Antenna Design Course

Electronics Research Institute (ERI)

Training Project Report:
Design and Veriﬁcation of mmWave Four-Element MIMO Antenna for 5G Systems

Ammar Yasser Mohamed

Student at Faculty of Engineering Helwan university

Supervisor: Dr.Hesham Mohamed

Contents

1. Abstract 3

2. Introduction 3

3. Designing the Single Antenna Structure 3

3.1 Designing the Structure .... Error! Bookmark not defined.

3.2 S-Parameter 3

3.3 Far%eld 2D and 3D 4

3.4 Total and Radiation E ciency 4

3.5 Gain 5

4. Designing the MIMO Antenna Structure 5

4.1 Structure 5

4.2 S-Parameters without Isolation Error! Bookmark not defined.

4.3 Surface Current without Isolation Error! Bookmark not defined.

4.4 S-Parameters with Isolation 6

4.5 Far Field for Each Antenna 7

4.6 Gain 8

4.7 Radiation E ciency 8

5. References 11

1. Abstract

This report presents the design and verification of a mmWave Four-Element MIMO Antenna for future 5G systems conducted during my training at the Electronics Research Institute (ERI). The project involved replicating a single antenna element design using CST software, analyzing its performance, and subsequently designing a MIMO configuration with detailed parameter extraction and analysis using MATLAB. This report covers the design process, simulation results, and performance metrics, demonstrating the potential of the antenna for 5G applications.

2. Introduction

The advent of 5G technology necessitates the development of advanced antenna systems capable of supporting high data rates, improved reliability, and low latency. This project focused on the design and verification of a mmWave Four-Element MIMO Antenna, crucial for meeting the stringent requirements of 5G networks. Utilizing CST for simulation and MATLAB for parameter analysis.

3. Designing the Single Antenna Structure

3.1 Designing the Structure

The first phase of the project involved replicating the single antenna structure as detailed in the provided research paper. Using CST, the antenna's physical parameters were meticulously modeled to ensure accuracy. The design parameters included substrate material, patch dimensions, and feed line configuration.

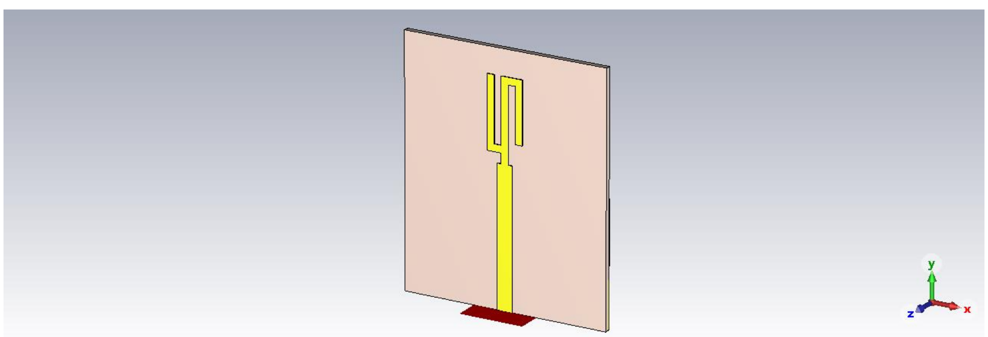

Figure 1:The structure design of single antenna

3.2 S-Parameter

The S-parameter analysis was conducted to evaluate the antenna's impedance matching and return loss. The simulation results were compared against the theoretical values to validate the design.

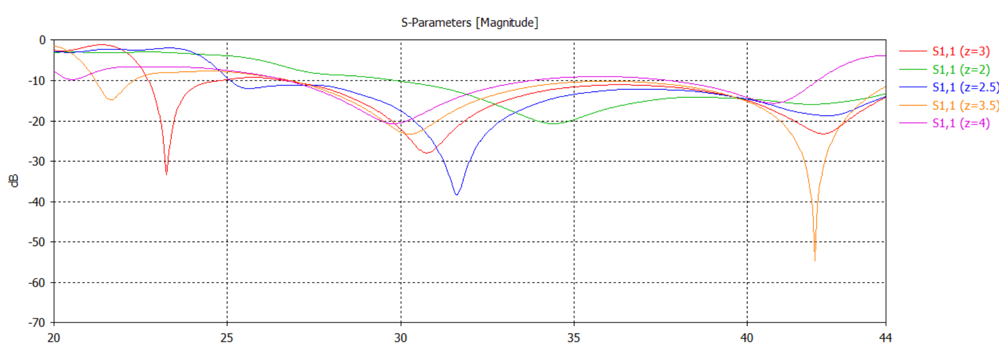

Figure 2: S-Parameter at d=7 for all Antennas

3.3 Far%eld 2D and 3D

Farfield analysis was performed to examine the radiation pattern of the antenna in both 2D and 3D. The results provided insights into the directional characteristics and beamwidth, which are critical for 5G applications.

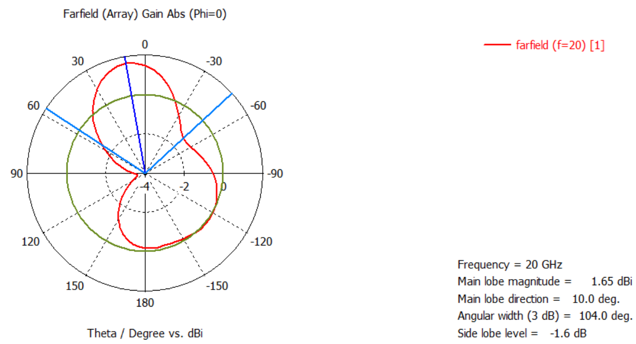

Figure 3: Farfield in 2D

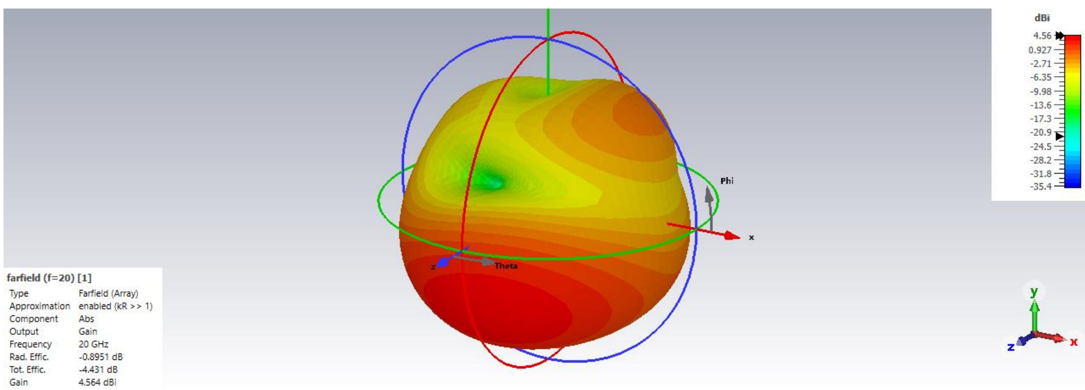

Figure 4: Farfield in 3D

3.4 Total and Radiation E ciency

The total and radiation efficiency of the antenna were assessed to determine the effectiveness of the antenna in converting input power into radiated power. These metrics are essential for understanding the antenna's performance in practical scenarios.

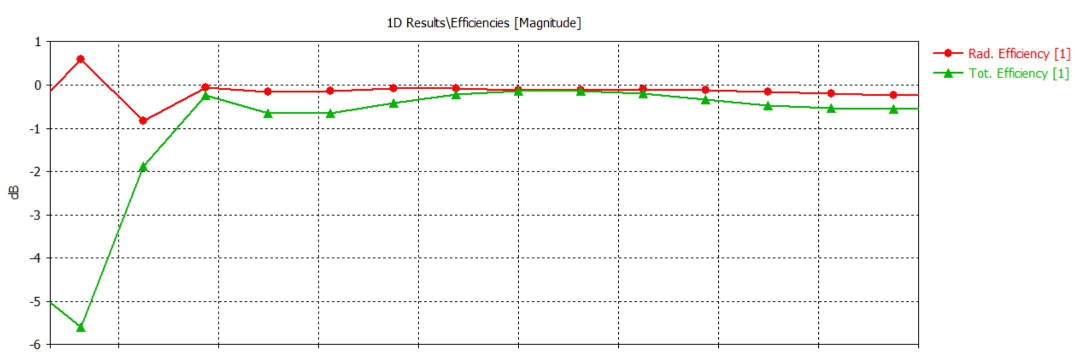

Figure 3: Antenna Efficiency graph

3.5 Gain

The antenna gain was measured to evaluate its ability to direct radiated power in a specific direction. High gain is desirable for long-range communication in 5G networks.

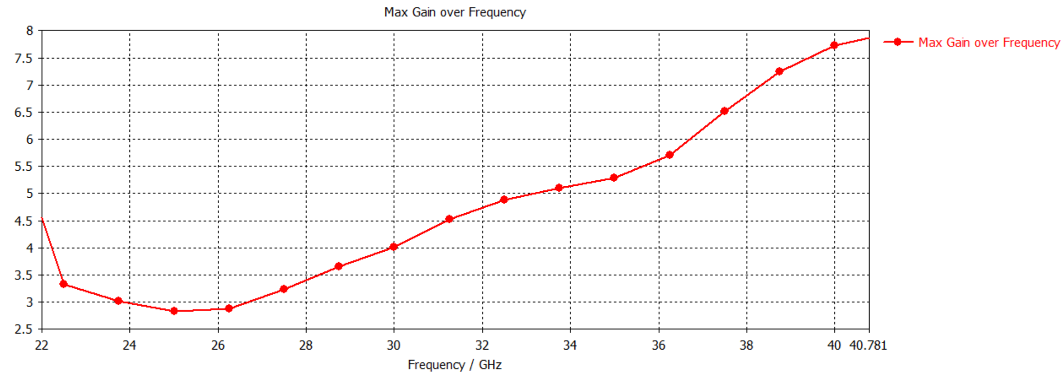

Figure 4: Single antenna gain

4. Designing the MIMO Antenna Structure

4.1 Structure

Building upon the single antenna design, a four-element MIMO configuration was developed. The spatial arrangement and mutual coupling effects were considered to optimize the performance of the MIMO system.

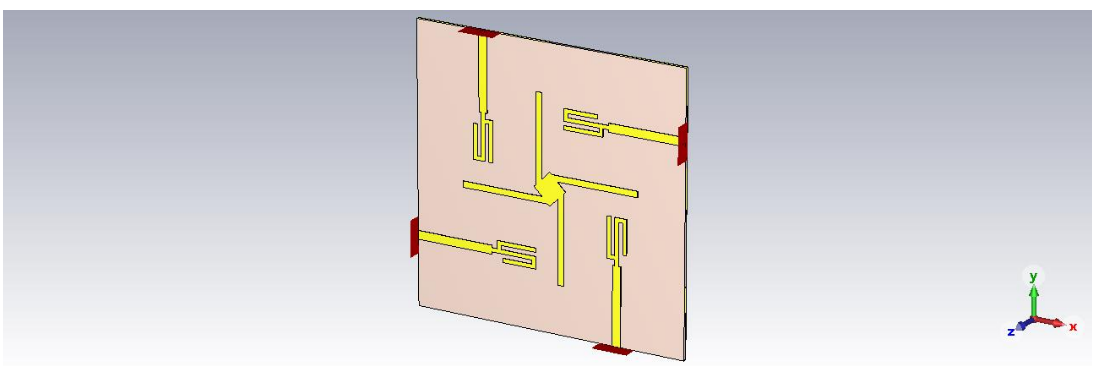

Figure 7: MIMO structure design

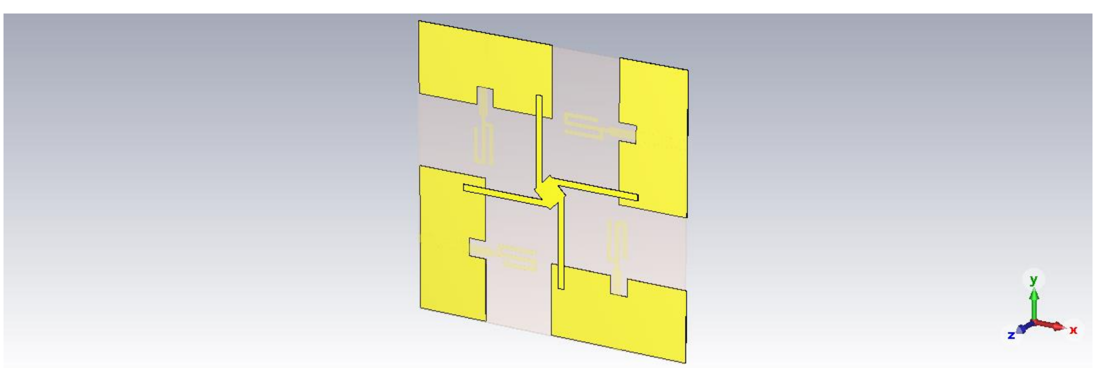

Figure 8: MIMO structure design (Ground and isolation network)

4.2 S-Parameters

Isolation techniques were applied to the MIMO antenna, and the S-parameters were re-evaluated. The effectiveness of these techniques in reducing mutual coupling was assessed.

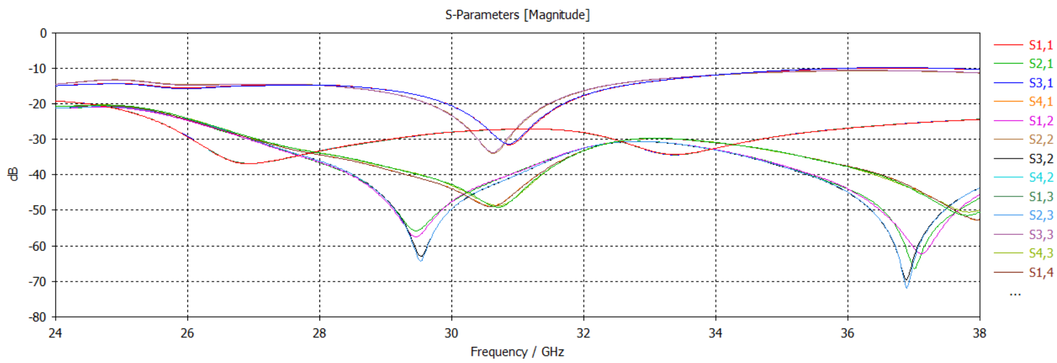

Figure 5: All S-parameters

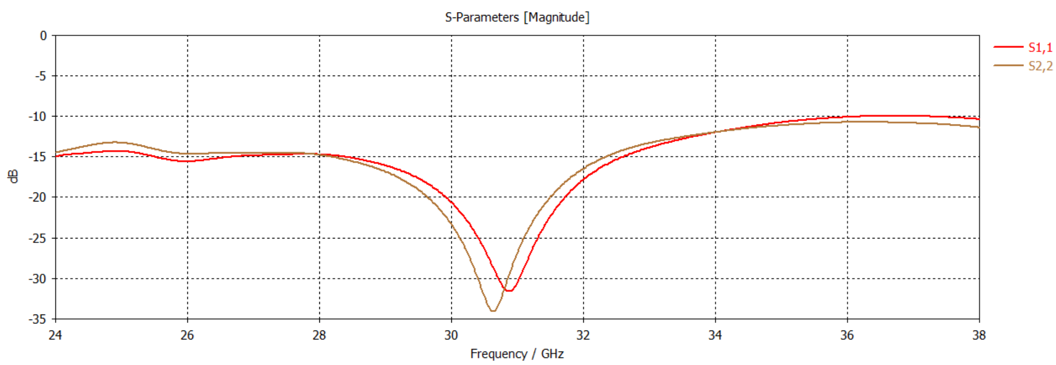

Figure 10: S(1,1) and S(2,2)

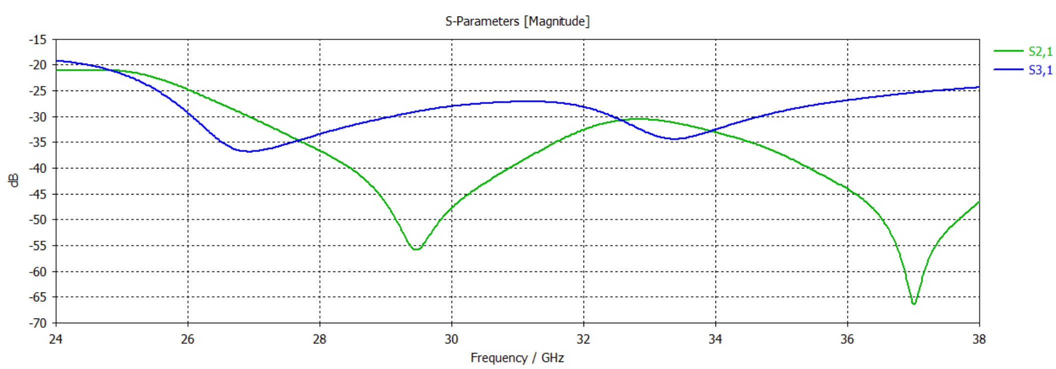

Figure 11: S(2,1) and S(3,1)

4.3 Far Field for Each Antenna

Farfield radiation patterns for each antenna element in the MIMO configuration were analyzed to ensure uniform and desirable radiation characteristics.

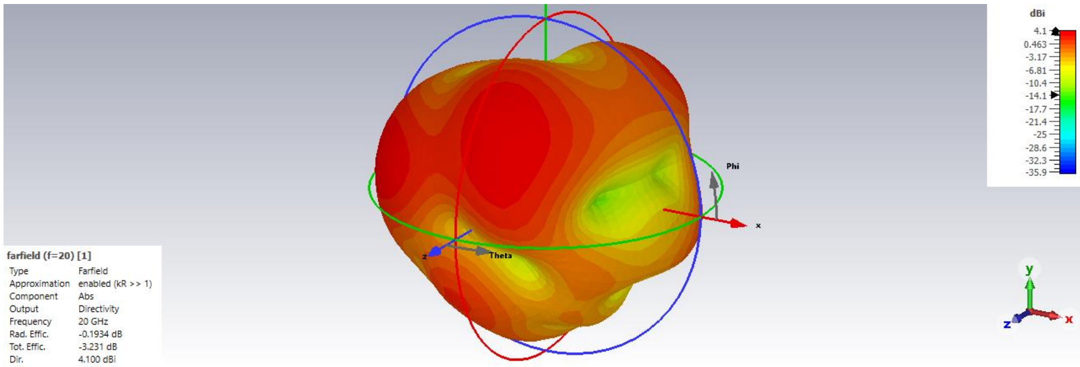

Figure 12: 3D farfield for antenna 1

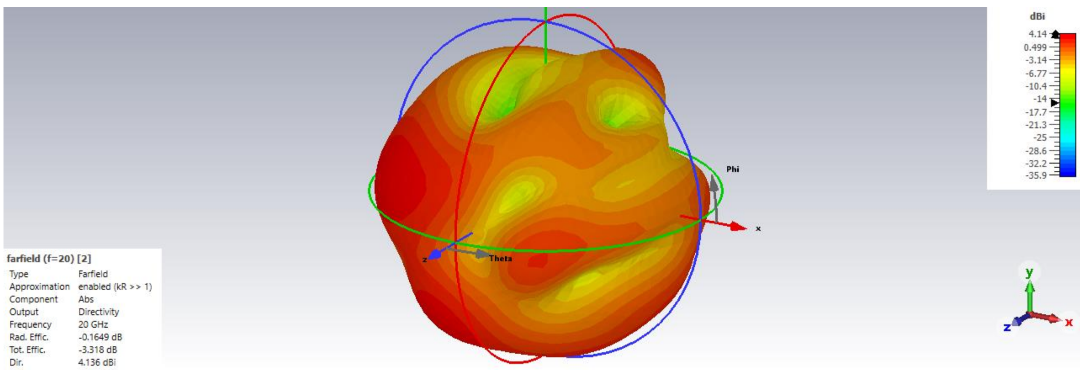

Figure 13: 3D farfield for antenna 2

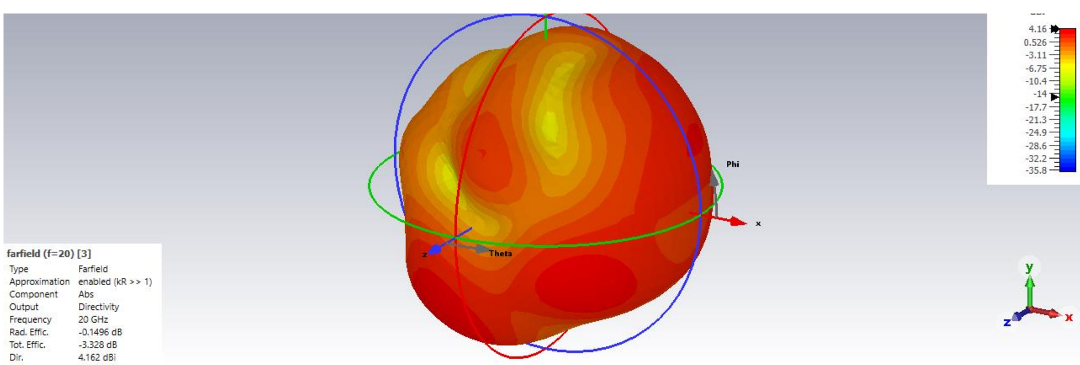

Figure 14: 3D farfield for antenna 3

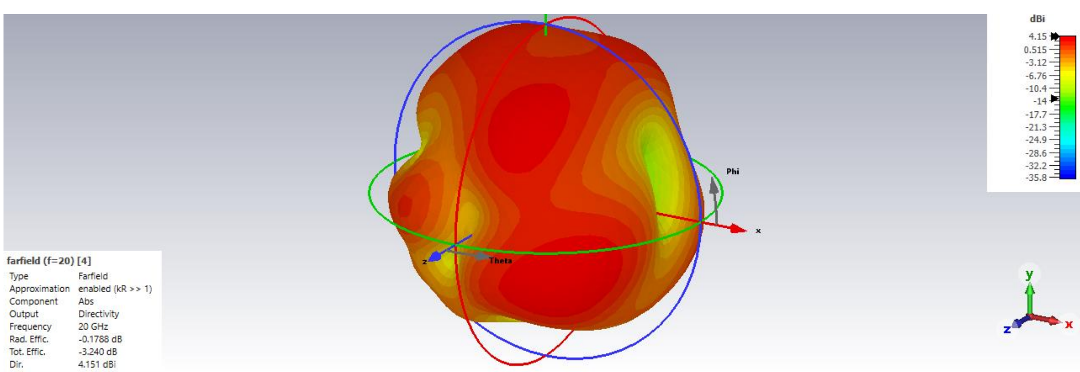

Figure 15: 3D farfield for antenna 4

4.4 Gain

The gain of each antenna element in the MIMO configuration was measured and compared to the single antenna design to evaluate the impact of the MIMO setup.

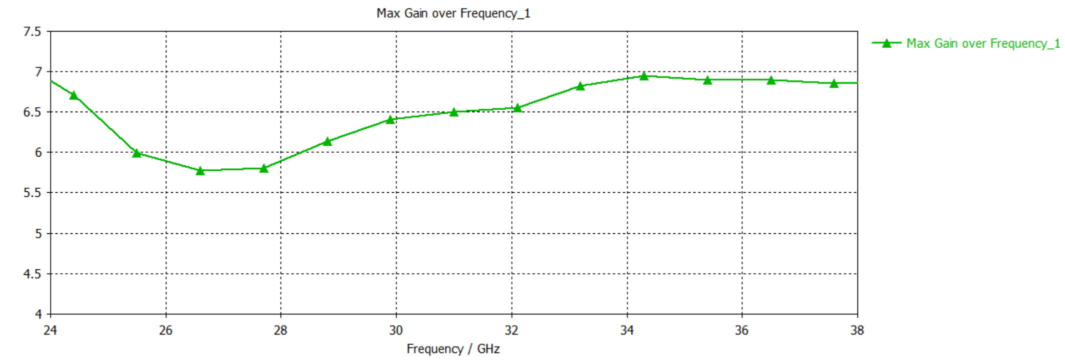

Figure 16: MIMO antenna gain

4.5 Radiation E ciency

Radiation efficiency of the MIMO antenna was assessed to determine the overall performance of the system in practical deployment scenarios.

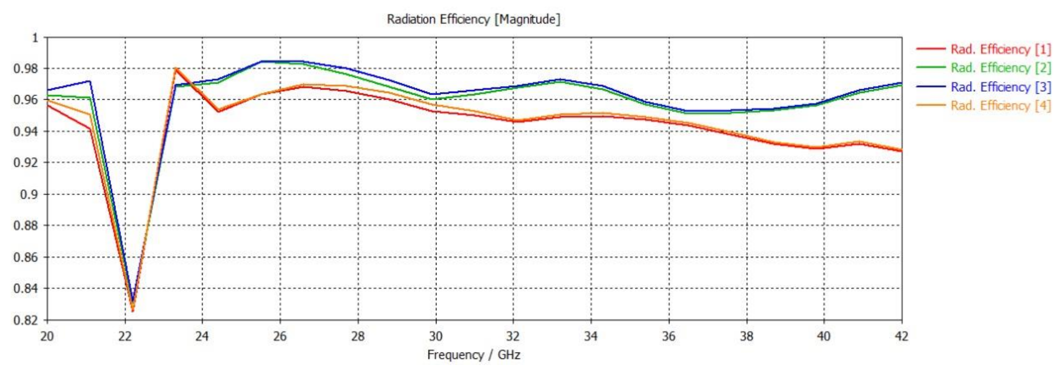

Figure 17:Radiation efficiency for all four antennas

5. MATLAB Analysis

5.1 ECC Output Graph

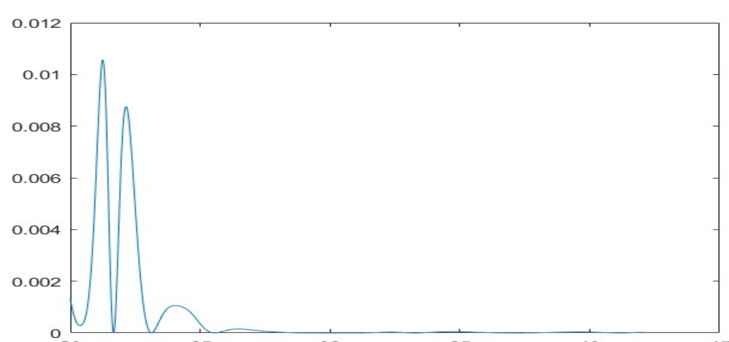

Figure 18: ECC for the MIMO antenna

5.2 ECC Calculations Code

```
format long

load('D:\2_Projects\CST\s11.txt');
load('D:\2_Projects\CST\s21.txt');
load('D:\2_Projects\CST\s31.txt');
load('D:\2_Projects\CST\s41.txt');
load('D:\2_Projects\CST\s12.txt');
load('D:\2_Projects\CST\s13.txt');
load('D:\2_Projects\CST\s14.txt');
load('D:\2_Projects\CST\s22.txt');
load('D:\2_Projects\CST\s23.txt');
load('D:\2_Projects\CST\s24.txt');
load('D:\2_Projects\CST\s32.txt');
load('D:\2_Projects\CST\s33.txt');
load('D:\2_Projects\CST\s34.txt');
load('D:\2_Projects\CST\s42.txt');
load('D:\2_Projects\CST\s43.txt');
load('D:\2_Projects\CST\s44.txt');

S11 = s11(:,2)+i*s11(:,3);
S12 = s12(:,2)+i*s12(:,3);
S22 = s22(:,2)+i*s22(:,3);
S21 = s21(:,2)+i*s21(:,3);

s11_c=conj(S11); % S11 conjuge ald?m
s21_c=conj(S21); % S21 conjuge ald?m

S11_Abs_Sqr=((abs(S11)).^2);
S12_Abs_Sqr=((abs(S12)).^2);
S22_Abs_Sqr=((abs(S22)).^2);
S21_Abs_Sqr=((abs(S21)).^2);

formulUp1=(s11_c.*(S12));
formulUp2=(s21_c.*(S22));
formulUp=formulUp1+formulUp2;
formulUpAbs=abs(formulUp);
formulUpAbsSqr=formulUpAbs.^2;

formulDown1=(1-(S11_Abs_Sqr)-(S21_Abs_Sqr));
formulDown2=(1-(S22_Abs_Sqr)-(S12_Abs_Sqr));
formulDown=formulDown1.*formulDown2;
p=formulUpAbsSqr./formulDown;

plot(s11(:,1),p);
```

5.3 ECC, DG, TARC, MEG, CCL Code (No Plotting)

```
% After Saving Sample S-parameter matrix for 4x4 MIMO antenna in variable “S”
% Number of antennas (4x4 means 4 antennas)
N = size(S, 1);

% Initialize variables
ECC = zeros(N, N);      DG = zeros(N, 1);       TARC = zeros(N, 1);     MEG = zeros(N, 1);      CCL = zeros(N, 1);

% Calculate ECC for each antenna pair
for i = 1:N
    for j = 1:N
        if i ~= j
            ECC(i, j) = abs(S(i, j))^2 / (abs(S(i, i)) * abs(S(j, j)));
        end
    end
end

% Calculate Diversity Gain (DG) for each antenna
for i = 1:N
    DG(i) = -10 * log10(1 - mean(ECC(i, :), 'omitnan')); % Average over other antennas
end

% Calculate TARC for each antenna
for i = 1:N
    TARC(i) = abs(S(i, i))^2 + sum(abs(S(i, :)).^2) - abs(S(i, i))^2; % Total active reflection
end

% Calculate MEG for each antenna
for i = 1:N
    MEG(i) = 20 * log10(1 - mean(ECC(i, :), 'omitnan')); % Average over other antennas
end

% Assume SNR in dB for Channel Capacity Loss calculation
SNR = 10; % Example value
for i = 1:N
    CCL(i) = 1 - (1 / (1 + 10^(SNR / 10))); % Channel Capacity Loss
end

% Display results
for i = 1:N
    fprintf('Antenna %d:\n', i);
    fprintf('    ECC: %.4f\n', mean(ECC(i, :), 'omitnan'));
    fprintf('    DG: %.4f dB\n', DG(i));
    fprintf('    TARC: %.4f\n', TARC(i));
    fprintf('    MEG: %.4f dB\n', MEG(i));
    fprintf('    CCL: %.4f\n', CCL(i));
end
```

5.4 Code Output For Each Antenna

```
Antenna 1:
    ECC: 0.0014
    DG: 0.0063 dB
    TARC: 0.5033
    MEG: -0.0125 dB
    CCL: 0.9091
Antenna 2:
    ECC: 0.0012
    DG: 0.0052 dB
    TARC: 0.5161
    MEG: -0.0104 dB
    CCL: 0.9091
Antenna 3:
    ECC: 0.0014
    DG: 0.0062 dB
    TARC: 0.5188
    MEG: -0.0124 dB
    CCL: 0.9091
Antenna 4:
    ECC: 0.0017
    DG: 0.0072 dB
    TARC: 0.5060
    MEG: -0.0145 dB
    CCL: 0.9091
>>
```

6. References

- Research Paper: https://www.mdpi.com/1601502

- CST Studio Suite Documentation: https://drive.google.com/drive/folders/1MwMWeN5Rx_L-lsvSHrqNyPdvemS9vWKr?usp=sharing

- MATLAB Documentation: MATLAB R2023a, MathWorks. Available at: https://drive.google.com/drive/folders/1MwMWeN5Rx_L-lsvSHrqNyPdvemS9vWKr?usp=sharing