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DESIGN OF DUAL-BAND MICROSTRIP PATCH ANTENNA FOR MIMO AND WIRELESS COMMUNICATION IN THE C BAND

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Abstract : A dual-band microstrip patch antenna designed for C-band wireless applications, including at 5.25 GHz, is presented in this study along with its simulation. For Multiple Input Multiple Output (MIMO) systems, which demand small, effective designs with low mutual coupling and great port isolation, the antenna is optimized. An FR-4 epoxy glass substrate of 1.6mm in thickness, 4.4 relative permittivity, and 0.0024 loss tangent is used for building the patch structure. With a return loss of 10dB, the suggested microstrip patch antenna (MPA) efficiently produces two separate frequency bands: 3.34–3.54GHz and 4.90–6.26GHz, with bandwidths of 200MHz and 1.36GHz, respectively. 3.3–3.5 GHz for MIMO applications, 5.15 to 5.35GHz and 5.725 to 5.825GHz for WLAN, 5.25 to 5.85GHz for WiMAX, 5.65–5.67 GHz for satellite uplink, 5.83–5.85 GHz for satellite downlink, and 5.9GHz for vehicular wireless communication are among the frequency ranges that cover a variety of wireless communication standards. Key performance factors, including return loss, gain, bandwidth, current distribution, “Voltage Standing Wave Ratio (VSWR),” E-plane and H-plane characteristics, radiation efficiency, and overall radiation pattern, are analyzed during the design and simulation of the antenna by employing HFSS software. The suggested design has a simple structure, is simple to fabricate, and has advantageous properties that make it appropriate for modern wireless communication systems.

***Keywords* - Radiation Pattern, Gain, Bandwidth, VSWR, Return loss, E-Plane Plot, H-Plane Plot, Microstrip Patch antenna, Dual Band, MIMO/Wireless communication applications.**

I. INTRODUCTION

Antennas that can provide fast data transfer rates, enhanced signal quality, and effective utilization of the available spectrum are becoming more and more necessary in the current wireless communication environment. MIMO technology has emerged as a key response to these demands. MIMO systems improve communication efficiency by employing multiple antennas on both the transmitting and receiving ends, allowing for higher reliability and quicker data rates. Due to its small size, low weight, and simplicity of integration into contemporary wireless devices, microstrip patch antennas (MPA) stand out among other antenna designs as the best option for MIMO applications. They are ideal for modern communication systems because of their simple design and affordable manufacturing.

The objective of this particular project is to create a dual-band microstrip patch antenna which can function in the C-band, namely at 5.25 GHz, which is a popular frequency for wireless communication technologies like Wi-Fi. The antenna's dual-band design guarantees that it can accommodate a variety of frequency ranges, increasing its adaptability for a variety of applications. To ensure the best possible signal transmission and reception, the suggested design also seeks to achieve high gain and wide bandwidth. Another critical consideration is minimizing interference between the antenna elements, a challenge that is paramount in MIMO systems. The antenna's design is tailored for wireless communication systems where efficiency and reliability are crucial. With the growing reliance on wireless networks for day-to-day operations, developing antennas that can seamlessly meet these demands is essential. In addition to developing MIMO technology, this dual-band microstrip patch antenna project meets the changing demands of wireless communication and offers up the possibilities for more reliable and effective network infrastructures.

II. Literature Survey

Because of its widespread use in wireless communication technologies, MPA has been the subject of extensive research. In their 2013 study, Kaur and Khanna examined the use of coaxial-fed patch antennas in Wi-MAX and IMT networks, emphasizing the possibility of effective and reasonably priced designs. Similarly, Wong et al. (2007) presented dual-band slot antennas with omnidirectional characteristics suitable for WLAN applications, emphasizing simplicity in design.

Eldek (2004) investigated wideband printed antennas for phased array systems, focusing on achieving high performance across varying frequency bands. Research by Lau et al. (2006) demonstrated a vertical patch antenna capable of dual-band operation, showcasing advancements in compact antenna configurations. Asrokin et al. (2005) also contributed with dual-band microstrip designs tailored for WLAN, emphasizing return loss and gain optimization. A notable contribution by Kim et al. (2005) introduced a spiral- structured dipole antenna, achieving dual-band functionality for WLAN. This work demonstrated how geometry adjustments could enhance bandwidth and gain. Further, Cao et al. (2008) highlighted miniaturized dual-band antennas for WLAN, reinforcing the importance of compactness in modern designs. Building on earlier research, the current work focuses on a dual-band MPA for MIMO systems. Its design makes use of a FR-4 substrate with optimized dielectric characteristics, and it functions effectively at 5.25 GHz in the C-band. The design aims to address challenges like mutual coupling and bandwidth limitations while ensuring high gain and reliability, aligning with the evolving demands of wireless communication systems.

III. Antenna Geometry

As shown in Figures 1.1 and 1.2, an MPA has a ground plane on one side of a dielectric substrate and a radiating patch on the other. Usually, the substrate's dielectric constant (DC) falls between 2.2 and 12. In this design, the patch is made from an easily accessible FR-4 epoxy glass substrate that has a thickness=1.6mm, relative permittivity=4.4, and loss tangent=0.0024.

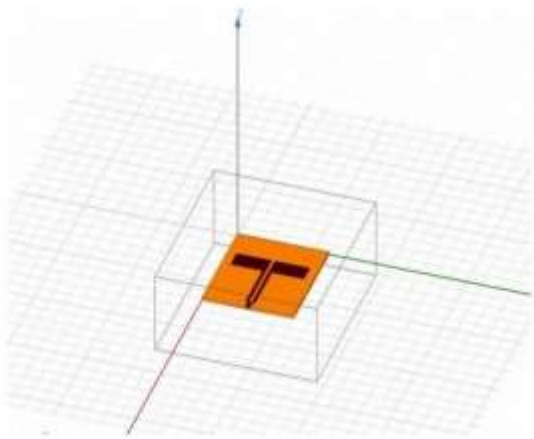

Fig 1.1: Antenna configuration of the proposed antenna front view

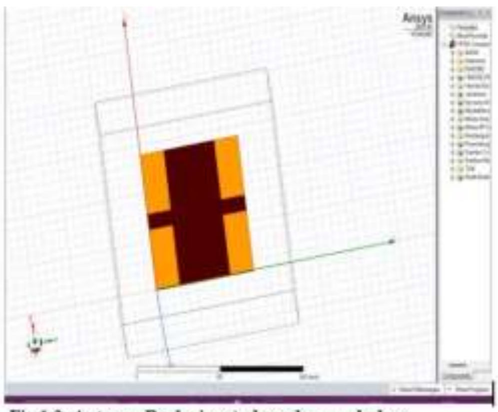

Fig 1.2: Antenna Back view,+ shaped ground plane

Antenna Design Parameters:

TABLE 1 Optimal Parameters of the Proposed MPA

Parameters	W_s	L_s	L_1	L_2	L_3	W_1	W_2	L_{g1}	W_{g1}	g	d
Unit (mm)	60	70	11.7	33.5	5	23	3	8	31	2	2

All the dimensions of the MSA shown in the table were calculated by using the rectangular patch design equations as shown below:

1. **Width of the Patch (W):**

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}}$$

where $c = 3 \times 10^8$ m/s (speed of light).

2. **Effective Dielectric Constant (ϵ_{eff}):**

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}}$$

3. **Length Extension (ΔL):**

$$\Delta L = 0.412h\frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

4. **Length of the Patch (L):**

$$L = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} - 2\Delta L$$

5. **Ground Plane Dimensions:**

$$L_g = 6h + L$$

$$W_g = 6h + W$$

IV. Simulation Results

4.1 Frequency vs Return Loss

The S-Parameter Plot you provided shows the S_{11} parameters for an MPA, which is a measure of the reflection coefficient, additionally called the return loss. Power reflected to the source at different frequencies is measured using this diagram. Two primary frequency bands where the antenna operates well are displayed in the plot: Approximately 3.36GHz. With a return loss of roughly -16dB

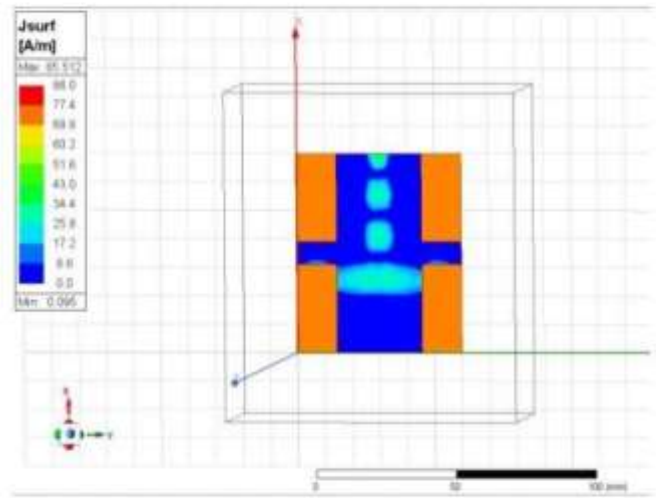

Fig 4.1. Surface Current Distribution at back view of antenna

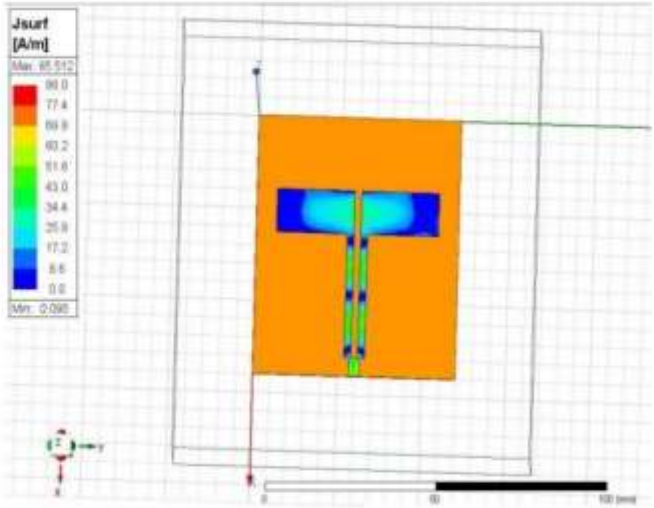

Fig 4.2. Surface Current Distribution at front view of antenna

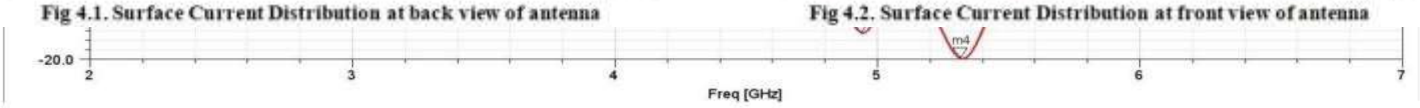

Fig2. Simulated return loss curve of proposed antenna S_{11} plot

4.2 : Gain vs Frequency Plot

Figure 3 shows the associated return losses when the DC is changed between 4.3 and 4.7. An increase in the Causes Lower shifts in both the first and second resonant frequencies, whereas the lower frequency range shows a decrease in return loss. Consequently, an FR-4 substrate with a DC of 4.4 is the ideal material to effectively bridge WLAN and MIMO frequency ranges.

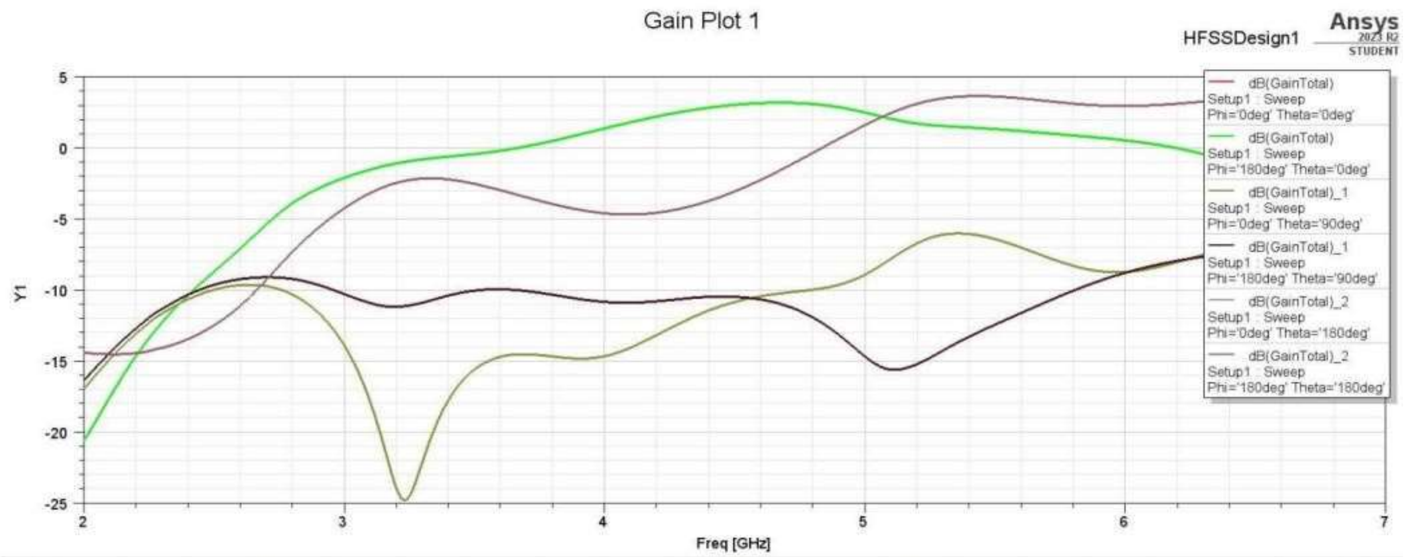

Fig 3. Gain vs Frequency curve of proposed antenna plot , Optimization of dielectric constant of substrate.

4.3: Current Distribution Results

The images show the Ansys HFSS simulation of the current distribution on a microstrip patch antenna. The change in color from blue to red, where blue indicates a lower current density and red, a larger one, indicates the surface current distribution on the antenna. High Current Density (Red to Yellow regions): Concentrated near the feed line and central part of patch. This indicates that these areas are responsible for most of the electromagnetic radiation, as more current flows here. Low Current Density (Blue regions): Found towards the edges of the patch, where there is minimal radiation, indicating weaker current flow. Overall, the distribution shows that most of the energy is focused near the feed point and middle of patch, essential for the antenna's operation and radiation characteristics.

4.4: VSWR(Voltage Standing Wave Ratio)

The graph shows the antenna's impedance matching with the transmission system by plotting frequency (in GHz) on the x-axis and VSWR values on the y-axis. Reduced signal reflection and improved impedance matching are indicated by a VSWR value nearer 1. The antenna's dual-band operation is confirmed by the plot's two distinct VSWR dips, which correspond to its resonance frequencies. These dips show the ideal impedance matching locations, which guarantee effective signal transmission and reception with low losses. Reliable performance can be ensured by evaluating the dual-band microstrip patch antenna's efficacy across its operating frequencies through the analysis of the VSWR curve.

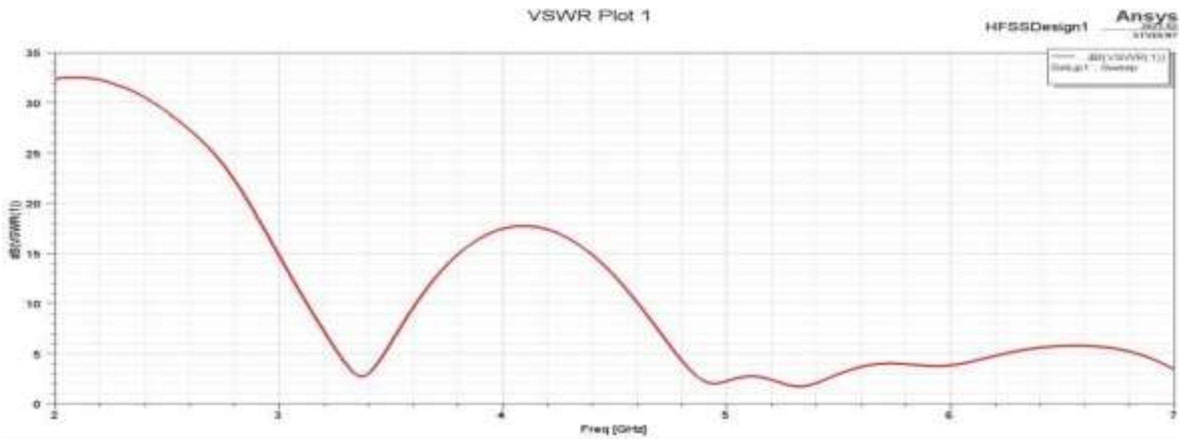

Fig. 5: VSWR of dual-band micro strip patch antenna

4.5: ELECTRIC PLANE AND MAGNETIC PLANE

The direction of the electric field vector is represented by the electric field plane, sometimes referred to as the E-plane. Since it represents the direction of maximum radiation, the E-plane of an MPA is usually parallel to the patch and perpendicular to the ground plane. The magnetic field plane, often known as the H-plane, is a representation of the magnetic field vector's direction. Since it indicates the direction of minimal radiation, H-plane for a MPA is usually parallel to the ground plane and perpendicular to the patch. Analyzing the radiation pattern requires taking into consideration both of the antenna's operating frequencies, which are 3.48GHz and 5.25GHz.

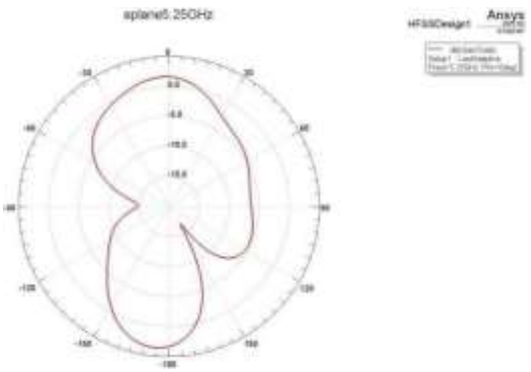

Fig. 6.1: Electric field plane radiation pattern at 5.25GHz.

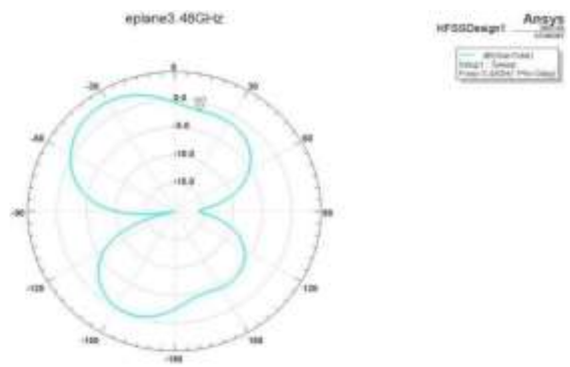

Fig. 6.2: Electric field plane radiation pattern at 3.48GHz

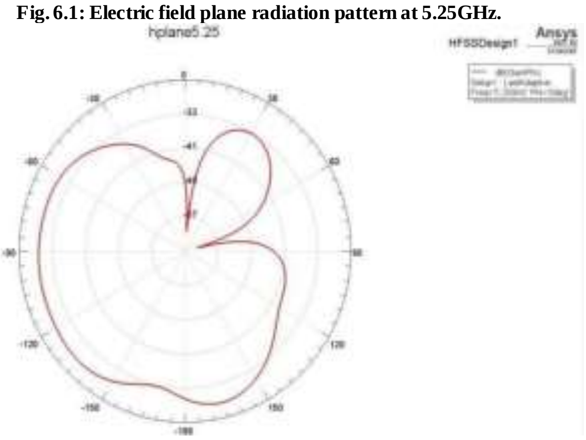

Fig. 6.3: Magnetic field plane radiation pattern at 5.25GHz.

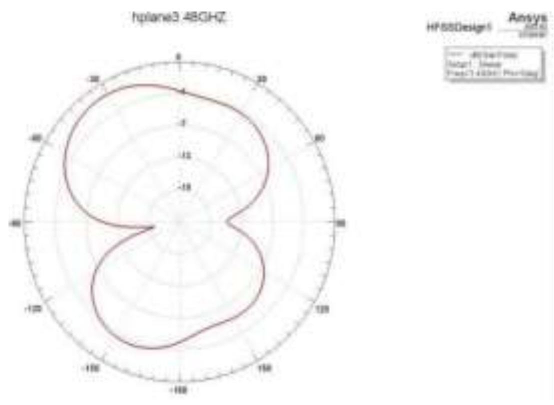

Fig. 6.4: Magnetic field plane radiation pattern at 3.48GHz.

4.6: RADIATION PATTERN

The antenna's directional dispersion of electromagnetic waves is described by the radiation pattern. The solution frequency for this analysis is set at 2.4 GHz, with a delta S limit of 0.02 and a maximum of 15 adaptive iterations. The suggested antenna is appropriate for WLAN applications because of its omnidirectional emission pattern. The 3D radiation pattern illustrates the power density of electromagnetic waves propagating from the antenna. The visualization resembles a distorted sphere, with the highest power concentration at the top. Different colors in the pattern indicate varying power density levels, where the brightest regions signify the strongest radiation. The x-axis and y-axis represent the azimuth angle (ϕ), while the z-axis corresponds to the elevation angle (θ). The peak radiation value, marked on the color scale to the left, is approximately 623.29.

The antenna is useful for applications that need focused radiation in a specific direction since the radiation pattern's form indicates that it mostly directs its signal upward. Each lobe in the pattern corresponds to a specific resonant frequency and radiation direction, confirming the dual-band operation. The presence of two lobes indicates that the antenna efficiently radiates energy at two distinct frequencies, with their orientation influenced by the antenna's geometry and feeding configuration.

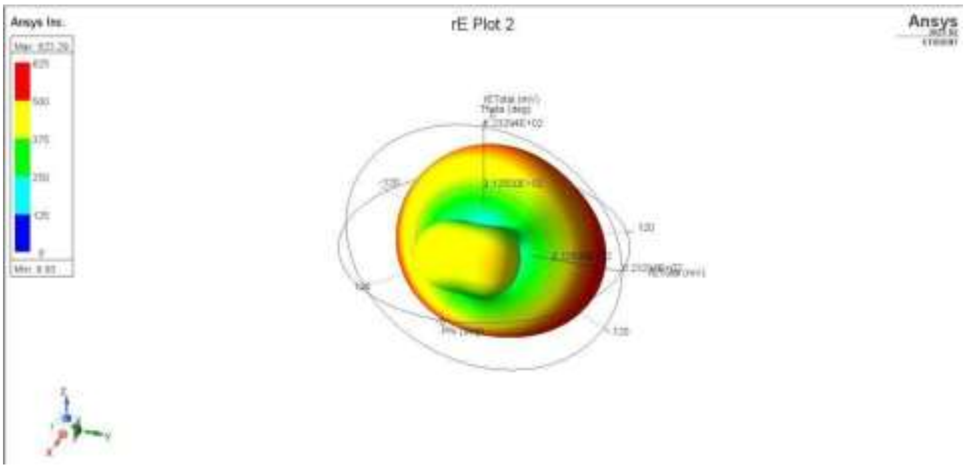

Fig. 7: Three-D Radiation Pattern

4.7: Radiation Efficiency vs Frequency Plot

A dual-band microstrip patch antenna's Radiation Efficiency vs. Frequency plot, which was simulated using HFSS, shows how effectively the antenna radiates energy between 2GHz and 7GHz. The graph shows two main resonance points, one around 3.7 GHz and another near 5.5 GHz, where the efficiency reaches approximately 0.75 and 0.7, respectively. These peaks indicate the antenna's optimal functioning at these frequencies, which is a typical characteristic of dual-band designs. At frequencies outside these resonant points, particularly below 3 GHz and above 6 GHz, the efficiency decreases due to factors like impedance mismatching and higher losses. Radiation efficiency is a measure of how well a dual-band patch antenna transforms input power into radiated energy at two different operating frequencies. This is an essential metric for applications involving wireless communication, particularly for applications involving wireless communication. Efficiency varies across the frequency spectrum, with maximum efficiency occurring at the designed resonance frequencies where the antenna operates with minimal losses. Beyond these points, the efficiency drops because of factors that include impedance mismatching, losses in the substrate, and conductor losses. Ensuring high radiation efficiency at both bands is essential for strong signal transmission and reception in dual-band applications like Wi-Fi, cellular communication, and GPS technology.

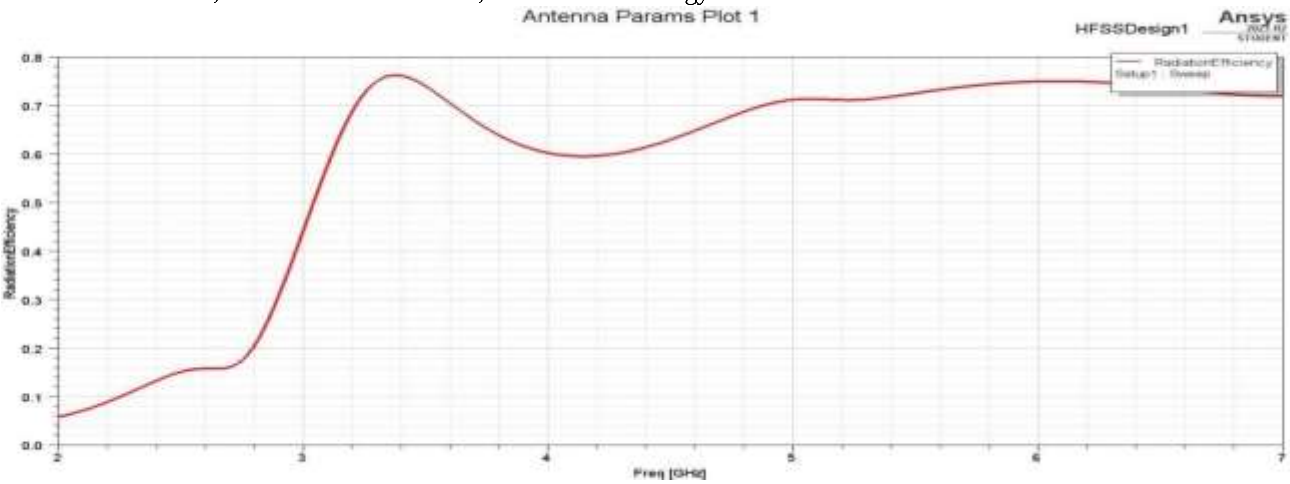

Fig. 8: Radiation Efficiency vs Frequency Plot

4.8: Antenna Parameters vs Frequency Plot

The HFSS-simulated Peak Gain vs. Frequency plot of a dual-band microstrip patch antenna shows how the antenna's gain changes with frequency. The X-axis demonstrates the frequency in GHz, and the Y-axis shows the peak gain in decibels (dB). The gain is roughly -12 dB at 2GHz but rises quickly, peaking at about 4dB close to 3.7GHz, the first resonant frequency. Following this peak, the gain slightly decreases before rising again near 5.5GHz, where it reaches the second peak at approximately 3 dB, aligning with the second operating band. These gain peaks indicate the antenna's best radiation performance at its designed resonant frequencies, whereas the lower gain values at other frequencies suggest reduced efficiency in those regions.

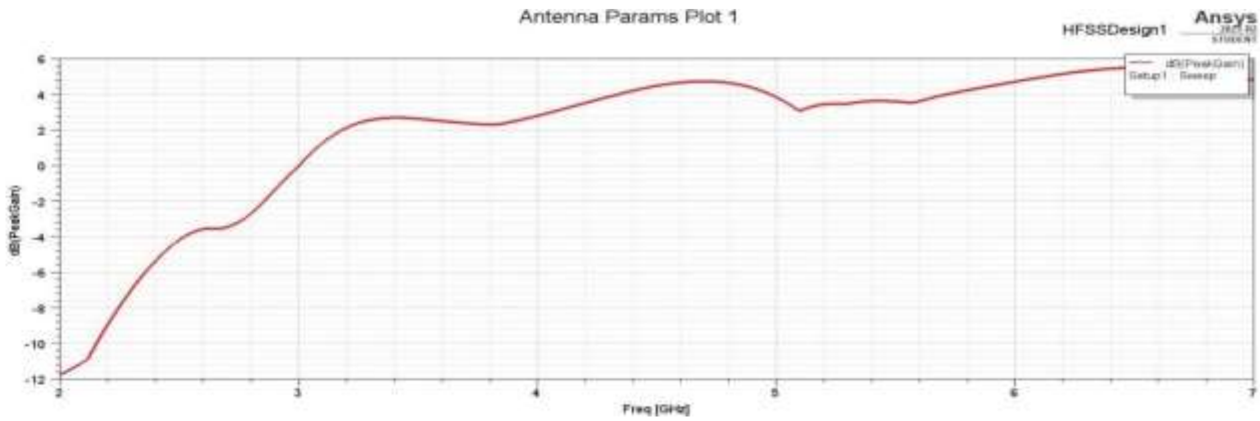

Fig. 9: Peak Gain vs Frequency Plot

V. CONCLUSION

This study successfully designs and simulates a dual-band MPA appropriate for MIMO and wireless applications in the C-band. With strong performance characteristics like low return loss, wide bandwidth, high gain, and well-optimized radiation patterns, the antenna functions effectively in the 3.34–3.54 GHz and 4.90–6.26 GHz frequency bands. The use of an FR-4 substrate and design refinement through ANSYS HFSS enhances the feasibility of fabrication and ensures reliable operation. Its dual-band functionality supports key communication technologies, including WLAN, MIMO, and satellite communication, making it highly suitable for advanced wireless networks. This design effectively balances compactness, cost-efficiency, and high performance, addressing the growing need for fast and reliable wireless communication systems.

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