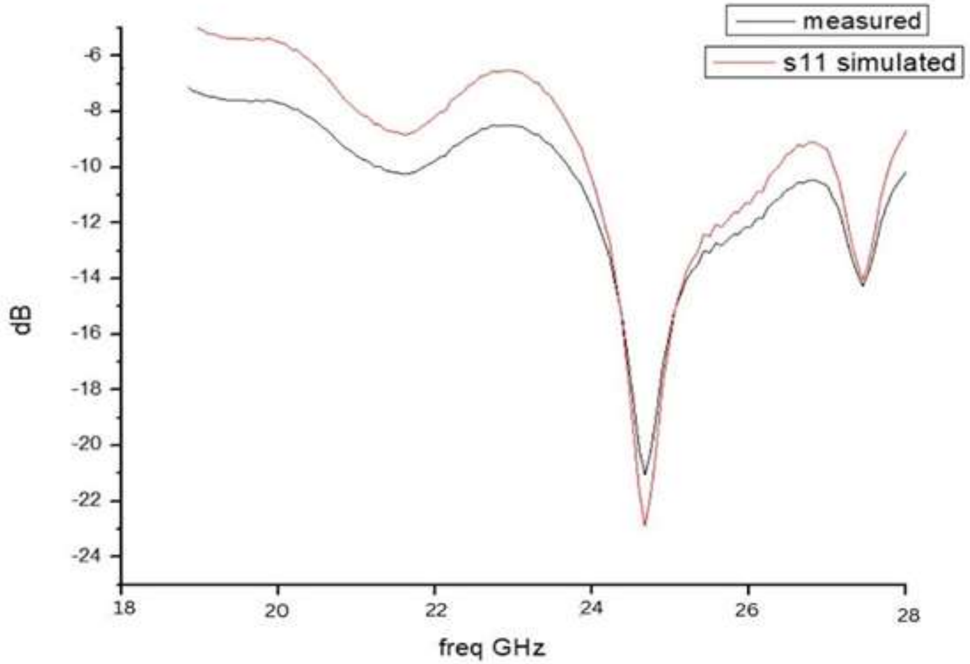


BACK VIEW

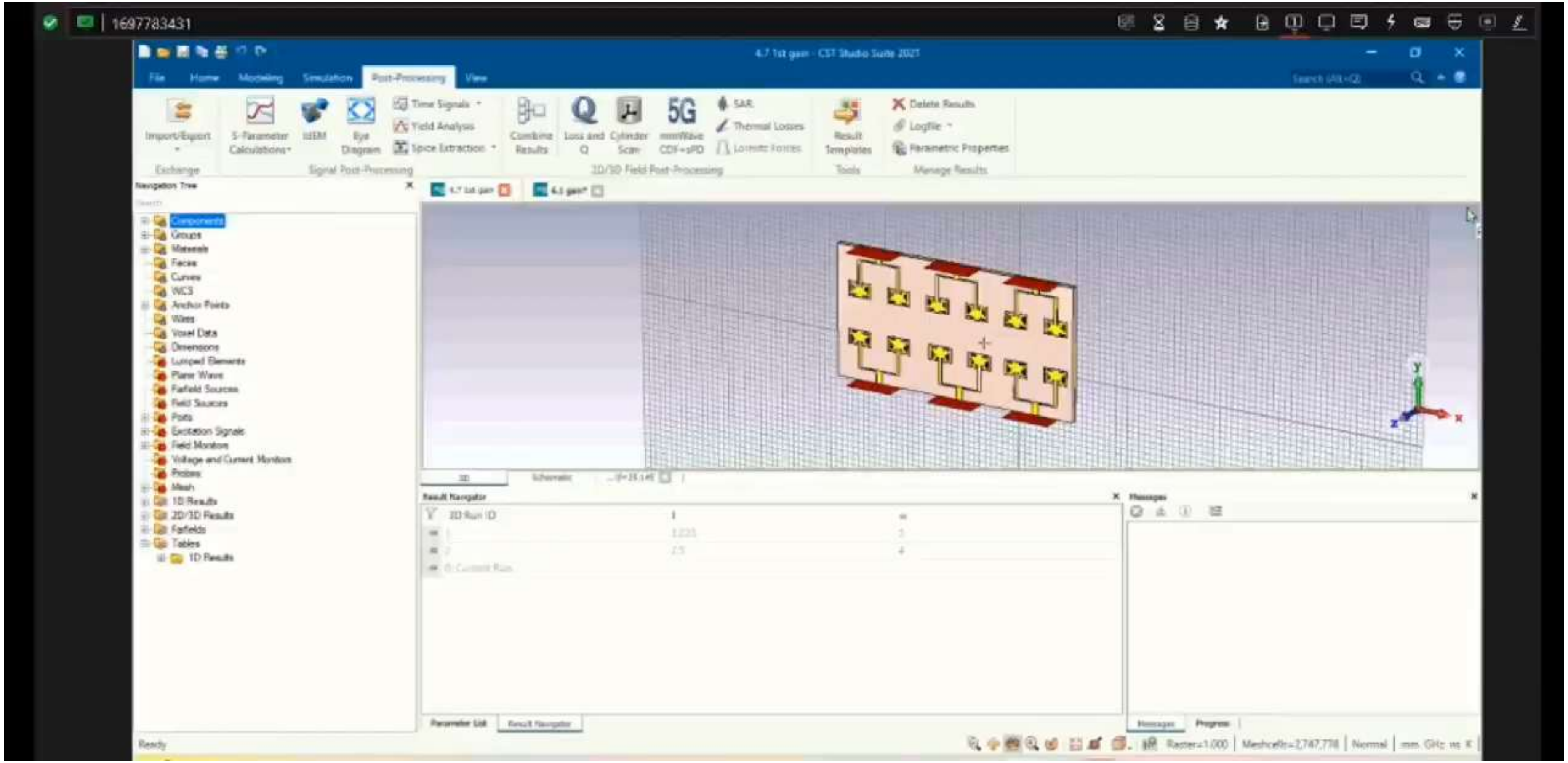
# TESTING OF ANTENNA

Once fabricated, the antenna undergoes testing to validate its performance against simulation data. Key parameters such as return loss (S11), gain, bandwidth are measured using Vector Network Analyzers (VNA).





# SIMULATION VIDEO



# WORK PLAN

| S.NO | Month | Work to be completed (2025) |
|---|---|---|
| 1 | January | Aim, Objectives, Literature Survey, Work Plan, References |
| 2 | February | High level Design of the Project, Simulation Output and ML Implementation and Presentation |
| 3 | March | Project demonstration, Publication, Project Report Submission, Project Work Plan Submission |

# REFERENCES


1. Xiaole, Y., Daning, N. and Wutu, W., “An Omnidirectional High-Gain Antenna Element for TD SCDMA Base Station. 7th International Symposium on Antennas, Propagation & EM Theory”. 2006.
2. Jingli Guo, Yanlin Zou and Chao Liu, "Compact Broadband Crescent Moon-Shape Patch-Pair Antenna. IEEE Antennas and Wireless Propagation".Letters 10, pp.435-437, 2011.
3. H. Liu, Y. Liu and S. Gong, “An ultra-wideband horizontally polarized omnidirectional connected vivaldi array antenna,”International Symposium on Antennas and Propagation (ISAP), 2016.
4. T. Turki, “An empirical study of machine learning algorithms for cancer identification,” IEEE 15th International Conference on Networking, Sensing and Control (ICNSC), 2018.
5. D. R. Prado, J. A. Lopez-Fern ́ andez, M. Arrebola and G. Goussetis, “Efficient Shaped-Beam Reflectarray Design Using Machine Learning Techniques,”15th European Radar Conference (EuRAD), pp. 525– 528, Madrid, 2018.

# REFERENCES


6. JIANG, X., JIAO, A., QIN, J. and JIANG, T.,"Detecting Faulty Elements in Antenna Array Using Extreme Learning Machine". 8th Asia-Pacific Conference on Antennas and Propagation (APCAP), 2019.
7. Antonio, M., Rosa, A., Marco, B., Pietro, B., Christian, C., Domenico, G. and Riccardo," A Machine Learning Based Fully Digital UWB Antenna for Direction Finding Systems".IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), 2021.
8. Mohammad Reza Ghaderi and Nasrin Am, "Application of Machine Learning Techniques in Phased Array Antenna' Synthesis: A Comprehensive Mini Review, *Journal of Communications "vol. 18, no. 10, October 2023.*
9. Mohammedi. waly, Mohsen Bakouri, Jamel Smida , Bakheet Awad Alresheedi, Tariq Malqahtani, Khalid a. Alonzi, and Amor Smida "Optimization of a Compact Wearable LoRa Patch Antenna for Vital Sign Monitoring in WBAN Medical Applications Using Machine Learning" , June 2024.

# PUBLICATION

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Thank You