



Simulation Based Design of a Compact Line-Fed Circular Microstrip Antenna for High Frequency Wireless Systems

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KEYWORDS

ABSTRACT

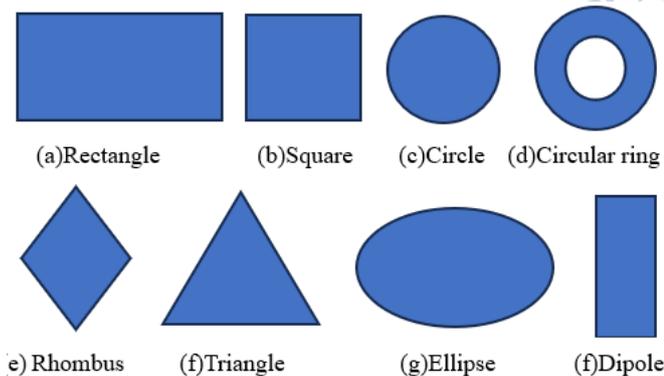
The rapid development of wireless communication technology resulted in a demand for small, highly effective, and cost-effective antennas. In this research, a circular microstrip patch antenna with a line feed mechanism is designed and simulated. It is specifically designed for wireless applications that use the GHz frequency range. The proposed antenna operates in a wide frequency range of 3 GHz to 4.5 GHz. A circular patch configuration is selected due to its advantages of producing uniform radiation patterns, minimizing size, and improving fabrication processes. The line feed architecture enhances the antenna's overall performance and helps to maintain constant impedance characteristics. The line feed architecture contributes to stable impedance characteristics and enhances the overall performance of the antenna. complete full wave electromagnetic simulations, made using the High Frequency Structure Simulator (HFSS), are conducted to refine and evaluate critical performance parameters, including return loss, bandwidth, gain, and radiation efficiency. Simulation results show that the antenna achieves a gain of up to 9 dB, with return loss values typically below 10 dB across the target frequency range. Its wideband response and high radiation efficiency highlight its suitability for integration into compact, next-generation wireless systems that need strong multi-band support.

INTRODUCTION

Antennas are used to establish communication in modern wireless systems. Among the different antenna

types, microstrip patch antennas (MPAs), also called printed antennas, are commonly used because of their small size and practical performance [1]. A microstrip

patch antenna is an electronic component that transmits and receives radio frequency signals over long distances. It was first introduced for practical use in the 1970s. A basic MPA structure includes a metal patch placed on one side of a dielectric substrate, while a metallic ground plane is placed on the other side [2]. Microstrip patch antennas are commonly used in wireless communication systems because they are thin, lightweight, low in cost, and easy to fabricate. Their design process is simple, and they can be connected to feeding networks without much complexity. These antennas are also suitable for high-frequency applications [2]. The performance of a microstrip patch antenna mainly depends on the shape of the radiating patch. Different shapes, such as rectangular, circular, triangular, square, elliptical, and disc types, are used. Among these, rectangular and circular patches are used more often since they are easier to design and manufacture [3].



MPA offers several advantages in improving key performance parameters, including gain, bandwidth, efficiency, return loss, and array configuration. The antenna performance strongly depends on its design parameters [4]. MPAs are frequently used in applications including healthcare devices, military communication systems, mobile networks, and satellite communications due to their unique and attractive characteristics. MPAs are suitable for such systems as these applications require more capacity and reliable operation [6]. This study describes the design of a circular MPA for high-frequency wireless network applications that operate in the 3GHz to 4.5GHz frequency range. The RT Duroid substrate is used to design the proposed antenna. The radius of the circular patch is expected to vary from 10 to 20 mm with the objective of studying the effect of geometric variation on antenna performance. An analysis and discussion of the proposed antenna's

performance characteristics are presented [5].

DESIGNING PROCESS

A. Metallic ground sheet :

The ground is a continuous conducting metal layer that is positioned across from the radiating patch on the bottom side of the dielectric substrate.

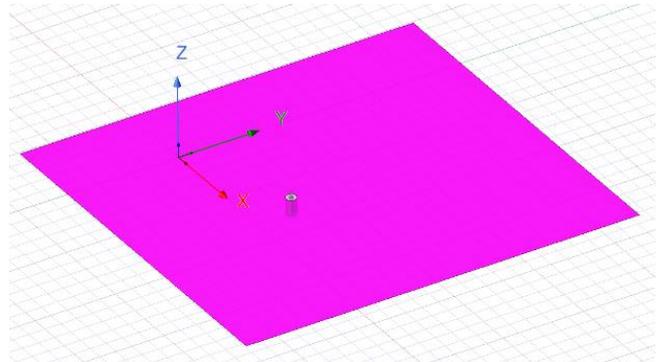


Fig 1(a): Metallic ground sheet

Properties: array2 - HFSSDesign1 - Modeler

Command |

Name	Value	Unit	Evaluated V...
Command	CreateRectangle		
Coordinate ...	Global		
Position	89.1,89.1,-1.6	mm	89.1mm, 89...
Axis	Z		
XSize	-115.7	mm	-115.7mm
YSize	-122.2	mm	-122.2mm

Fig 1(b): Specifications

A copper PEC sheet is located at the bottom of the substrate. Draw a rectangle and name it as Metallic ground sheet positioned at (89.1,89.1,-1.6) with coordinates X=115.7mm, Y=122.2mm, and Z plane is 0.

B. Substrate:

Substrate is the dielectric layer placed between the circular radiating patch and the metallic ground sheet. The substrate thickness or height typically ranges from $0.003\lambda_0$ to $0.05\lambda_0$.

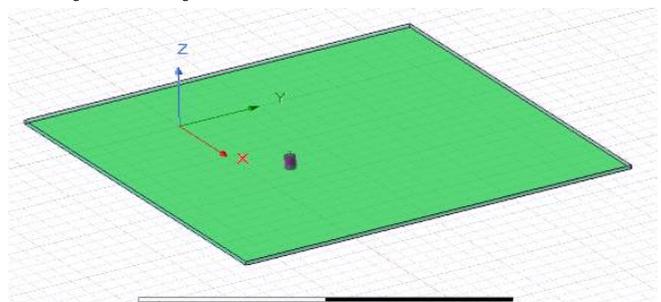


Fig 2(a): Substrate

Properties: array2 - HFSSDesign1 - Modeler

Command |

Name	Value	Unit	Evaluated V...
Command	CreateBox		
Coordinate...	Global		
Position	-26.6, -33.1, -1.6	mm	-26.6mm, -3...
XSize	115.7	mm	115.7mm
YSize	122.2	mm	122.2mm
ZSize	1.6	mm	1.6mm

Fig 2(b): Specifications

Draw a 3D rectangular box on the top of the ground from one corner to the other corner and name it as Substrate. Select the material RT Duriod 5880 with a Dielectric permittivity (ϵ_r) 2.2mm and a thickness of 1.6mm. The substrate is positioned at (-26.6, -38.1, -1.6) with coordinates $X = 115.4$ mm, $Y = 122.2$ mm, and $Z = 1.6$ mm.

Mathematical Calculations Used:

To calculate the effective radius(r) of the patch:

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

Where r is the radius of the circular patch, ϵ_r is the dielectric permittivity of the substrate, h is the substrate thickness, and F is the intermediate frequency.

To calculate the intermediate frequency (F) :

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

Where f_r is the resonant frequency.

To calculate the resonant frequency (f_r) :

$$f_r = \frac{1 \cdot 8412c}{2\pi r \sqrt{\epsilon_r}}$$

Where c is the speed of light(3×10^8 m/s), r is the radius of the patch and ϵ_r is the dielectric permittivity of the substrate ($\epsilon_r = 2.2$).

C. Circular patch elements:

A circular metal patch is positioned on a dielectric substrate separated by a metallic ground sheet in a circular patch antenna, a kind of microstrip antenna. Because of its fringing fields at its edges, the patch emits electromagnetic waves when the power is applied.

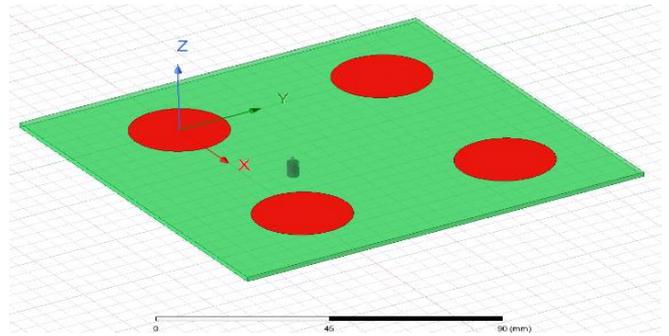


Fig 3: Circular patch

Properties: array2 - HFSSDesign1 - Modeler

Command |

Name	Value	Unit	Evaluated V...
Command	CreateCircle		
Coordinate...	Global		
Center Posi...	0, 62.5, 0	mm	0mm, 62.5m...
Axis	Z		
Radius	13.5	mm	13.5mm
Number of...	0		0

Fig 3(b): Specifications

Four identical patches are placed on the top of the substrate surface($Z=0$). The spacing between the patches is 62.5mm. The diameter of the patches is are same. Draw a circle and name it as Patch1 positioned at (0,0,0) with a diameter of 27.4mm. Draw another circle and name it as Patch2 positioned at (0,62.5,0) with a diameter of 27.4mm. Draw a circle with a diameter of 27.4mm and name it as Patch3 positioned at (62.5,0,0). Take a circle and name it as Patch4 with a diameter of 27.4mm positioned at (62.5,62.5,0).

D. Feed Mechanism and Excitation:



Fig 4: Coaxial Feeding

Draw a circle and name it Ground. Cut out. Circle is positioned at (31.25,16,-1.6) with a diameter of 3.2mm. Select the Ground and Ground cut out and click on the subtract to create a small opening in the ground. The coaxial probe feeding consists of an inner conductor (pin) and outer conductor (probe), and a

dielectric(coaxial). Take a cylinder and name it as Probe acts as the outer conductor, and assign the material PEC. Cylinder is positioned at (31.25,16,0) with radius 0.35mm and height -1.6mm. Take the cylinder and name it as Pin acts as inner conductor and select the material PEC positioned at (31.25,16, -1.6) with radius 0.7mm and height -5mm. Draw a cylinder and name it as Coax, and assign the material Teflon($\epsilon_r = 2.1$) positioned at (31.25,16, -1.6) with radius 1.6mm and height -5mm. Take a circle with a diameter of 3.2mm and name it as Source positioned at (31.25,16, -6.6).

E. Feed Network Rectangles:

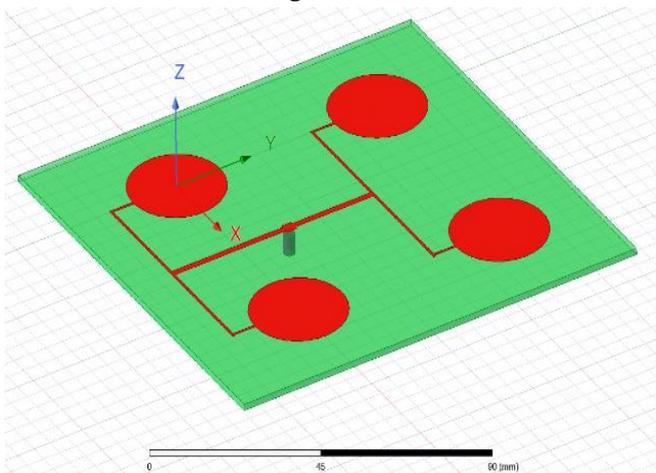


Fig 5: Feeding Network

Rectangular feed lines are used for feeding the patches on the substrate. These feed lines are used to ensure equal power across all four patches. Take a rectangle named as Rectangle1 with coordinates X value = -0.7mm and Y value -20mm positioned at (0.35,62.5,0). Draw a rectangle named as Rectangle2 with coordinates X value= -0.7mm and Y value= -20mm positioned at (0.35,62.5,0).Rectangle3 is drawn with coordinates X value=-0.7mm and Y value= -20mm positioned at (62.5,0,0).Rectangle4 is positioned at (62.5,62.5,0) with coordinates X value= -0.7mm and Y value= -20mm.Rectangle5 is drawn to join the rectangle1 and rectangle 3 positioned at (-0.35,-20.7,0) with coordinates X value= 68.2mm and Y value= -0.7mm. Take a rectangle to join the rectangle2 and rectangle4 and name it as Rectangle6 positioned at (-0.35,42.5,0) with coordinates X value=68.2mm and Y value=-0.7mm. Draw Rectangle7 with coordinates X value=1.6mm and Y value=62.5mm positioned at (30.45,-20.7,0). Rectangle8 is drawn at position(29.95,14.55,0) with coordinates X value=3mm and Y value=3mm. Select all four patches and all the

Rectangles from 1 to 8, and click on the unite to distribute the power equally to all four patches.

F.Radiation box :

The radiation box is an air region created around the microstrip patch antenna in a simulation for open space. It allows the antenna to radiate electromagnetic waves freely without reflections from the boundaries.

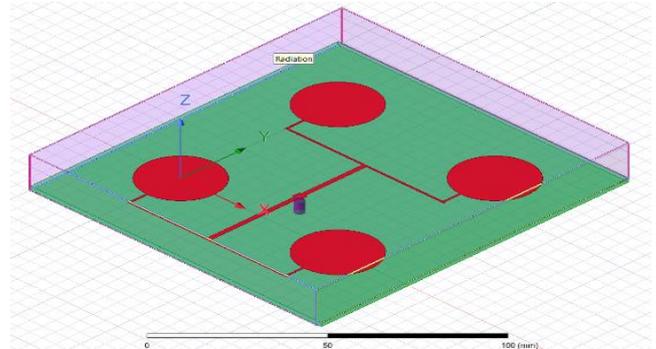


Fig 6(a): Radiation box

Properties: array2 - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated V...
Command	CreateBox		
Coordinate ...	Global		
Position	-25,-35,0	mm	-25mm,-35...
XSize	114.1	mm	114.1mm
YSize	124.1	mm	124.1mm
ZSize	15	mm	15mm

Fig 6(b): Specifications

Select the 3D rectangle box and draw from one end of the substrate to another end of the substrate, and name it as radiation. Select the material vacuum and set the transparency to 0.9. The height of the radiation is 15mm, and set X value=114.1mm and Y value=124.1 mm.

Simulation Setup:

Select all the faces of the radiation box, right-click, and assign a radiation boundary to allow proper radiation. Then select all four patch elements and set the excitation as Perfect E1. After that, choose the metallic ground sheet and assign Perfect E2 as the excitation. Finally, select the source and apply a lumped wave port excitation to complete the setup.

To validate the performance, click on Add Solution setup and set the frequency at 4.05GHz and set the sweep from 2GHz to 5GHz.Save the HFSS design and validate the result. Click on Analyze all to analyze and check the results.

To check the radiation pattern, also known as the far field pattern and gain performance, click on radiation and select create far field reports, and then right click on the infinite sphere. Change the values of ϕ from 0^0 to 360^0 and theta values from -180^0 to 180^0 Save the

design and check the results section to view the far field pattern.

2 by 2 CIRCULAR MICROSTRIP PATCH ARRAY ANTENNA USING HFSS:

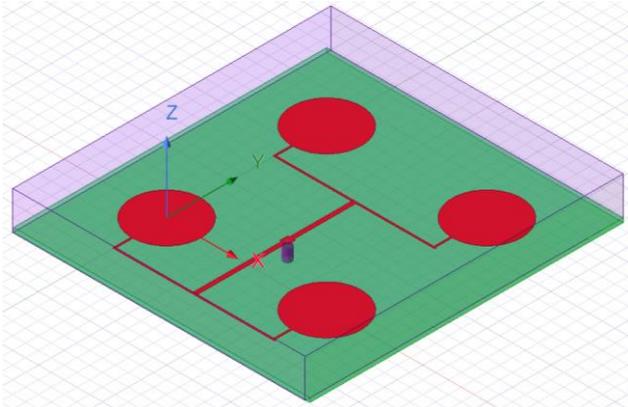


Fig 8: 2 by 2 Microstrip circular patch antenna array design

Figure 8 shows a 2 by 2 circular microstrip patch antenna array designed on a substrate of material RT Duroid, and the four patches are radiating patches. Coaxial feed excites the structure, and the power is distributed to all four patches equally using feed lines. This design improves the gain and radiation characteristics.

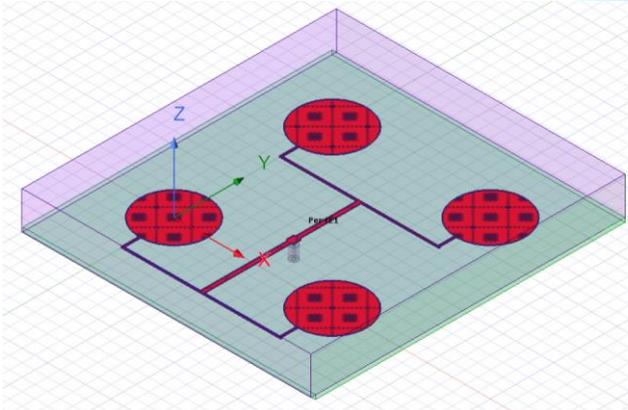


Fig 9: 2 by 2 Circular patch antenna array showing perfect E1(patch – plane)

Figure 9 shows a 2 by 2 circular patch antenna array with the perfect excitation boundary applied to the radiating patches. To assign the excitation to the radiating patches, select all the patches and right click on them and select boundary and assign perfect excitation(perfE1).

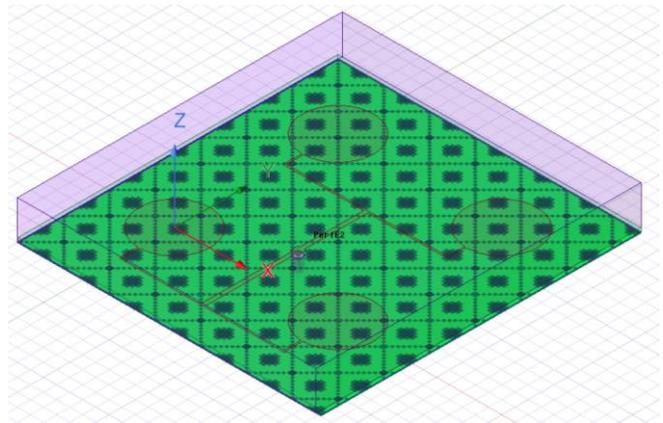


Fig 10: 2 by 2 circular patch antenna array showing perfect E2(metallic ground sheet)

Figure 10 shows a 2 by 2 circular patch antenna array with the perfect excitation boundary applied to the metallic ground sheet. To assign the excitation, select the ground right click on it, and select boundary assign perfect excitation (perfE2).

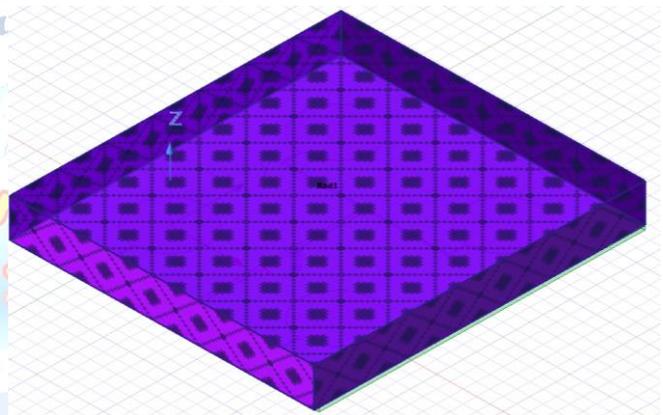


Fig 11: 2 by 2 circular patch antenna array showing radiation box

Figure 11 shows the radiation boundary. To assign a radiation boundary, select the radiation box faces and right click on it. Select the boundary and assign the radiation boundary. This setup helps to calculate the far field pattern, gain, and other antenna parameters at 4.05GHz.

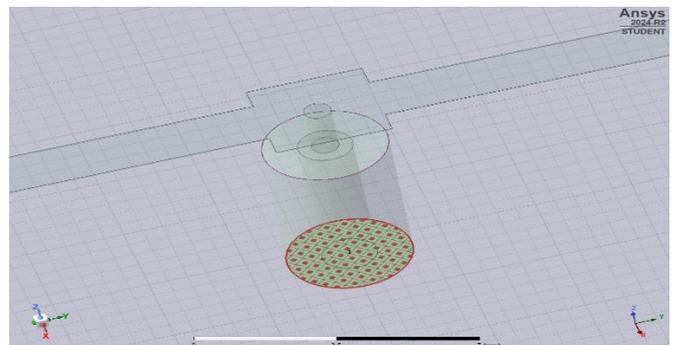


Fig 12: 2 by 2 circular patch antenna array showing lumped port excitation

Figure 12 shows a 2 by 2 circular patch antenna array with the lumped port excitation. To assign the port excitation, select the source right click on it, and assign lumped wave port excitation. It ensures proper field generation and impedance matching for radiation.

STIMULATION RESULTS:

To simulate the results in HFSS, go to HFSS and then click Analysis setup and add solution setup, set the operating frequency to 4.05GHz. Then add Frequency sweep and set the sweep range 2-5GHz. After setting up the solution setup and frequency sweep, click HFSS and then Analyse all to start the stimulation. Once the analysis is complete, open the results section to view S11/Return loss, far field pattern, Gain, and 3D Far-field plots.

Return loss(S11) parameters:

Create a Terminal Solution Report in the Results section and choose a rectangular plot to view the S11 parameters. Set the domain to Sweep and the solution to Setup1: Sweep. Choose Terminal S-Parameter under the category, and select the quantity ST(pin_T1) with the dB value. Finally, to view the S11 results, choose New Report.

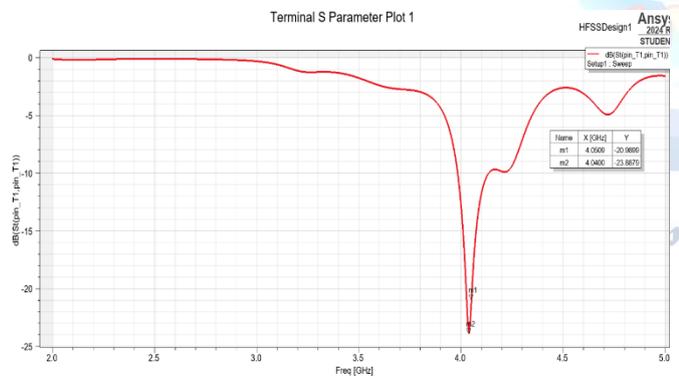


Fig 13: S11 parameter Graph

The above graph shows the S11 characteristics of the designed antenna array. The S11 curve reaches a minimum value of -20.98dB at resonant frequency 4.05GHz, showing good impedance matching. The sharp resonance confirms that the antenna is well tuned for 4.05GHz operation.

3D Gain plot :

To view the 3D gain plot, go to the Results section and choose Create Far Field Reports. Then right-click on the 3D Polar Plot option. Set the solution to Setup1: Last Adaptive and select Infinite Sphere as the geometry. Choose Gain as the category, select gainTotal as the

quantity, and set the function to dB. Finally, click New Report to display the 3D gain plot.

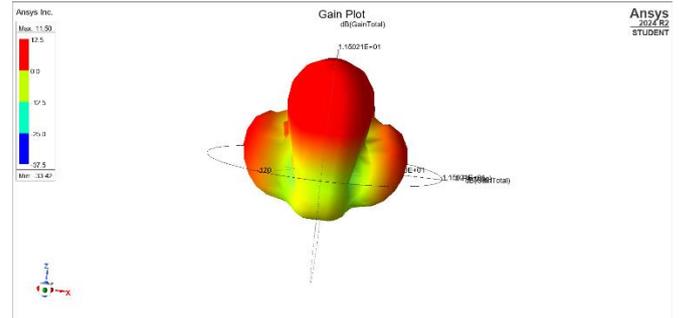


Fig 14: Gain in 3D spherical plot

The Figure represents the 3D Gain plot of the designed antenna array at the operating frequency 4.05GHz. The plot indicates a maximum gain of 11.50dB. The colored far field pattern represents how the antenna radiates energy.

2D Far field pattern :

To view the 2D far-field pattern, go to the Results section and select Create Far Field Reports, then choose Far Field Pattern. Set the solution to Setup1: Last Adaptive and select Infinite Sphere as the geometry. Choose Theta as the primary sweep and select Gain as the category. Set the quantity to gainTotal and the function to dB. Next, open the Families option, change the ϕ values to 0° for the E-plane and 90° for the H-plane, and finally click New Report to view the 2D far-field radiation patterns.

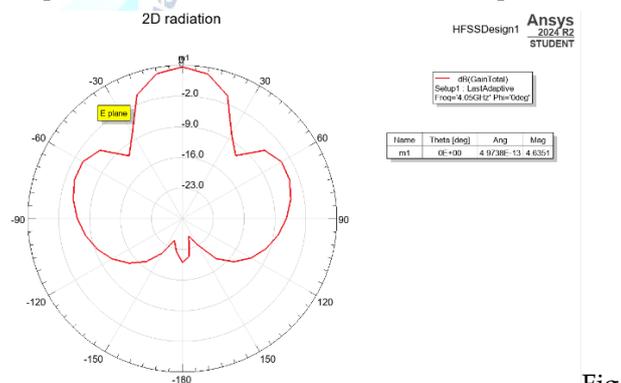


Fig 15: 2D far field pattern of antenna, plotted at 4.05GHz for $\phi = 0^\circ$ (E-plane)

The figure shows the 2D far field pattern of the array antenna at 4.05GHz for $\phi = 0^\circ$ (E plane). The pattern shows a clear main lobe in the forward direction.

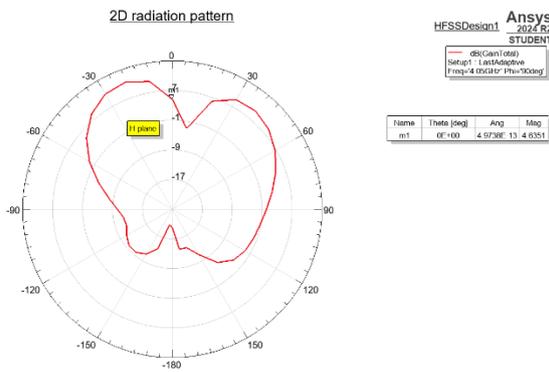


Fig 16: 2D far field pattern of antenna, plotted at 4.05GHz for $\phi = 90^\circ$ (H-plane)

The figure shows the 2D far field pattern of the array antenna at 4.05GHz for $\phi = 90^\circ$ (H-plane). The pattern shows a smooth and stable pattern with small side lobes, showing that the antenna maintains uniform radiation.

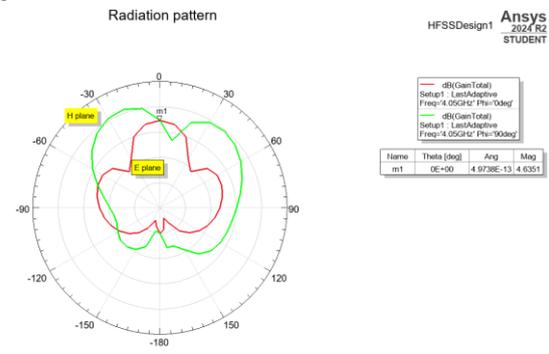


Fig 17: 2D far field pattern of antenna, plotted at 4.05GHz for E and H plane

The figure shows the 2D far field pattern of the antenna at 4.05GHz for both E-plane and H-plane. The red curve represents the E planar field pattern at $\phi = 0$. The green curve represents the H plane far field pattern at $\phi = 90$.

Directivity Gain:

To view the directivity gain, click on Create Far Field Reports and select the far field pattern. Choose the solution as Last Adaptive and set the geometry to Infinite Sphere. In the primary sweep, select Theta and choose Directivity as the category. Set the quantity to DirTotal and the function to dB. Next, open the Families option, change the ϕ values to 0° for the E-plane and 90° for the H-plane, and then click on New Report to generate the directivity plots.

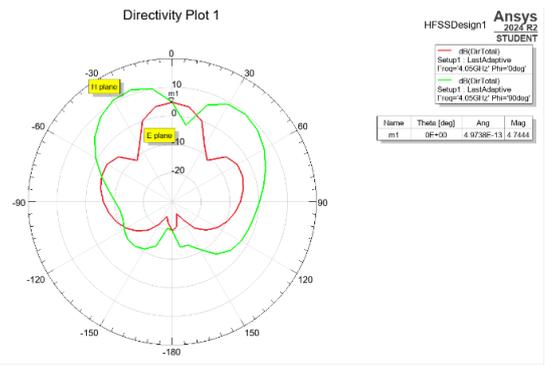


Fig18: 2D Directivity gain of antenna, plotted at 4.05GHz for E and H plane

Figure 18 presents the 2D directivity gain characteristics of the antenna at 4.05 GHz for the E-plane and H plane. The red curve denotes the E planar field pattern at $\phi = 0^\circ$, whereas the green curve denotes the H plane far field pattern at $\phi = 90^\circ$.

Antenna Parameters table:

To view the antenna parameters table, click on the results section and click on antenna parameters table, then click on data table. The antenna parameters table is viewed as

1	
Freq [GHz]	4.050000
PeakDirectivity	14.492432
Setup1 : LastAdaptive	
PeakGain	14.132161
Setup1 : LastAdaptive	
PeakRealizedGain	13.794999
Setup1 : LastAdaptive	
BeamArea	0.867119
Setup1 : LastAdaptive	
RadiatedPower	0.009519
Setup1 : LastAdaptive	
AcceptedPower	0.009761
Setup1 : LastAdaptive	
IncidentPower	0.010000
Setup1 : LastAdaptive	
RadiationEfficiency	0.975141
Setup1 : LastAdaptive	
TotalEfficiency	0.951876
Setup1 : LastAdaptive	

Fig 19: Antenna parameters Table

The antenna parameters table shows the extracted antenna performance parameters at the operating frequency of 4.05GHz. The peak directivity of the antenna is approximately 14.49dBi, indicating maximum directional radiation capacity. The total efficiency is 95.18% showing that the antenna operates with very little loss and excellent efficiency.

PERFORMANCE COMPARISON :

In the following section, the performance of the proposed antenna is compared with that of present designs. This comparison shows the improvements obtained by the proposed design, particularly with respect to return loss, gain, and bandwidth. The table is shown below :

Parameters	[3]	[7]	Proposed method
Operating frequency	2.4GHz	2.4GHz	4.05GHz
Return loss	-16.515dB	-14.6561dB	-20.9dB
Gain	8.0346dB	6.7118dB	11.50dB
Directivity	11.950dB	10.5220dB	17.69dB

CONCLUSION:

Using ANSYS HFSS, this study developed a compact 2x2 circular microstrip patch antenna array aimed at wireless applications operating from 3 to 4.5 GHz. The proposed antenna operates at a resonant frequency of 4.05 GHz and shows strong radiation performance at this frequency. It achieves a maximum 3D polar gain of 11.50 dB. A return loss of -20.9 dB at 4.0509 GHz confirms good impedance matching. In addition, the antenna delivers a peak gain of 14.13 dB along with a directivity of 17.69 dB, highlighting its effective directional radiation characteristics. Compared to a single circular patch antenna, the array structure provides better radiation characteristics and higher directivity. This improvement occurs because multiple antenna elements work together to focus the radiated energy in a specific direction. For applications that need highly directional signals, such as point-to-point wireless links, radar systems, and long-range communication, increasing the number of elements the antenna array can further improve directivity and overall performance.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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