FINAL YEAR PROJECT REPORT (2025)

[Compact Micro strip Patch Antenna Design for 5G Communications]

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CERTIFICATE

This is to Certify that this project report entitled "**Compact Micro strip Patch Antenna Design for 5G Communications**" is submitted to **MAULANA ABUL KALAM AZAD UNIVERSITY OF TECHNOLOGY** in the complete fulfilment of the requirement for the award of the B. TECH degree in **ELECTRONICS AND COMMUNICATION ENGINEERING** is original work carried out by:

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The matter embodied in this project report is genuine work done by the student and has not been submitted whether to this University or to any other University/Institute for the fulfilment of the requirement of any course of study.

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Abstract:

The design, simulation, and analysis of a sub-6 GHz microstrip patch antenna using CST Studio Suite would be focused, but this time more oriented toward high-frequency wireless communications, such as 5G, radar, or satellite systems. Microstrip patch antennas are widely preferred for their low profile, ease of fabrication, and integration with modern circuitry. However, the design of an antenna at such a high frequency of sub-6 GHz poses several challenges- achieving optimum performance while being compact and efficient.

Several patch geometries, such as circular and rectangular, as well as specially shaped, with a variety of substrate materials, have been explored in order to get the optimal performance. Of course, critical antenna parameters like return loss, VSWR, gain, and radiation efficiency have been properly optimized. Special attention has been paid to reducing surface wave losses and enhancing bandwidth while having a minimal form factor.

With the Final E-MPA, it was possible to obtain a return loss under -10 dB while maintaining good impedance matching, with suitable gain for applications that require long-range communication. Simulations were done and proved the antenna's capability of giving a smooth, undistorted radiation pattern, which makes the antenna highly suitable for high frequency operations. This project proves the applicability of microstrip patch antennas in advanced communication systems and thus the need for very accurate design according to the requirements of modern technologies.

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INTRODUCTION

Introduction

Microstrip patch antennas (MPAs) have gained significant popularity in recent years due to their low-profile structure, lightweight nature, and cost-effective fabrication, making them well-suited for applications such as satellite communications, radar systems, and modern wireless networks. With the ongoing advancements in wireless technologies—particularly 5G—the demand for compact and high-frequency antennas has grown considerably, emphasizing the importance of designing efficient antennas in the GHz frequency spectrum.

In the initial stage of this work, a microstrip patch antenna was designed to operate at 3 GHz, serving as a reference model for performance evaluation. To further enhance the antenna's characteristics, a substrate analysis was conducted using various dielectric materials— FR-4, Arlon AD 300C, Rogers RT5880 and TLC30—while keeping all other design parameters constant. Among these, **TLC30** emerged as the most favourable substrate, offering superior performance in terms of return loss, gain, and bandwidth.

Based on this analysis, the final optimized design was developed using TLC30 as the substrate. Key design improvements included the introduction of **two rectangular slots** in the patch and an **increase in substrate height**, which collectively resulted in enhanced bandwidth and radiation efficiency. These modifications led to a shift in the operating frequency, with the final antenna designed to operate at **3.4 GHz**, aligning with the **n78 band or C-band** of the **sub-6 GHz spectrum**, a key band for 5G communications.

The final antenna was simulated and optimized using **CST Studio Suite**, a high-performance electromagnetic simulation tool. The simulation results demonstrated significant improvements in return loss, bandwidth, and overall efficiency, confirming the design's suitability for real-world applications, particularly in **5G systems** where high data rates, reliable connectivity, and broad coverage are essential.

CHAPTER - 2

Compact Microstrip Patch Antenna Design for 5G Communications

REVIEW OF PREVIOUS WORK

Review of Previous Work

During the revolution in electronic circuit miniaturization and large-scale integration in 1970, the idea of a microstrip antenna with a conducting patch on a ground plane separated by a dielectric substrate was undeveloped. Patch antennas are essential component of wireless communication networks, with microstrip patch antennas being simple to construct and widely used. Popular configurations include rectangular and circular shapes, serving diverse applications in a straightforward manner. The mid-band spectrum accounted for more than 60% of all allocated frequencies as of recent. Governments are looking for answers as pressure on mid-band spectrum increases in order to satisfy the growing need for 5G and 5G-Advanced. Since mid-band spectrum (1 GHz - 6 GHz) can transmit large amounts of data over long distances, it is thought to be ideal for 5G mobile systems are expanding their spectrum to accommodate high data rates, with proposed frequency ranges below 6 GHz, including 470-694, 1427-1518, 3300-3800, and 4500-4990 MHz, at the World Radio Communication Conference in 2015. Since most countries and researches have approved less than or equal to 2.4GHz and 3.5GHz equal or above, they have drawn the most attention. As a result, the operating frequency of 3.4 GHz—known for its availability and suitability across various 5G network deployments—forms the core focus of this project.

To support the design and development of efficient antennas for 5G communication, various microstrip patch antenna (MPA) configurations have been explored in recent literature, emphasizing compactness, bandwidth enhancement, and radiation efficiency.

Verma and Srivastava [1] developed a T-shaped patch antenna with a rectangular slot to enhance bandwidth at 2.45 GHz. Their work employed IE3D simulation tools to optimize four parameters, increasing the antenna's bandwidth from 40.05% to 81.34%, with a resonant frequency at 2.181 GHz and a high return loss of –47.47 dB. The proposed structure supports applications such as Bluetooth, WLAN, and WiMAX.

Paul et al. [2] proposed a π-shaped slotted MPA with a partial ground plane designed using CST Microwave Studio. Their design, intended for lower 5G/WiFi/WiMAX bands (2.87–5.47 GHz), achieved a wide impedance bandwidth of 2.6 GHz, a gain of 2.647 dB, and a high radiation efficiency of approximately 90.88%. The antenna demonstrated strong performance in terms of return loss (simulated: –36.81 dB), stable gain, and nearly omnidirectional radiation, confirming its suitability for high-speed wireless applications.

In another work focused on C-band, Prashanth et al. [3] introduced a dual-slot inset-fed patch antenna resonating at 4.28 GHz using Rogers RT5880 substrate. With a 1 GHz bandwidth and 6.46 dBi gain, the design achieved a return loss of –16.32 dB and minimized cross-polarization to –16.4 dB. This antenna is suitable for satellite-ground communication and other C-band applications.

For S-band systems, Hossain et al. [4] designed a rectangular patch antenna optimized at 3.3 GHz. Using ADS Momentum software and a Duroid 5880 substrate, the antenna showed satisfactory values of gain, efficiency, and return loss. Its compact and low-profile structure makes it applicable for radar and wireless communication.

Murugan [5] presented a compact square patch antenna utilizing a coaxial feed and a central square slot etched from the patch. Operating within the 3.4–3.6 GHz range for 5G communication, the design employed RT Duroid substrate and a shorting pin to improve compactness. The antenna attained a gain of up to 6 dB and bandwidth of 150 MHz, with S11 values below –24 dB and reliable radiation performance.

In the present work, a flipped-P shaped elliptical slot microstrip antenna has been developed for future 5G wireless communication applications. The proposed antenna operates around the widely adopted 3.4 GHz frequency, offering a broad impedance bandwidth from 3.2 GHz to 3.705 GHz, with S11 values consistently below –20 dB. The design demonstrates near-omnidirectional radiation, reliable gain, and excellent radiation efficiency (94.9%), thereby establishing it as a strong candidate for sub-6 GHz 5G systems.

Table 2.1: Study of Recent 5G Antenna Designs

Ref.	Size of Antenna (mm^2)	Return Loss(dB)	Gain(dBi)
[1]	37.3×46.86	-47.47	3.271
[2]	35×31	-36.81	2.647
[3]	30×30	-16.32	6.46
[4]	29.5×42.5	-5.325	7.59
[5]	56×56	-24.51	6
Proposed	***25.2×48***	***-22.34***	***5.68***

The report is organised as follows. Chapter 1 and 2 describe the introduction and the literature review of related work, respectively. In Chapter 3, the Theoretical Background and Working Principles are discussed. In Chapter 4, the suggested antenna design and dimension calculation are shown. The simulation results and performance analysis are presented in Chapter 5. Chapter 6 consists of the Future Scopes and Conclusion.

CHAPTER - 3

Compact Microstrip Patch Antenna Design for 5G Communications

THEORITICAL BACKGROUND

Theory:

Microstrip patch antennas are highly used in modern wireless communications today because they have a low profile, can be easily fabricated, and integrated on circuit boards. The theory of microstrip patch antennas revolves around knowing their structure, working principles, and parameters influencing performance. Structure of Microstrip Patch Antenna. A simple three-layer microstrip patch antenna includes the patch, dielectric, and ground plane layers.

1. Patch: This describes the thin conductive layer made of copper. At the top surface of an antenna, it acts as a radiating element. Such a patch may frequently be square, but other shapes have been found, such as circle, triangle, or others, depending on what it is to be applied to.

2. Dielectric Substrate: The patch is mounted on a dielectric substrate separating it from the ground plane. The dielectric constant of the substrate, that is $\boldsymbol{\varepsilon}_r$, influences antenna efficiency, bandwidth, and resonant frequency.

3. Ground Plane: Conductive ground plane located on the bottom side of the substrate is taken as the ground reference plane for the antenna.

Working Principle:

A microstrip patch antenna is based on the principle of electromagnetic resonance. A surface current on the patch is generated when the RF signal excites it. These surface currents produce electric and magnetic fields, which travel through the dielectric and then radiate from the edges of the patch. The most common mode of operation for an elliptical patch is the fundamental $\mathbf{TM_{10}}$, where Mode- The electric field is maximum near the center of the patch and decreases toward the edges.

- **Key Parameters**

1. **Resonant Frequency (f_0):**

   The frequency at which the antenna naturally resonates is largely determined by the patch's length ***L*** and the dielectric constant $\boldsymbol{\varepsilon_r}$.

2. **Effective Dielectric Constant:**
   The effective dielectric constant considers that the fields also penetrate into the air besides penetrating into the substrate. This does affect the fringing fields and therefore decreases the resonant frequency of the antenna a bit only.

3. **Bandwidth:**
   The bandwidth of a microstrip antenna is generally very low, but one can improve the bandwidth with the aid of a much more substantial substrate thickness, a decreased dielectric constant, or by employing stacked patches techniques.

4. **Radiation Pattern:**
   Microstrip patch has broadside radiation pattern, therefore, radiating in a direction perpendicular to its surface and with gain lies between 5-6dBi.

CHAPTER - 4

Compact Microstrip Patch Antenna Design for 5G Communications

DESIGN/ CALCULATION

Design:

From the final year project on designing a microstrip patch antenna for 5G communication under the sub-6 GHz frequency range, we started experimenting with a variety of different shapes in the shapes of an antenna design to trace the most effective design. Therefore, a circular, rectangular configuration were chosen in the first place since each shape has relative advantages concerning bandwidth, gain, efficiency and return loss. Considering that the two requirements of compactness and high efficiency are stringent for 5G applications, we have spent considerable time in the optimization of the circular design so that the performance improves with different parameters. Still, even after that, the efficiency realized with the circular design was **21%(total),60.3%(rad)** and hence it couldn't meet the stringent requirements of 5G communications.

We have then redesigned a flipped P-shaped design. This structure was better optimized in terms of efficiency than the original one and also more aligned with what the frequency range we were targeting required. After going through detailed simulation and parameter optimization, we achieved an efficiency of 32.7%with the flipped P -shaped (**full ground**) and around 84.72% with the flipped P-shaped design (**partial ground**). This was hugely improved from the baseline aligned well with our project goals, as increased efficiency made this design apt for high performance in 5G applications. Ultimately, this design decision here ensured that the project succeeded and demonstrated the impact of shape and structure on the performance of antennas in the sub-6 GHz band.

We have considered **Resonant Frequency (f_r)** = 3GHz, **Substrate Relative Permittivity** ($\in_r$) = 4.3, **Substrate height(h)**=1.6mm

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}}} ------(4.1)$$

Where,

$$F = \frac{8.791e^9}{f_r\sqrt{\in_r}} ------------------ (4.2)$$

Now, for the effective radius of the antenna;

$$a_e = a\left\{1 + \frac{2h}{\pi a \in_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}} ---------------------(4.3)$$

<u>Output Gained:</u>

Patch physical radius (**a**) = 13.63707mm.

Effective Radius (**a_e**) = 14.14485mm.

Table-4.1: Materials

Substrate	FR-4 lossy
Ground	Copper (annealed)
Patch	Copper (annealed)

- **Initial Prototype (Circular Patch):**

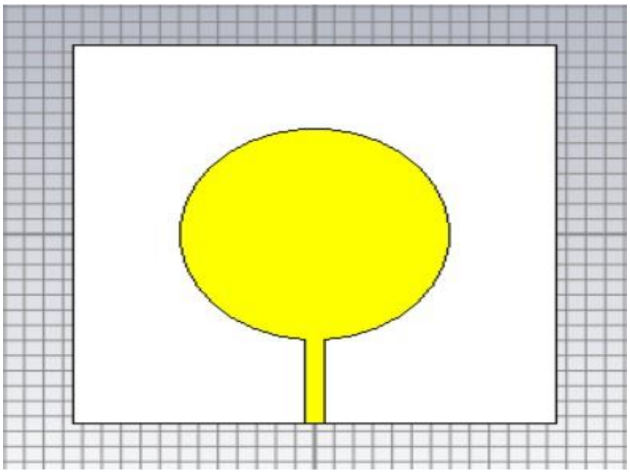


Fig.4.1: Front view of the initial prototype

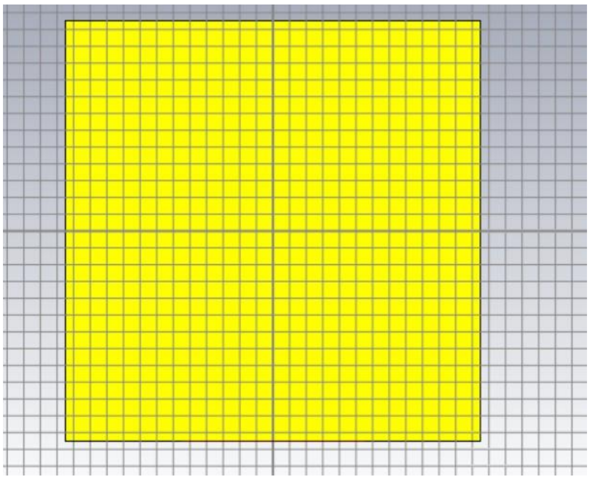


Fig.4.2: Rear view of the Initial prototype

- **Intermediate Prototype (Elliptical Patch with Full ground)**

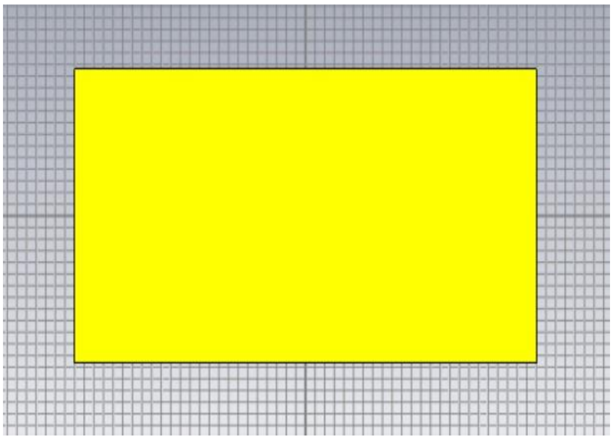


Fig.4.3: Rear View of Intermediate Prototype

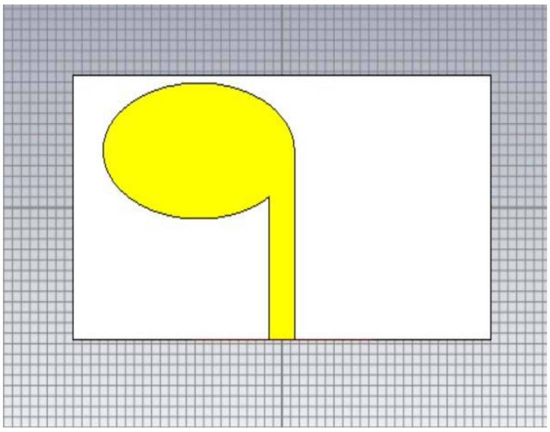
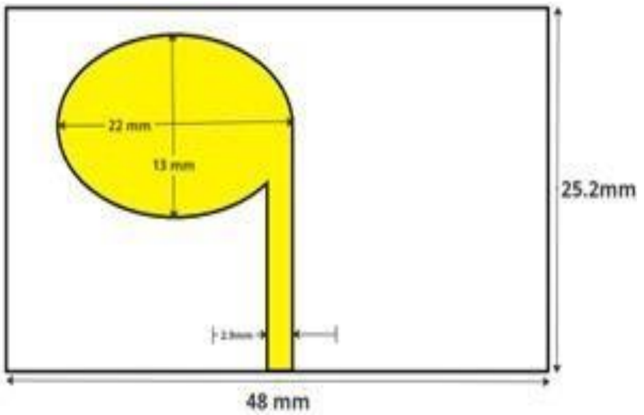


Fig.4.4: Front View of Intermediate Prototype

- **Final Prototype (Elliptical Patch or E-MPA):**



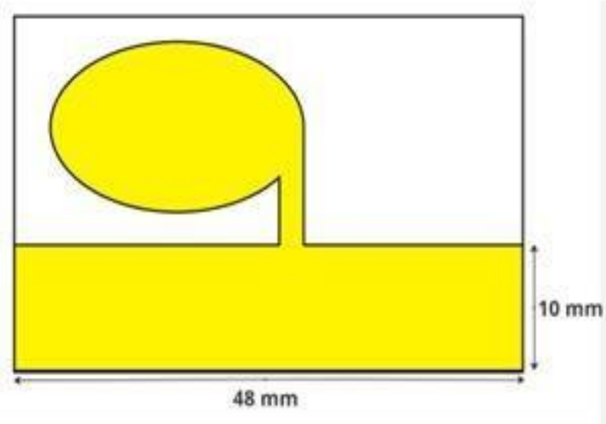


Fig.4.5: Front view of the Initial proposed E-MPA **Fig.4.6: Rear view of the Initial proposed E-MPA**

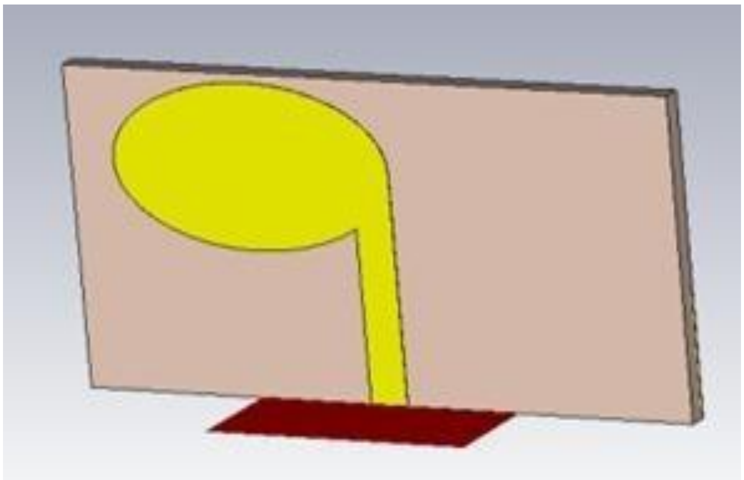


Fig.4.7: Initial Proposed E-MPA

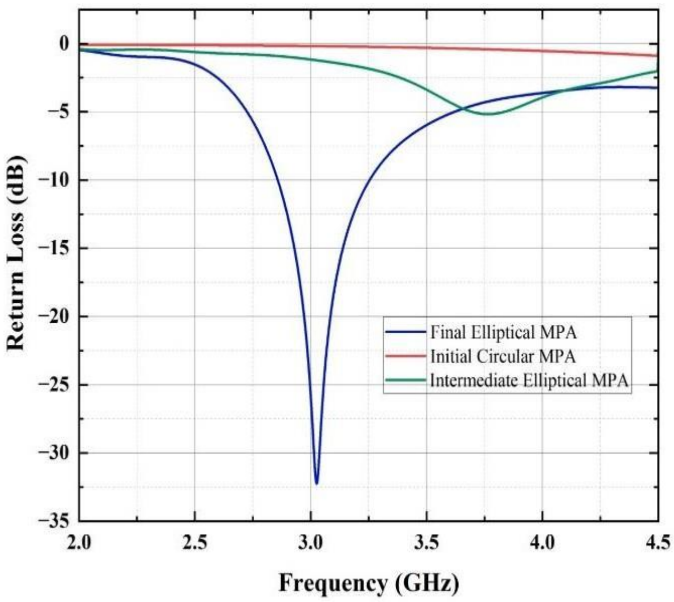


Fig. 4.8: S_{11}Comparison Graph of all the prototype

The graph displays the differences between each model's S11 parameters. The original circular antenna's resonant frequency was between 2 and 4.5 GHz. Although it had complete ground, the intermediate elliptical antenna's resonating frequency of about 3.7 GHz was not adequate. The last partial-ground elliptical antenna was then proposed; it had a resonance frequency within the range and the desired S_{11} value.

- **Table 4.2: Parameter Specification (Initial E-MPA):**

Parameters	**Optimized Value**
Frequency, $\mathbf{f_r}$ (GHz)	3.025
Dielectric Constant, ϵ_r (FR 4)	4.3
Substrate Height, **h** (mm)	1.6
Ellipse Major Axis, (mm)	22
Ellipse Minor Axis, (mm)	13
Substrate Length, L_s (mm)	25.2
Substrate Width, $\mathbf{W_s}$ (mm)	48
Feedline Width, (mm)	2.9
Feedline Length, (mm)	18
Ground Length, (mm)	48
Ground Width, (mm)	10

- **Table 4.3: Comparative Study using Different Substrate materials:**

Substrate Name	**Dielectric Constant (ε_r)**
FR-4	4.3
Arlon AD 300C	2.98
Rogers RT5880	2.2
TLC30	3.0

Table 4.3 presents a comparative study of different substrate materials based on their dielectric constants (ε_r), which significantly influence the performance of microstrip patch antennas. The dielectric constant determines how much electric energy can be stored in the material and affects parameters like bandwidth, efficiency, size, and resonant frequency. Among the listed substrates, FR-4 has the highest dielectric constant of 4.3, making it a cost-effective but less efficient material due to higher losses and reduced bandwidth, which is why it's commonly used for low-frequency applications. Arlon AD 300C, with a dielectric constant of 2.98, offers a balance between cost, performance, and manufacturability, making it suitable for moderate-frequency designs. Rogers RT5880, having the lowest dielectric constant of 2.2, is ideal for high-frequency applications as it provides low loss, high efficiency, and wider bandwidth, though it is relatively more expensive.

TLC30, with a dielectric constant of 3.0, serves as a mid-range option offering decent performance in terms of size and efficiency. Overall, the choice of substrate depends on the specific requirements of the antenna design, such as size constraints, frequency range, and desired efficiency.

• Final E-MPA (E-MPA with Slot):

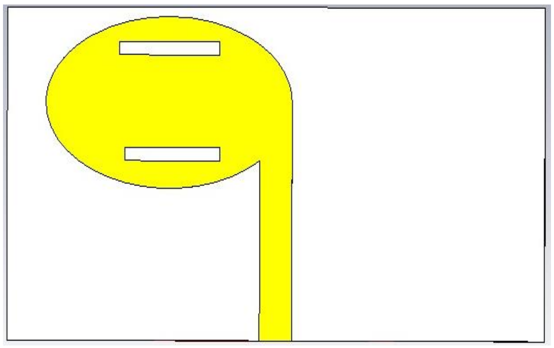


Fig.4.9: Front view of the Final proposed antenna

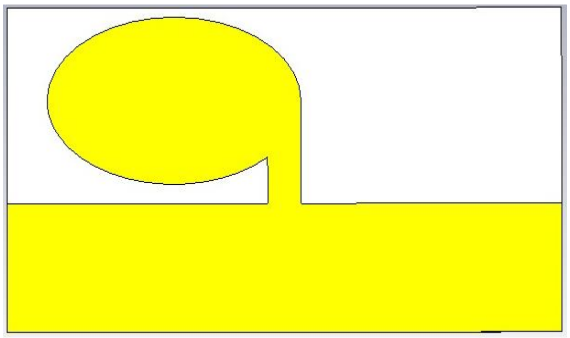


Fig.4.10: Rear view of the Final proposed antenna

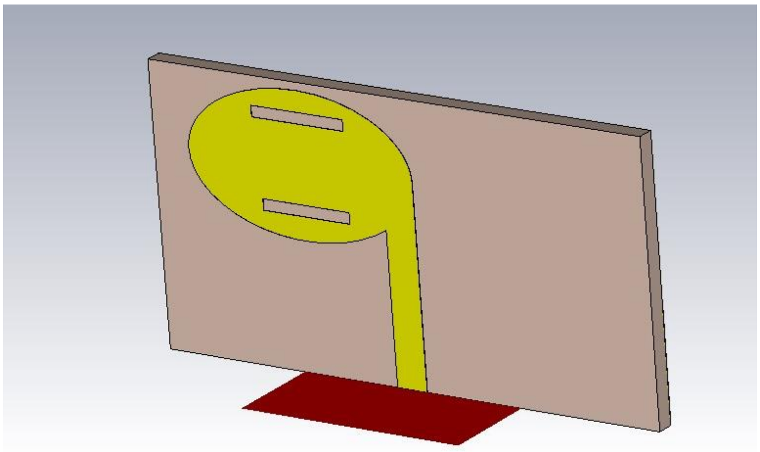


Fig.4.11: Final Proposed E-MPA

TLC30 is a suitable substrate material for this project due to its balanced dielectric constant of 3.0, which offers a good compromise between antenna size, efficiency, and bandwidth. It supports reliable performance in the sub-6 GHz range required for 5G applications, while also being moderately cost-effective and easy to manufacture compared to higher-end materials. This makes TLC30 a practical choice for achieving both performance and affordability in modern antenna designs.

- **Table 4.4: <u>Parameter Specification (Final E-MPA):</u>**

Parameters	**Optimized Value**
Frequency, $\mathbf{f_r}$ (GHz)	3.45
Dielectric Constant, ϵ_r (TLC30)	3.0
Substrate Height, **h** (mm)	1.8
Ellipse Major Axis, (mm)	22
Ellipse Minor Axis, (mm)	13
Substrate Length, L_s (mm)	25.2
Substrate Width, $\mathbf{W_s}$ (mm)	48
Feedline Width, (mm)	2.9
Feedline Length, (mm)	18
Ground Length, (mm)	48
Ground Width, (mm)	10
Number of slots	2

CHAPTER - 5

Compact Microstrip Patch Antenna Design for 5G Communications

RESULTS & DISCUSSIONS

Results and Discussion for Initial Proposed E-MPA:

- **VSWR: (1.048)**

The measured VSWR value of 1.048 using CST software indicates a near-optimal or ideal VSWR, demonstrating perfect impedance matching between the antenna and the transmission line, resulting in very little reflected power and maximum efficiency for power transfer.

A VSWR value close to 1:1 is very important in antenna design for 5G frequency bands, affecting the antenna's ability to transmit and accept signals while fulfilling objectives for frequency bands and overall system performance. The low VSWR of 1.048 shows that the antenna design is well-optimized for 5G frequency bands.

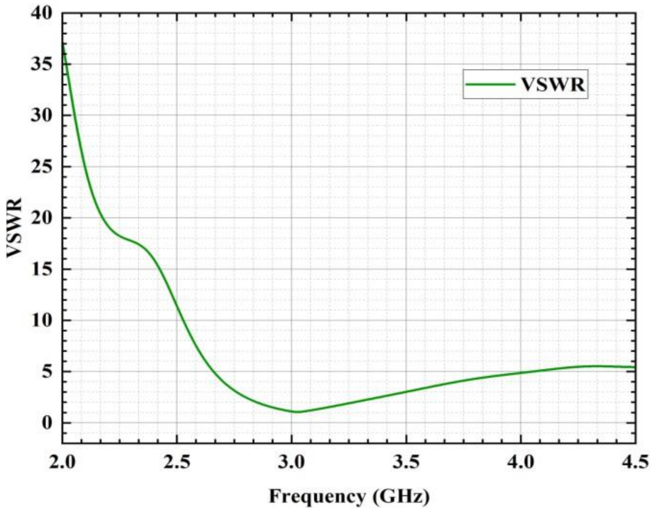


Fig.5.1: Voltage Standing Wave Ratio (VSWR)

- **S_{11}/Return Loss:**

The obtained S11 (Return Loss) value is -32.27 dB via CST software. This noted return loss indicates a good match between the antenna and the transmission line, which results in negligible reflected power. Return loss measures an antenna's ability to radiate the power received; higher negative S11 values like -32.27 dB indicate that almost all power is transmitted with little or no reflection. This voltage reflection coefficient shows the efficiency of the antenna, and its suitability for 5G applications, where a low return loss is necessary for good transmission reception and to facilitate a strong transmitted signal.

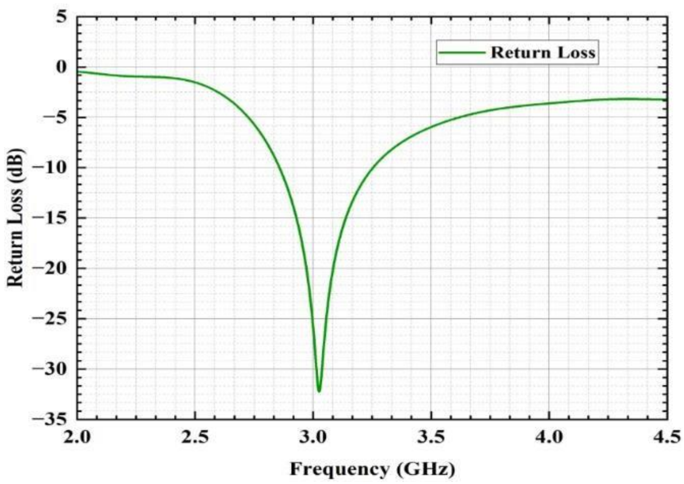


Fig.5.2: Return Loss vs. Frequency for proposed Antenna

- **Bandwidth:(2.86Ghz to 3.25Ghz)**

The antenna's bandwidth, with a range of 2.86 GHz – 3.25 GHz, was determined using CST software. Bandwidth is an important parameter in antenna design for indicating the range of frequencies where the antenna will operate to a suitable level of performance. The bandwidth of 390 MHz is sufficient for 5G applications, and spans a large portion of the frequency band for the allocation of 5G communication. In addition, the large bandwidth of an antenna can allow for very high data rates and modulation across channels, concurrent and non-concurrent, which is suitable for modern wireless communication systems.

- **Gain:(5.12dBi)**

The antenna achieved a gain of 5.12 dBi, as calculated by the CST software. Gain is an important factor which reveals how good the antenna is at directing radio frequency energy in one specific direction relevant to an isotropic source. The 5.12 dBi gain represents how efficient the antenna was at concentrating energy and giving a stronger signal in the desired direction. This gain is acceptable for use with 5G applications since reliable and efficient signal transmission is the main goal, especially in an environment that requires focused communication channels that improves performance and extends coverage.

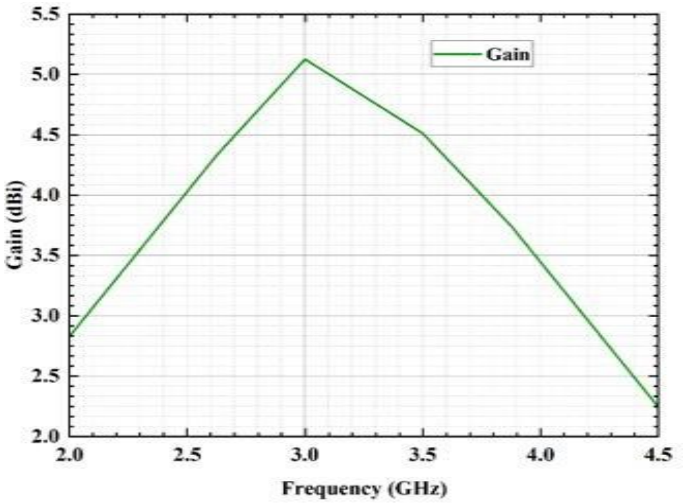


Fig.5.3: Peak Gain vs Frequency for proposed antenna

- **Radiation Pattern:**

When investigating a compact microstrip patch antenna design for the domain of 5G communications, gain is an important parameter, indicating how effectively the antenna can direct the radiated energy. CST software was used to assess the performance of the antenna using the E-Field (Electric Field) and H-Field (Magnetic Field). The study of the E-Field indicates the distribution of electric potential, while the study of the H-Field indicates the distribution of the magnetic field. The E-Field and H-Field both contribute to the distribution of the radiation pattern, and gain impacts the ability of the antenna to transmit and receive signals in a certain frequency range, as desired, for 5G communications. Generally, gain is calculated from the far-field analysis as these two fields interact.

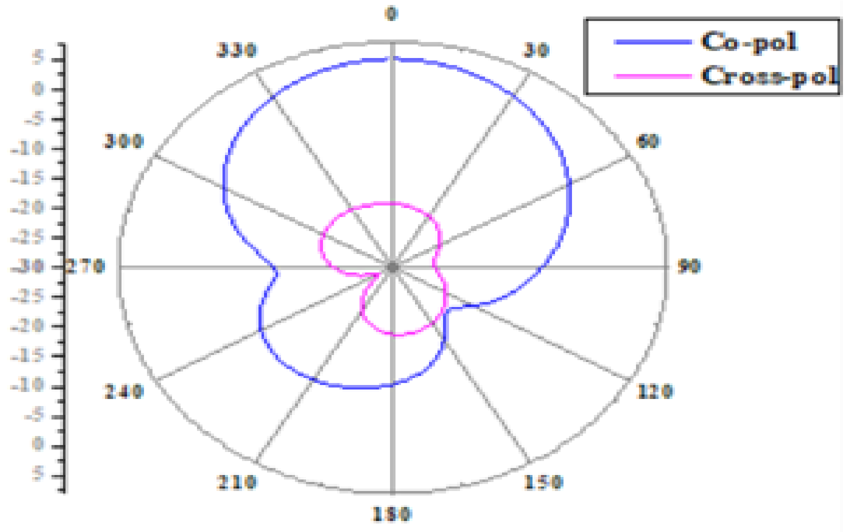


Fig.5.4: <u>Normalized E-plane Radiation Pattern at 3.025GHz</u>

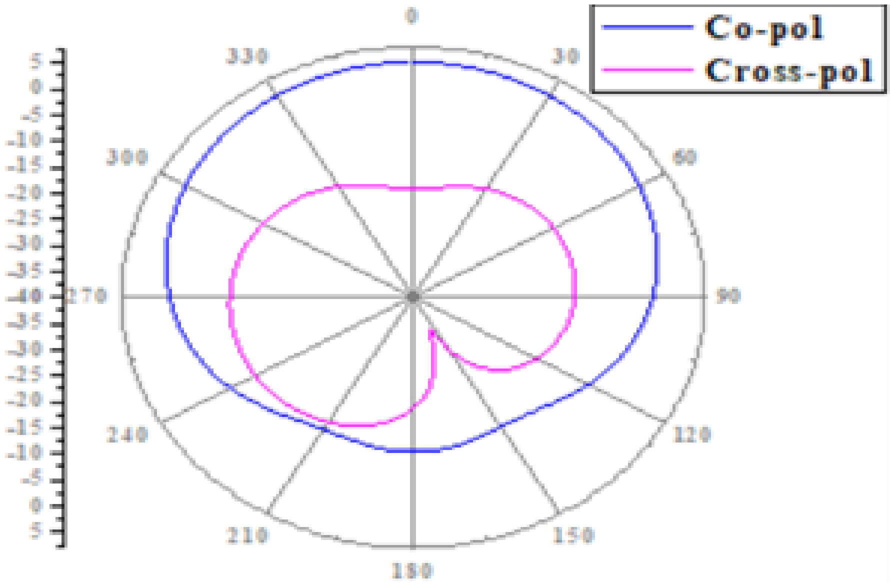


Fig.5.5: <u>Normalized H-plane Radiation Pattern at 3.025 GHz</u>

- **<u>Total and Radiation Efficiency</u>: (84.72%)**

Total efficiency and radiation efficiency are critical parameters that illustrate how effective the antenna is in converting input power into radiated power. The total efficiency considers all losses, including the dielectric substrate and conductor loss, while radiation efficiency only considers the efficiency of the radiated power to the provided power supplied to the antenna. In this experiment and using CST Software, the antenna exhibited a total and radiation efficiency of 84.72%. This indicates that a highly efficient and well-designed antenna has low losses, making it suitable for the high-performance requirements of 5G communications systems.

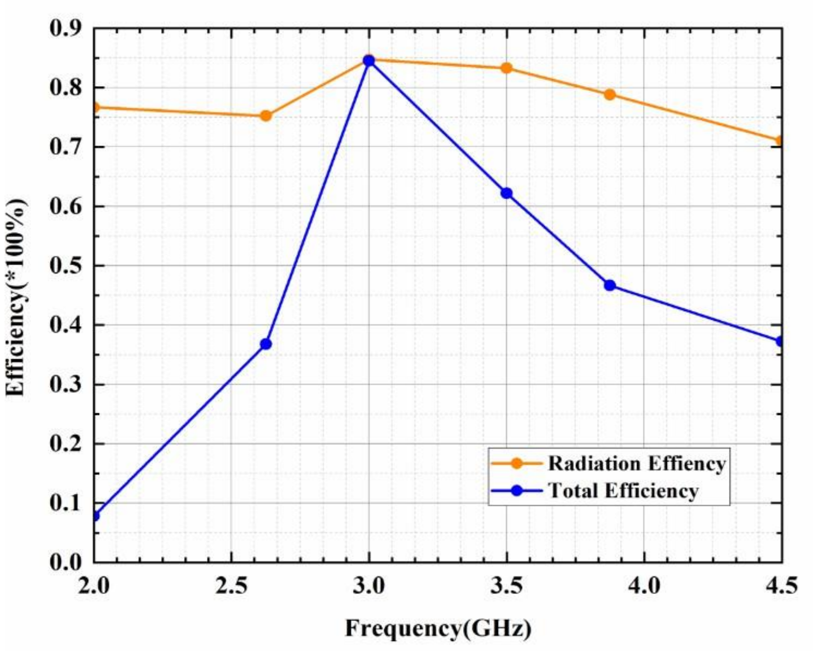


Fig.5.6: Efficiency vs Frequency for proposed antenna

- ## Table 5.1: Comparative Study Table

Substrate Name	Resonant Frequency (GHz)	Efficiency (Total)	S11 Parameter(dB)	Gain(dB)
FR-4	3.025	84.72	-32.27	5.12
Arlon AD 300C	3.045	93.004	-23.64	5.34
Rogers RT 5880	3.725	92.68	-20.83	5.68
TLC30	3.405	92.48	-20.89	5.67

- ## Return Loss or S_{11} Parameter of Different Substrate Material:

The graph compares the S_{11} parameter (return loss) for four substrates: TLC 30, FR4, Rogers RT 5880, and Arlon AD 300C. Lower S_{11} values indicate better impedance matching, ideally below -10 dB. FR4 exhibits the best performance with a minimum S11 of -32.27 dB at 3.025 GHz, indicating excellent impedance matching. Arlon AD 300C follows with S11 of -23.64 dB at 3.045 GHz, showing good matching. TLC 30 performs moderately with a S11 of -20.89 dB at 3.405 GHz. Rogers RT 5880 shows the least optimal matching, with a minimum S11 of -20.83 dB at 3.725 GHz.

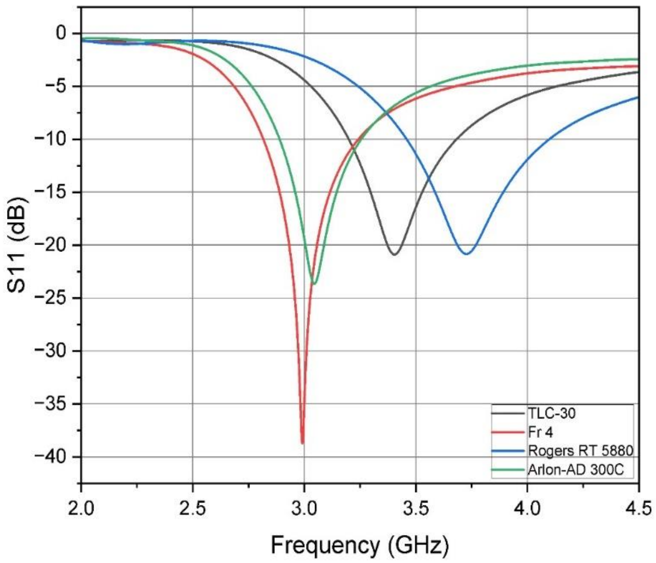


Fig 5.7: <u>Return Loss or S11 Parameter</u>

- ## <u>Gain Comparison for Different Substrate material:-</u>

The graph shows a comparison of maximum gain versus frequency for various dielectric substrates: TLC 30, FR4, Rogers RT 5880, and Arlon AD 300C. The frequency range is from 2.0 GHz to 4.5 GHz, and the maximum gain is in decibels (dB). Rogers RT 5880, marked as the blue curve, provides maximum gain with approximately 5.68 dB at 3.0 GHz followed by a little decrease towards the higher end. Arlon AD 300C, plotted as green, and TLC 30, in black, perform quite similarly, giving around 5.67 dB at 3.0 GHz. FR4, indicated by the red curve, has the worst performance with a peak at around 5.12 dB at 3.0 GHz but dropping quite drastically at the higher frequencies. Generally, Rogers RT 5880 has the best performance, and FR4 has the poorest gain over the frequency range.

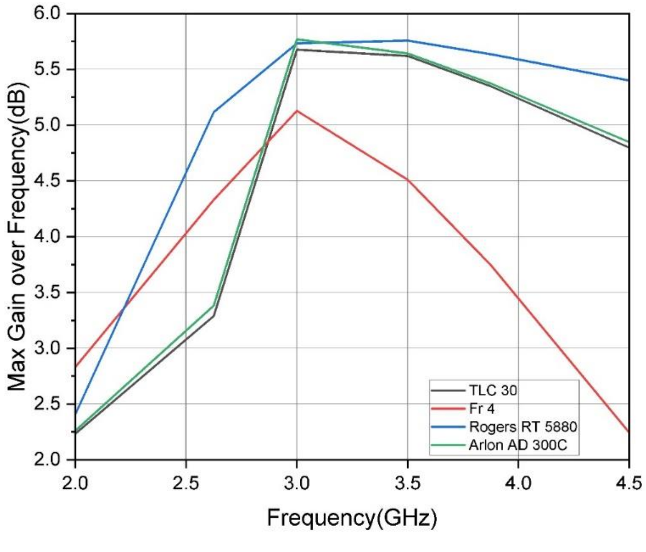


Fig 5.8: <u>Gain plot for different substrate materials</u>

Results for Final Proposed E-MPA:

- **S_{11}/Return Loss:**

The below graph shows the return loss (S_{11} parameter) versus frequency for two elliptical microstrip patch antennas: one with a slot and substrate height of 1.8 mm (red curve), and one without a slot and substrate height of 1.6 mm (blue curve). Return loss indicates how much power is reflected back; lower values (more negative) mean better performance. The antenna with the slot achieves a slightly better return loss of –22.34 dB compared to –20.89 dB for the antenna without the slot, both near 3.4 GHz. This means the slotted design reflects less power and has better impedance matching, resulting in more efficient signal transmission at that frequency.

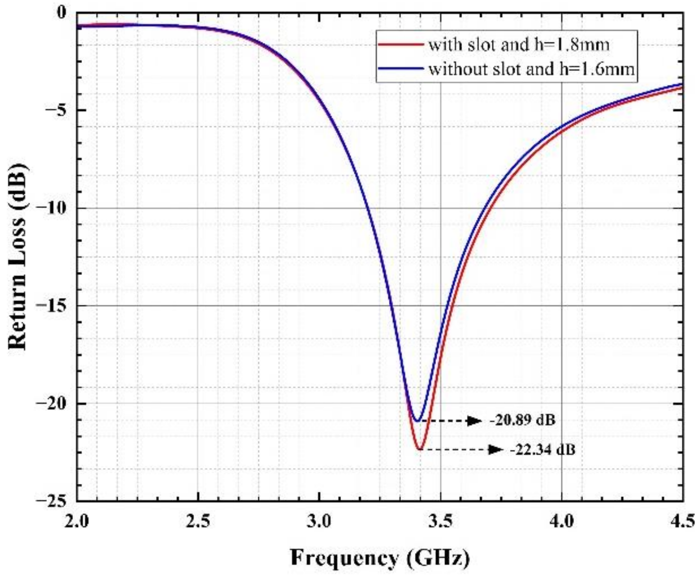


Fig 5.9: Return Loss for Final E-MPA

- **VSWR:**

The below graph shows the VSWR (Voltage Standing Wave Ratio) versus frequency for elliptical microstrip patch antennas—one with slots and substrate height 1.8 mm (red curve), and one without slots and height 1.6 mm (blue curve). VSWR indicates how efficiently power is transmitted from the antenna; a lower value (close to 1) means better matching and less reflected power. Both designs show their best performance around 3.4 GHz, where VSWR drops below 2, which is acceptable for good antenna operation. The slotted antenna (red) achieves slightly better VSWR at the resonant frequency, showing improved radiation efficiency at that point.

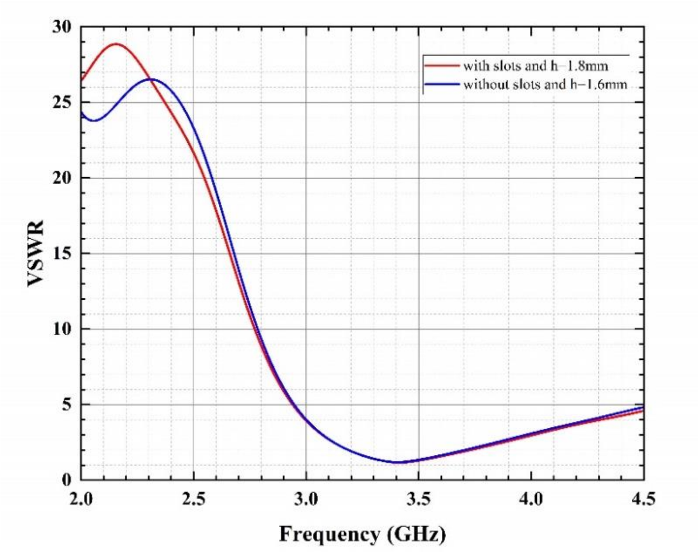


Fig 5.10: VSWR for Final E-MPA

- **Gain:**

The below graph illustrates how the gain of elliptical microstrip patch antennas changes with frequency for two configurations: one with slots and substrate height of 1.8 mm, and another without slots and a 1.6 mm height. Gain, measured in dBi, reflects how effectively the antenna radiates in a particular direction. As frequency increases, both antennas show a rise in gain, leveling off around 3.1–3.5 GHz. The antenna without slots reaches a slightly higher peak gain of 5.68 dBi, while the slotted version achieves 5.63 dBi. Although the difference is minor, it suggests that the non-slotted antenna offers slightly better directional performance at the target frequency range.

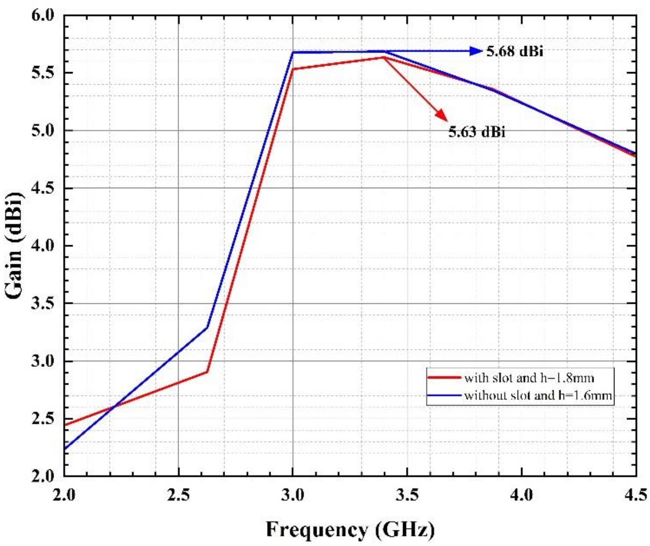


Fig 5.11: Gain for Final E-MPA

- **Bandwidth:**

The antenna's bandwidth was determined using CST software, with the slotted design operating from 3.2 GHz to 3.705 GHz and the non-slotted design from 3.2 GHz to 3.68 GHz. Bandwidth is a key parameter in antenna design, as it defines the frequency range over which the antenna performs efficiently. The slotted antenna with 1.8 mm substrate height provides a slightly wider bandwidth of 505 MHz compared to 480 MHz for the non-slotted version. Both bandwidths are adequate for 5G applications, covering a significant portion of the allocated 5G spectrum. A broader bandwidth enables higher data rates and supports both concurrent and non-concurrent channel transmissions, making these antennas well-suited for modern high-speed wireless communication systems.

- **Radiation Pattern:**

The H-field and E-field radiation patterns of the designed elliptical Microstrip Patch Antenna (MPA), resonating at 3.4 GHz, are depicted in Figures 5.12 and 5.13, respectively. The H-field pattern demonstrates a broad main lobe with dominant co-polarized (Co-pole) radiation and relatively low cross-polarized (Cross-pole) components, indicating good polarization purity in the magnetic field distribution. Conversely, the E-field pattern exhibits a more directional response with a distinct main lobe and suppressed cross-polarization levels, signifying effective electric field radiation. The observed symmetry and consistency in both radiation patterns confirm the stable and efficient performance of the elliptical MPA at the specified resonant frequency, making it well-suited for modern wireless communication applications.

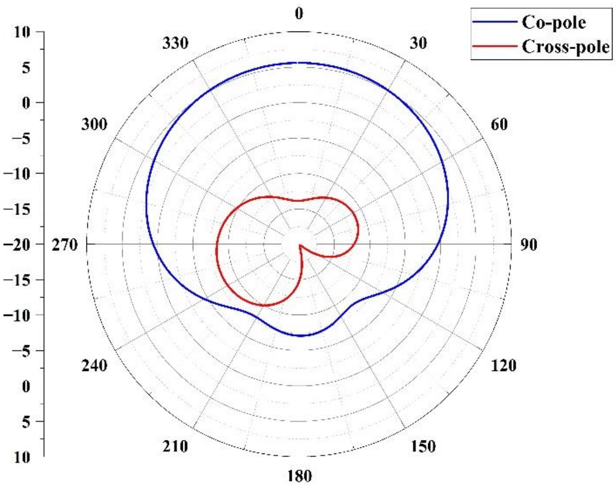


Fig.5.12: **Normalized H-plane Radiation Pattern at 3.4GHz**

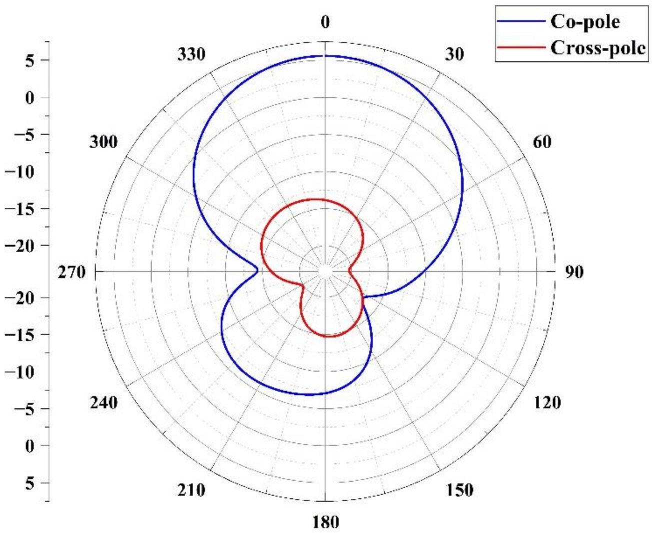


Fig.5.13: **Normalized E-plane Radiation Pattern at 3.4GHz**

- **Total and Radiation Efficiency:**

This graph illustrates how the radiation efficiency (red line) and total efficiency (blue line) of the elliptical microstrip patch antenna with slots vary across the frequency range of 2.0 GHz to 4.5 GHz. The radiation efficiency stays consistently high, approximately 94.9%, showing that the antenna effectively converts input power into radiated energy throughout the band. Meanwhile, the total efficiency rises sharply and peaks at around 3.4 GHz, reaching approximately 94.1%, before gradually decreasing. This peak aligns with the antenna's resonant frequency, where return loss and VSWR are optimal. The slotted design and increased substrate height likely enhance this performance by improving impedance matching and reducing losses, making the antenna highly efficient and well-suited for 5G applications.

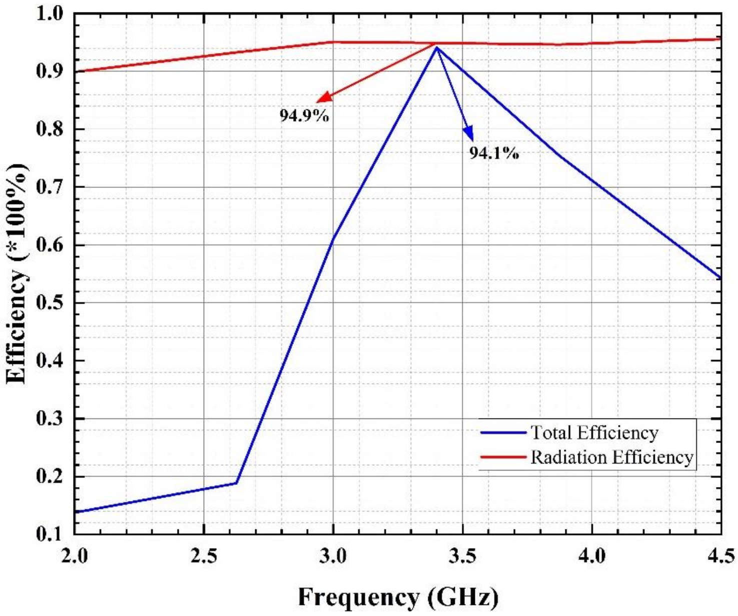


Fig 5.14: Efficiency for Final E-MPA

Discussions for Final Proposed E-MPA:

Based on the analyses of return loss, VSWR, gain, bandwidth, and efficiency, it is evident that the elliptical microstrip patch antenna with slots offers notable advantages over the non-slotted version for 5G applications. The slotted antenna achieves better impedance matching, as reflected by a lower return loss (–22.34 dB) and slightly improved VSWR, both centered around the resonant frequency of 3.4 GHz. Although the gain of the slotted antenna is marginally lower than the non-slotted version, its broader bandwidth of 505 MHz (compared to 480 MHz) allows it to support higher data rates and better accommodate wideband 5G signals. Moreover, the high and stable radiation efficiency, along with a total efficiency peaking at 94.1% near resonance, confirms the effectiveness of the slot design in reducing losses and enhancing performance. These characteristics together suggest that the slotted elliptical patch antenna is well-optimized for modern wireless systems requiring efficient, compact, and wideband solutions

CHAPTER - 6

Compact Microstrip Patch Antenna Design for 5G Communications

FUTURE SCOPE & CONCLUSION

Future - Scope:

The compact microstrip patch antenna (MPA) design for 5G communications is proposed and proved to be effective. Nevertheless, there are several aspects for future research and development that may have a positive impact on the performance, scalability, and application of our design. The following sections outline the potential areas of improvement and exploration:

1. Integration into MIMO Systems

- Extend the single-element design to a multi-element array for use in Multiple-Input Multiple-Output (MIMO) configurations.
- Study mutual coupling effects and implement decoupling techniques to maintain isolation and system performance.

2. Reconfigurability

- Incorporate tunable components such as PIN diodes, varactors, or MEMS to enable frequency and pattern reconfigurability.
- Facilitate dynamic adaptation for cognitive radio and future 5G/6G networks.

3. Flexible and Wearable Applications

- Explore the fabrication of the antenna on flexible substrates to investigate its suitability for wearable or conformal applications.
- Evaluate mechanical durability and biocompatibility for integration into biomedical or body-worn systems.

4. Performance Optimization

- Employ optimization algorithms or machine learning models to fine-tune design parameters such as slot dimensions, substrate height, and feed position.
- Aim to achieve improved gain, bandwidth, and radiation characteristics with reduced design iterations.

5. Environmental and EMC Testing

- Conduct thermal, humidity, and mechanical stress testing to assess antenna reliability under real-world operating conditions.
- Perform electromagnetic compatibility (EMC) and interference (EMI) analysis to ensure compliance with communication standards.

6. Advanced Beamforming and Radiation Control

- Investigate the potential for beam shaping or steering through structural modifications or active components.
- Support directional communication and smart antenna system applications, such as in vehicular or UAV platforms.

Conclusion:

The design and simulation of the elliptical FR-4 microstrip patch antenna proved that it is suitable for 5G communication in the sub-6 GHz range. The project started by testing different antenna shapes, like circular and rectangular ones, but they didn’t meet the high efficiency and bandwidth needs of 5G. After experimenting, the elliptical shape was selected and carefully optimized because it offered a good balance of compact size, signal gain, and good performance. The Final E-MPA achieved observable results, including a low VSWR of 1.048 (showing good impedance matching), a strong return loss of –32.27 dB, and a gain of 5.12 db for good signal coverage. It also offered a bandwidth of 3.025 GHz, covering a large portion of the 5G spectrum, and a total efficiency of 84.72% with a partial ground structure—making it well-suited for modern wireless communication needs.

To enhance the performance of the microstrip antenna substrate material plays an important role, especially in terms of efficiency, bandwidth, and size. Rogers RT5880, with the lowest dielectric constant, offers high efficiency and wide bandwidth for high-frequency use but is costly. FR-4 is a budget-friendly option for low-frequency designs, though with lower performance. Arlon AD 300C provides a good balance between cost and performance. TLC30, with a dielectric constant of 3.0, offers decent efficiency and compact size, making it suitable for mid-range applications.

Using TLC30 as the substrate material, the elliptical microstrip patch antenna showed strong performance after design modifications. By increasing the substrate height to 1.8 mm and adding two slots, the antenna achieved an S11 of –22.34 dB at 3.4 GHz, a radiation efficiency of 94.9%, a gain of 5.634 dB, and a bandwidth of 505 MHz. In comparison, the non-slotted design with a 1.6 mm substrate height delivered a slightly higher efficiency of 94.1%, a gain of 5.68 dB, and a narrower bandwidth of 480 MHz. Although the slotted antenna had marginally lower gain, it offered improved impedance matching and a better VSWR at the resonant frequency of 3.45 GHz. Overall, the slotted design provides enhanced bandwidth and better performance near resonance, making it more suitable for 5G applications requiring wider frequency coverage.

These results validate the importance of optimizing the shape, structure, and substrate materials used in microstrip patch antennas. This project highlights the significance of careful design considerations and optimization processes, making the proposed antenna a reliable solution for 5G applications requiring.

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