Compact Microstrip Patch Antenna Design for 5G Communications

~Presented by~

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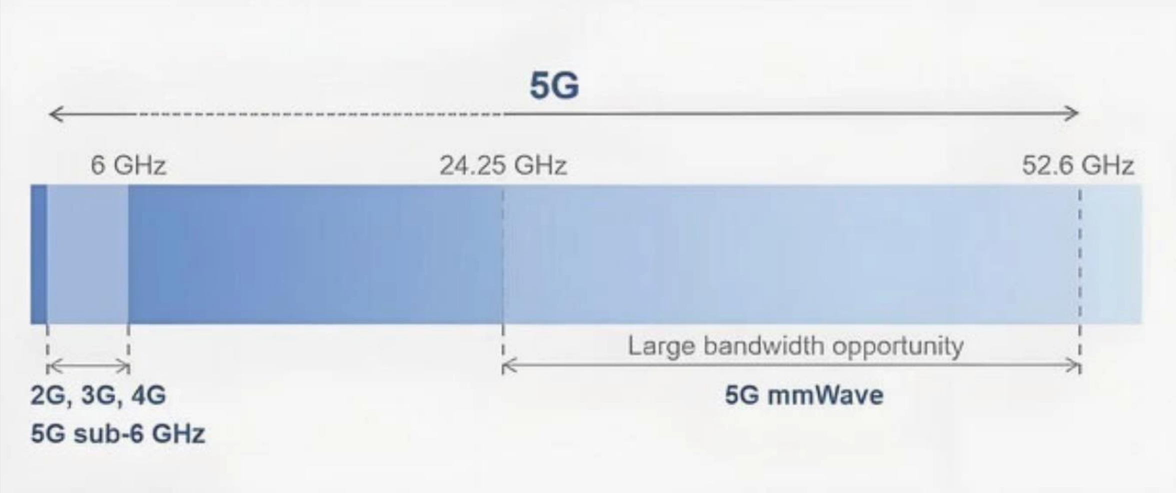
OUTLINE

- ❑*Introduction*
- ❑*Objective*
- ❑*A Glimpse of the Antenna and it's Scope*
- ❑*Results and Discussions for Initial E-MPA*
- ❑*Comparative Study using Different Substrate materials*
- ❑*Final E-MPA Design(with Slots)*
- ❑*Results and Discussion for Final Proposed E-MPA*
- ❑*Conclusion*
- ❑*Acknowledgement*
- ❑*Reference*

Exploring 5G in Sub-6 GHz

❑ 5G Sub-6 GHz

- ***Frequency Range:*** Below 6 GHz
- ***Coverage Area:*** Wider area; can cover several km
- ***Penetration & Propagation:*** Can penetrate walls and buildings effectively
- ***Deployment:*** Urban, Sub-urban and rural areas



Focus and Purpose

- **Sub-6 GHz** supports reliable 5G for **mobile broadband**, **IoT**, and **wide-area coverage**, ensuring strong connectivity in diverse environments
- With **wider coverage per cell**, Sub-6 GHz **lowers infrastructure costs**, making large-scale **5G deployment more affordable**
- Most modern devices support Sub-6 GHz, enabling **widespread 5G adoption** and **seamless connectivity** across various devices
- **Microstrip antennas** are widely utilized due to their **ease of integration** with **circuitry**, **low cost**, **lightweight design**, and **conformability**

Proposed Antenna Design

- Initial design was for a conventional circular microstrip patch antenna (MPA)
- Modifications in dimension values were made, but the intended outcome was not achieved
- As a result, the patch shape was modified from circular to elliptical
- Formulas used for the elliptical patch are similar to those for the circular MPA

Initial Prototype

- As mentioned earlier this is the Initial Prototype of the Circular Microstrip Patch Antenna

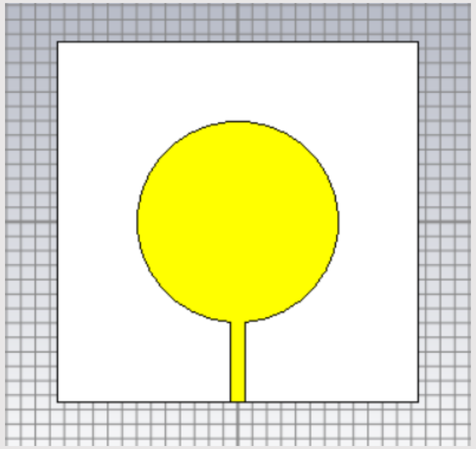


Fig: *Front view of the initial prototype*

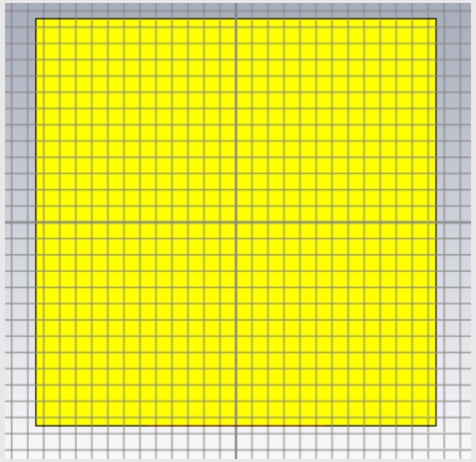


Fig: *Rear-view of the Initial prototype*

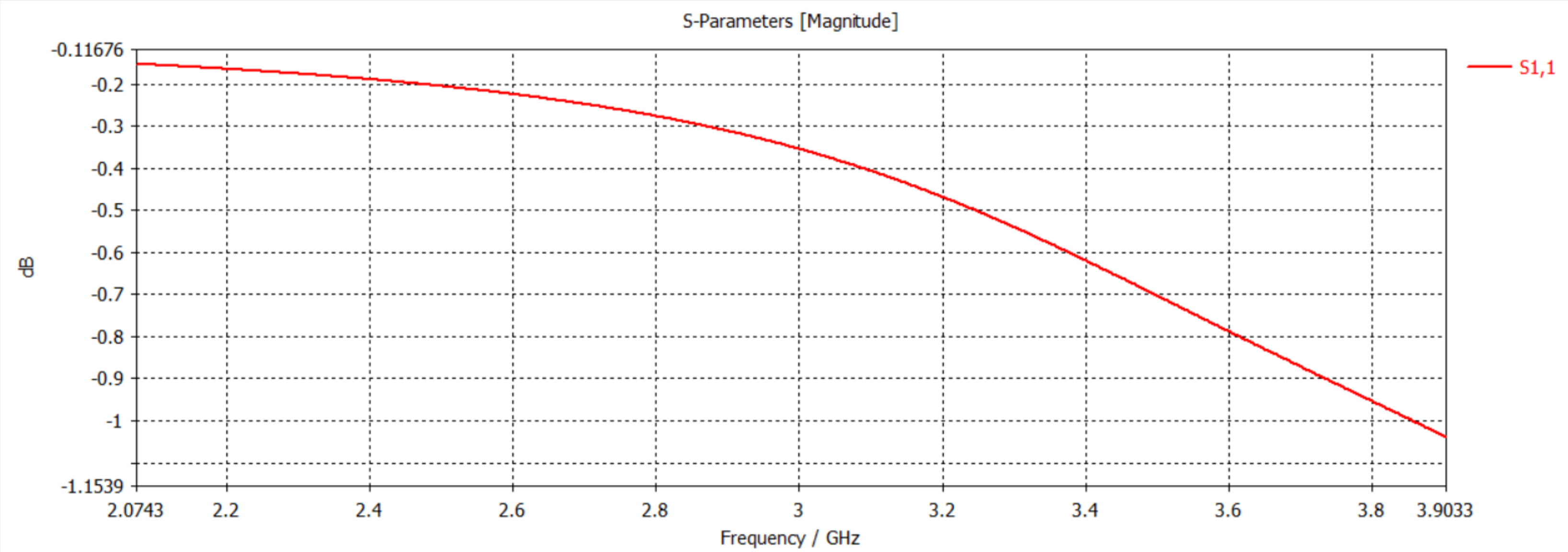


Fig: *Return Loss Graph of the initial prototype*

Intermediate Prototype

- This is the intermediate design- a flipped P-shaped Elliptical MPA(i,e E-MPA) with full-ground

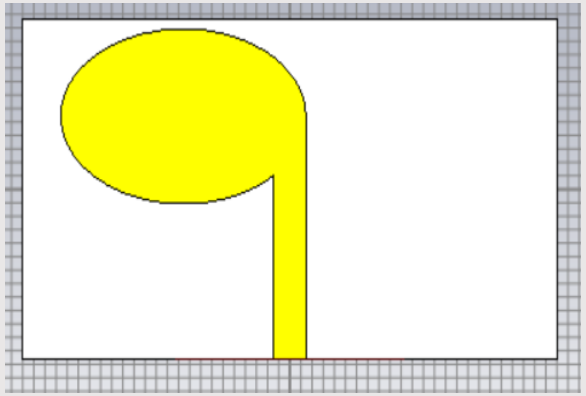


Fig: *Front View of Intermediate Prototype*

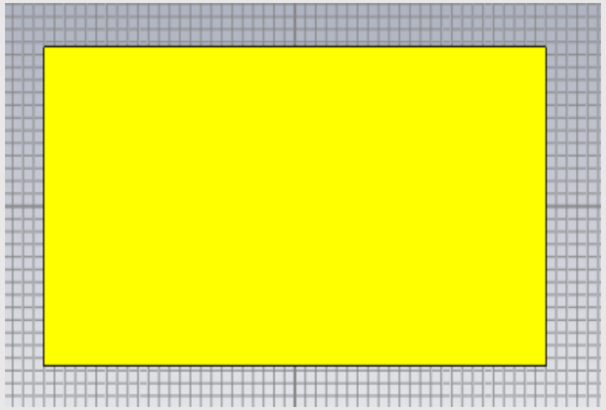


Fig: *Rear-view of Intermediate Prototype*

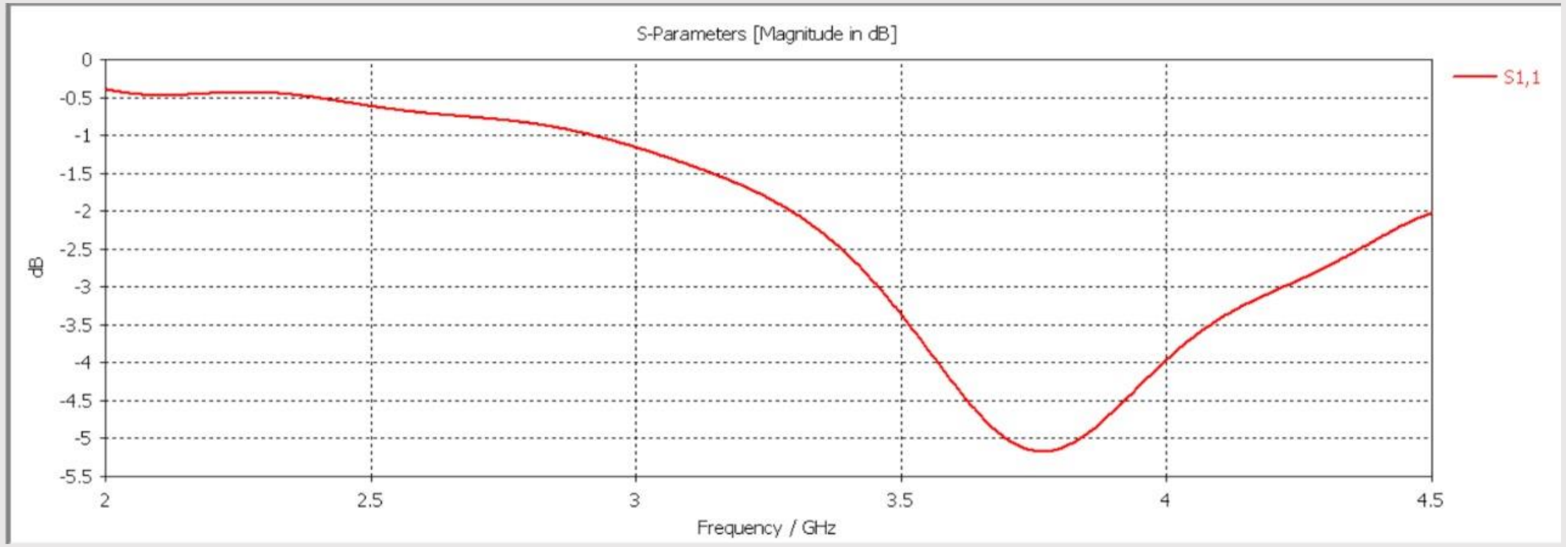


Fig: *Return Loss Graph of the intermediate prototype*

A Glimpse of the Initial Antenna Design and it's Scope

- **Proposed:** A Flipped-P Shaped E-MPA
- **Discussion:** The five primary characteristics of antennae are discussed later
- **Scope:** high speed lower 5G/Wi-Fi communication, short range radar system, digital TV and radio broadcasting applications

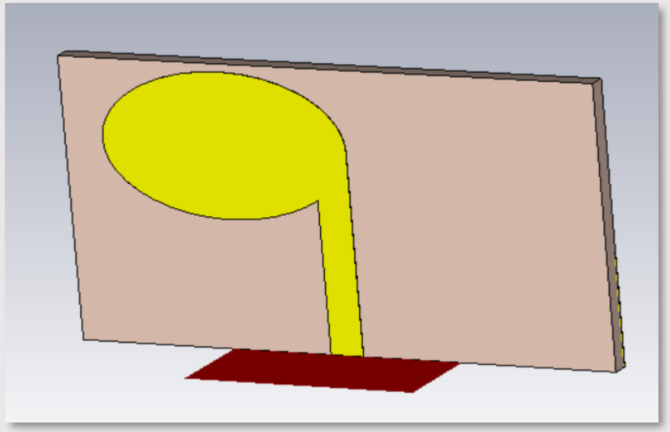


Fig: *Initial Proposed E-MPA*

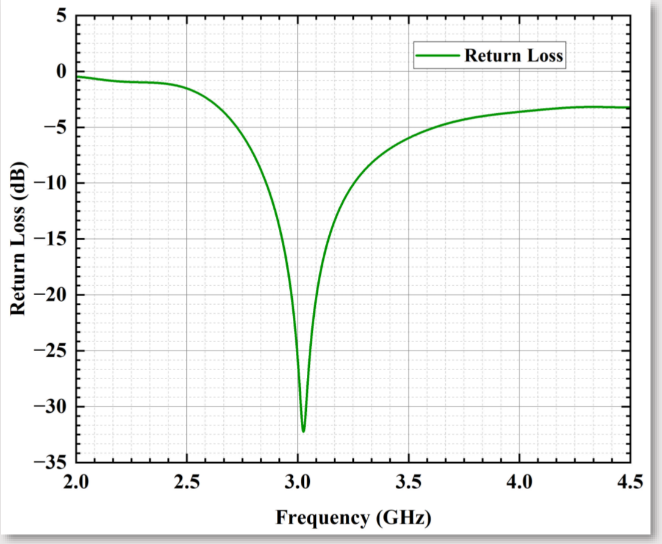


Fig: *Return Loss Graph of Initial E-MPA*

Comparison of S11 parameters of all designs

- Graph shows how the S11 parameters of the individual models differ from each other
- Initial Circular Antenna had no resonating frequency around 2-4.5 GHz
- The intermediate Elliptical Antenna with full ground however had a resonating frequency around 3.7 GHz but not desirable enough
- Then the final Elliptical Antenna with partial ground was suggested which had both desirable S11 parameter and a resonant frequency within the range

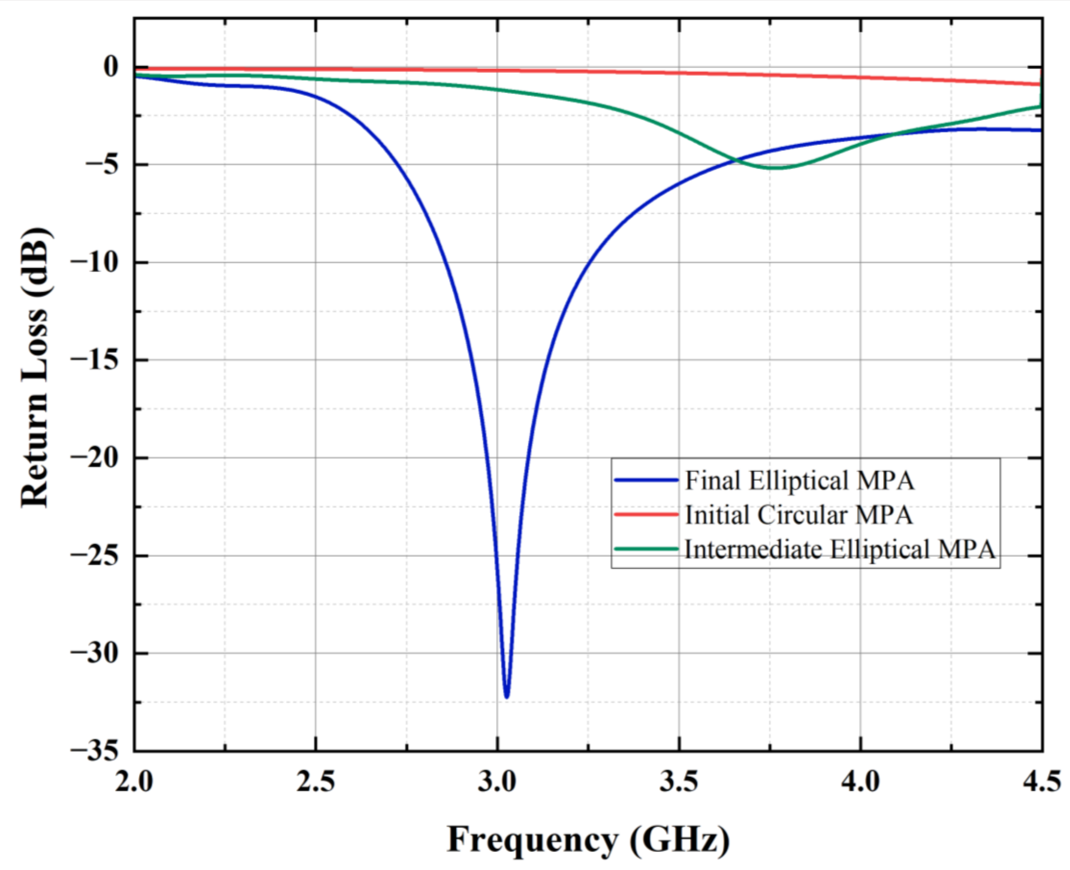


Fig: *S11 Comparison Graph for all three prototypes*

Initial Antenna Specifications:

Parameters	Optimized Value
Resonant Frequency, 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, W_s (mm)	48
Feedline Width, (mm)	2.9
Feedline Length, (mm)	18
Ground length, (mm)	48
Ground Width, (mm)	10

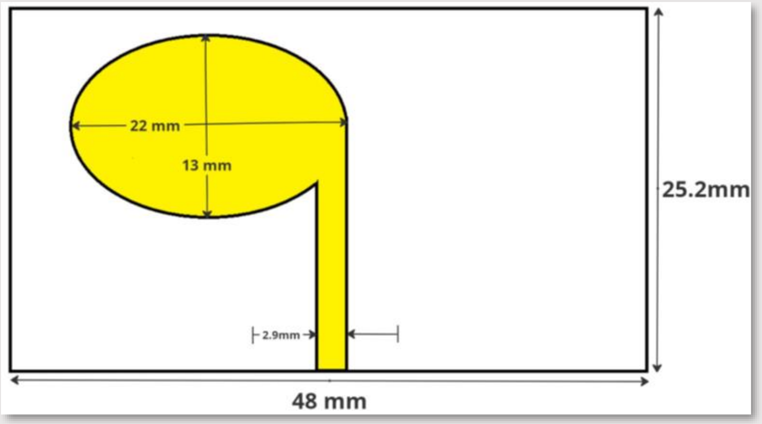


Fig: *Front view of the proposed antenna*

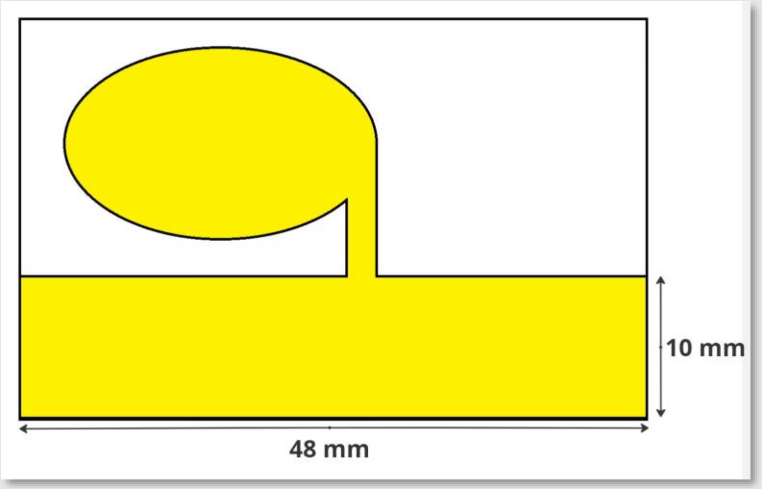


Fig: *Rear view of the proposed antenna with partial ground*

Results and Discussions for Initial E-MPA:

Return Loss or S_{11} parameter

- ***S_{11} Formula:***

  Return Loss$=-20log_{10}(\Gamma)$ dB

- ***EMPA Reflection Loss*: -32.27 dB** at **3.025 GHz**
- ***Reflection Meaning*:** High reflection with -32.27 dB, indicating efficient signal reflection.

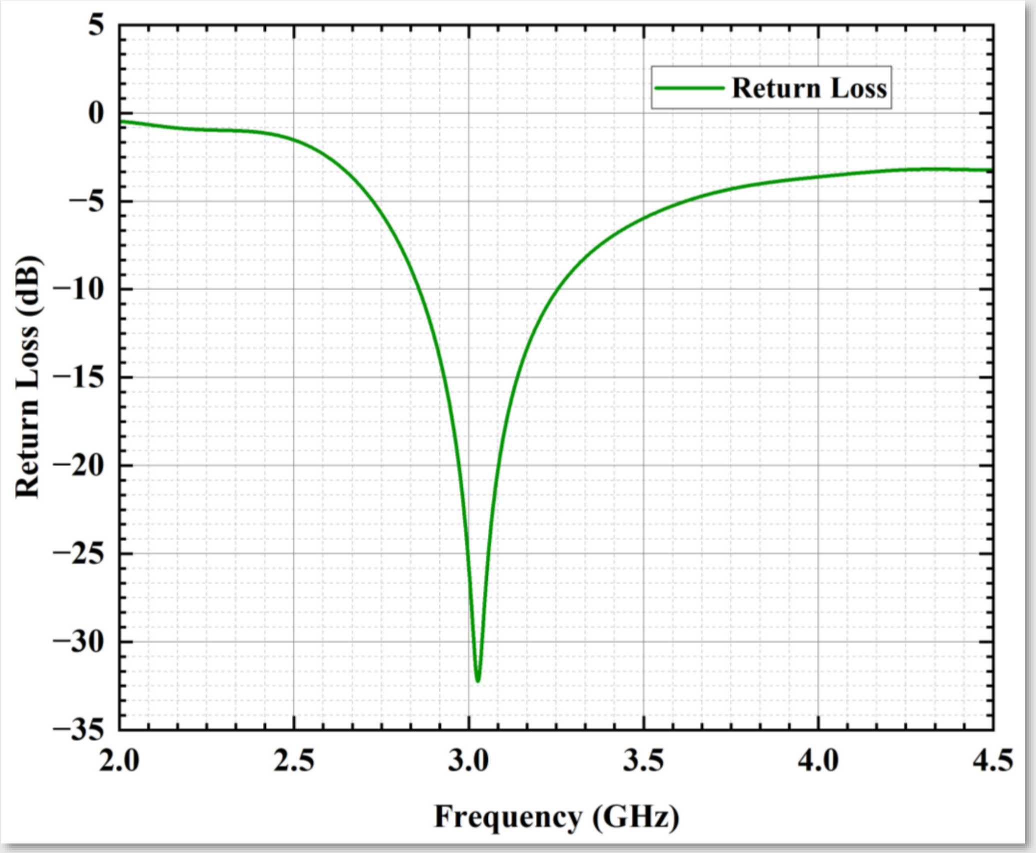


Fig: *Return Loss vs. Frequency for proposed antenna*

Results and Discussions for Initial E-MPA:

Bandwidth & Gain

- ***S11 Criterion:*** Bandwidth computed where S11 < -10 dB
- ***Antenna BW:*** **2.86 GHz** to **3.25 GHz**
- ***Figure :*** Shows **5.12 dBi** gain at 3.025 GHz
- ***Benefit:*** High gain for greater range and signal quality in a specific direction

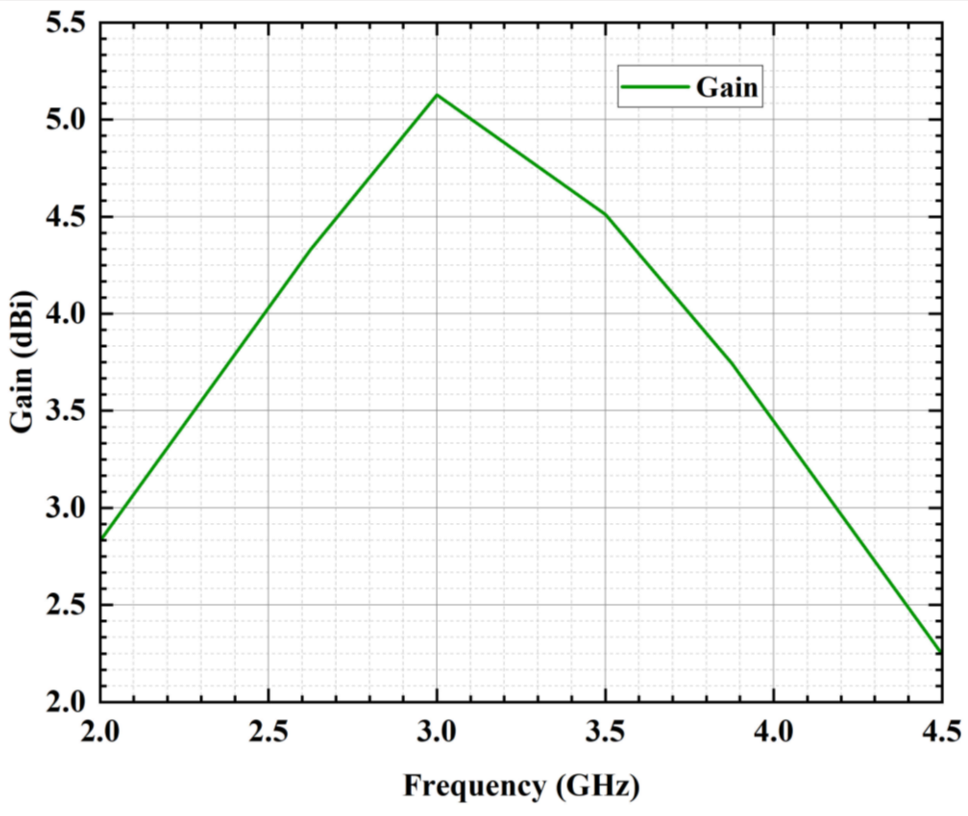


Fig: *Peak Gain vs Frequency for proposed antenna*

Results and Discussions for Initial E-MPA:

Efficiency

- ***Efficiency Figures***: Radiation and total efficiency at 84.72%.

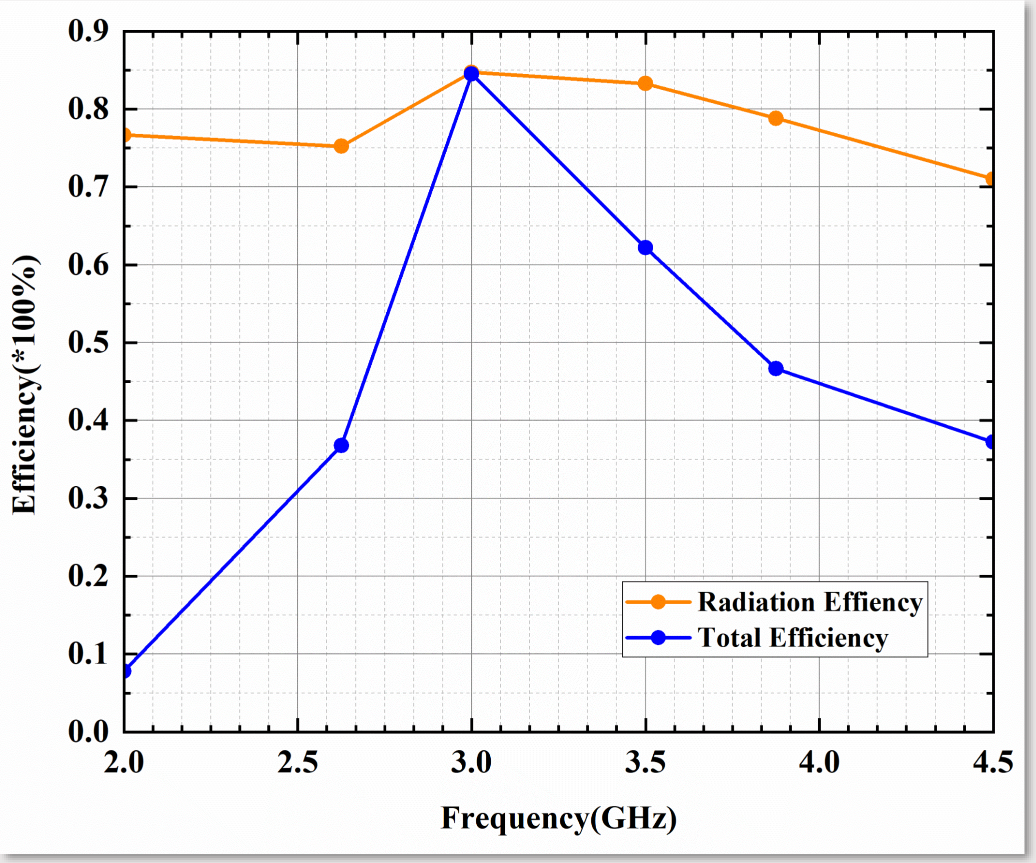


Fig: *Efficiency vs Frequency for proposed antenna*

Results and Discussions for Initial E-MPA:

VSWR

- ***Figure:*** Shows VSWR of 1.048 at 3.025 GHz.

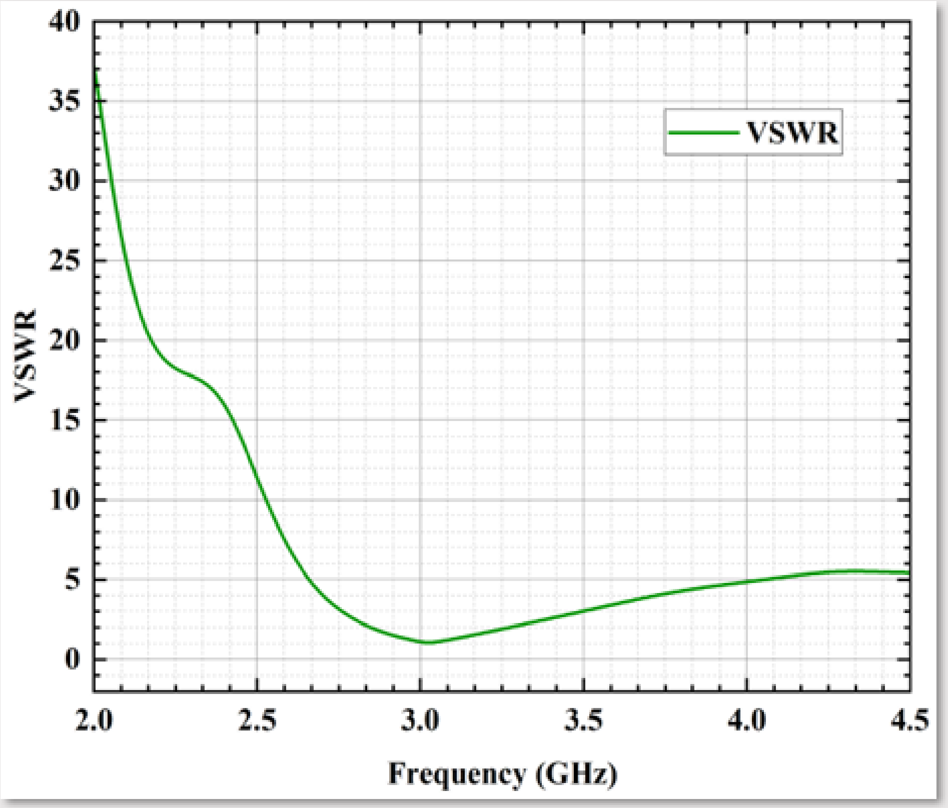


Fig: *Voltage Standing Wave Ratio (VSWR)*

Results and Discussions for Initial E-MPA:

Radiation Pattern

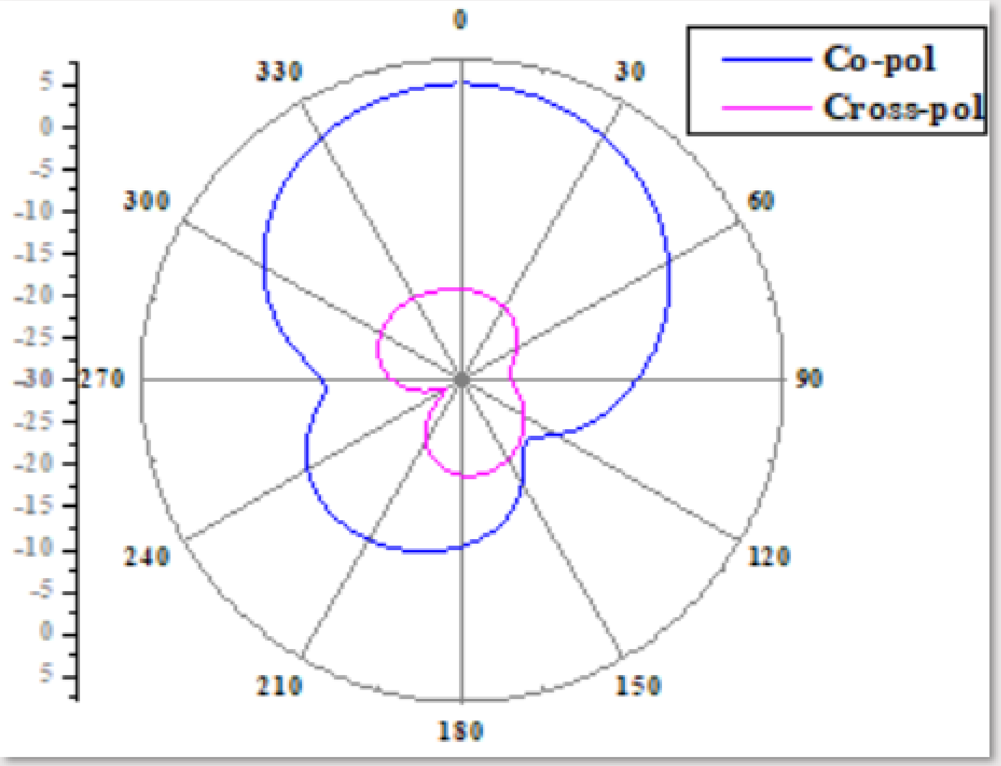


Fig: *Normalized E-plane Radiation Pattern at 3.025GHz*

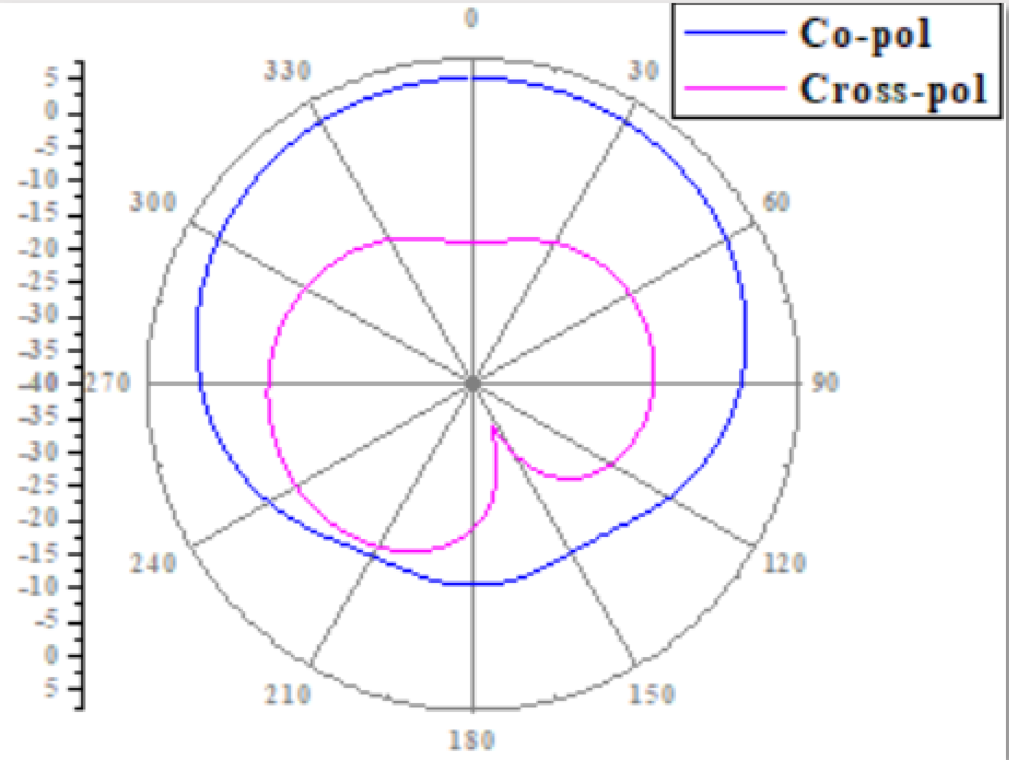


Fig: *Normalized H-plane Radiation Pattern at 3.025 GHz*

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*

- **FR-4 (ε_r = 4.3):** Low cost, high loss, narrow bandwidth – for low-frequency use
- **Arlon AD300C (ε_r = 2.98):** Balanced performance for mid-frequency designs
- **Rogers RT5880 (ε_r = 2.2):** Low loss, high efficiency – ideal for high-frequency applications
- **TLC30 (ε_r = 3.0):** Mid-range option with decent performance

Comparative Study using Different Substrate materials:

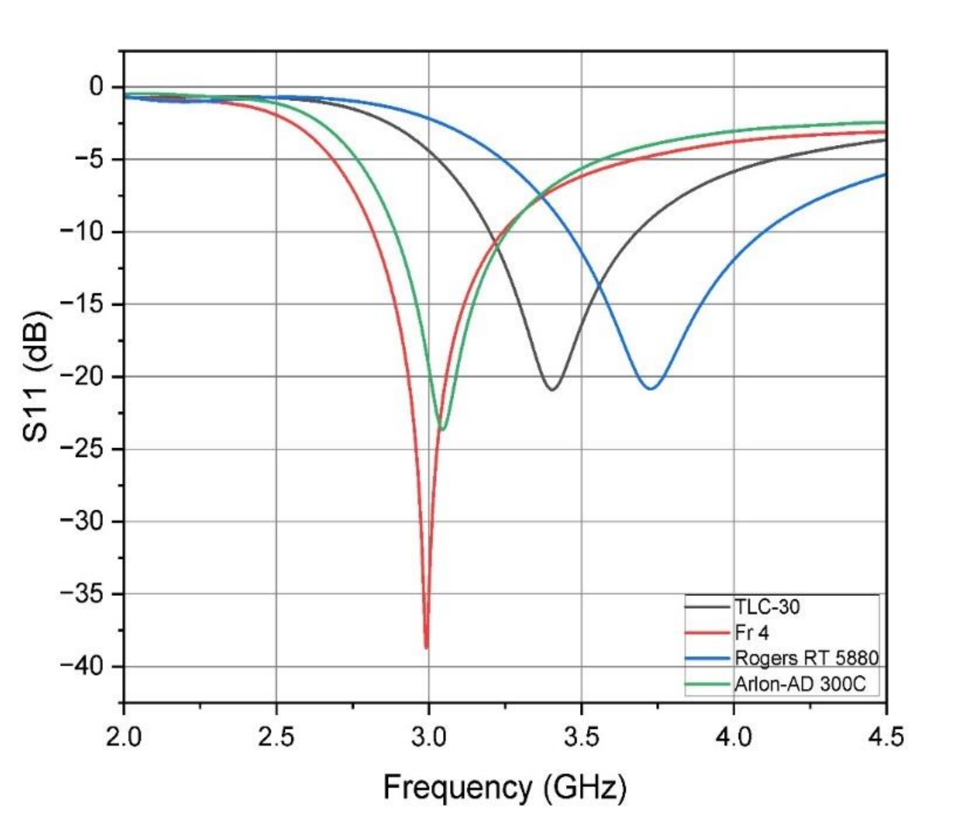


Fig : *Return Loss Comparison Graph*

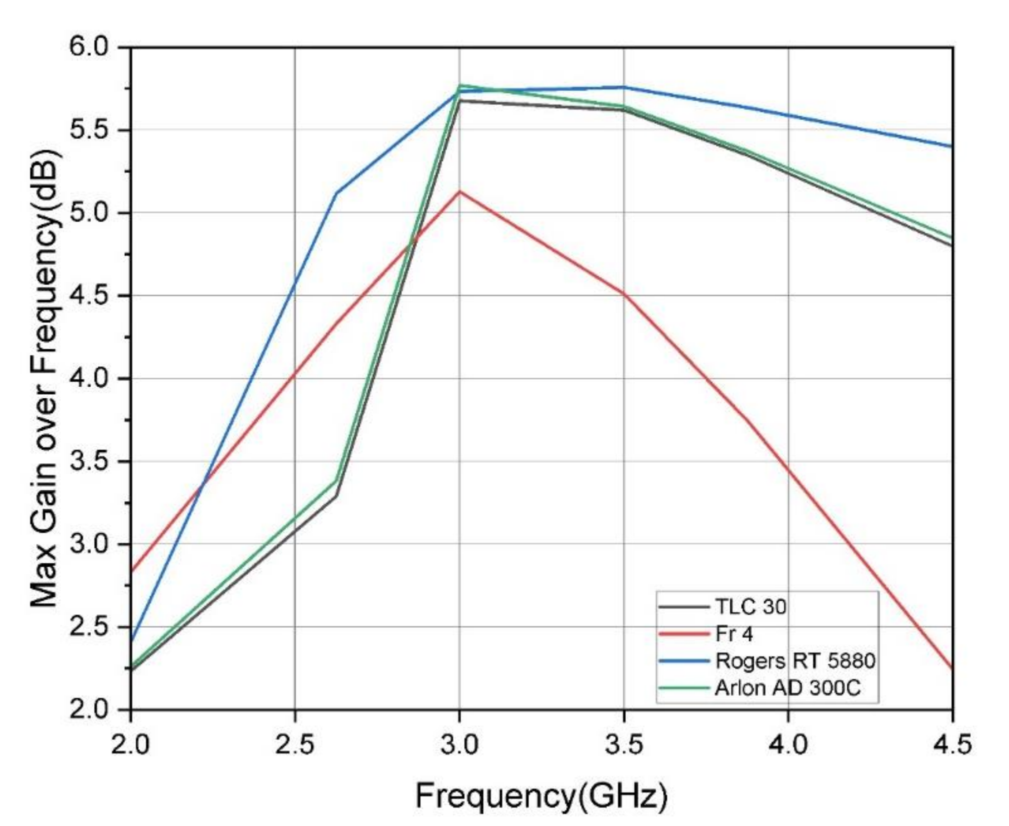


Fig: *Gain Comparison Graph*

Comparative Study using Different Substrate materials:

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

S11 (Return Loss):

- *FR4: Best (-32.27 dB at 3.025 GHz)*
- *AD 300C: Good (-23.64 dB at 3.045 GHz)*
- *TLC30: Moderate (-20.89 dB at 3.405 GHz)*
- *RT 5880: Least (-20.83 dB at 3.725 GHz)*

Gain (at 3 GHz):

- *RT 5880:Highest (~5.68 dB)*
- *TLC30 : Good (~5.67 dB)*
- *AD 300C: Moderate(~5.67 dB)*
- *FR4:Lowest (~5.12 dB)*

Final Choice:

- *TLC30 selected for E-MPA design (balanced S11 & gain)*

Final E-MPA Design(with Slots):

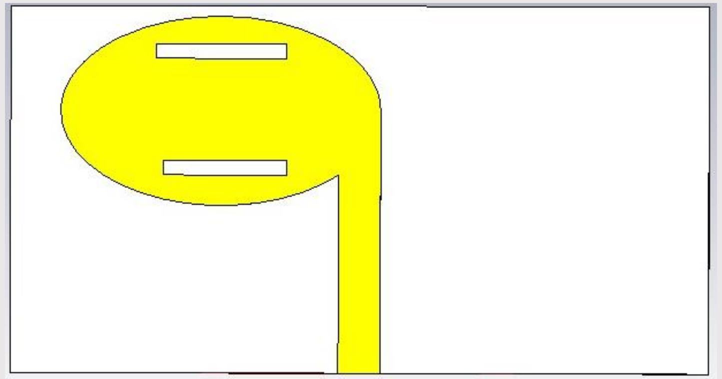


Fig: *Front view of the Final proposed antenna*

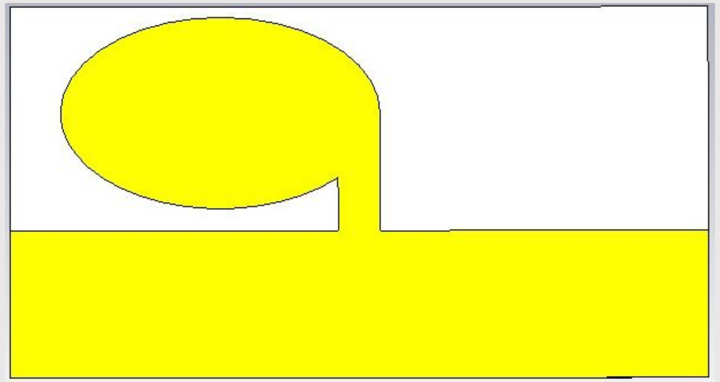


Fig: *Rear view of the Final proposed antenna*

Why TLC30 Was Chosen!!

Dielectric Constant (εr = 3.0):

- ✓ *Balanced trade-off between size, efficiency, and bandwidth*

Performance:

- ✓ *Reliable in sub-6 GHz range (ideal for 5G)*

Cost & Manufacturing:

- ✓ *More affordable and easier to fabricate than premium substrates*

So, Practical choice for high performance and cost-effective antenna design.

Parameter Specification (Final E-MPA):

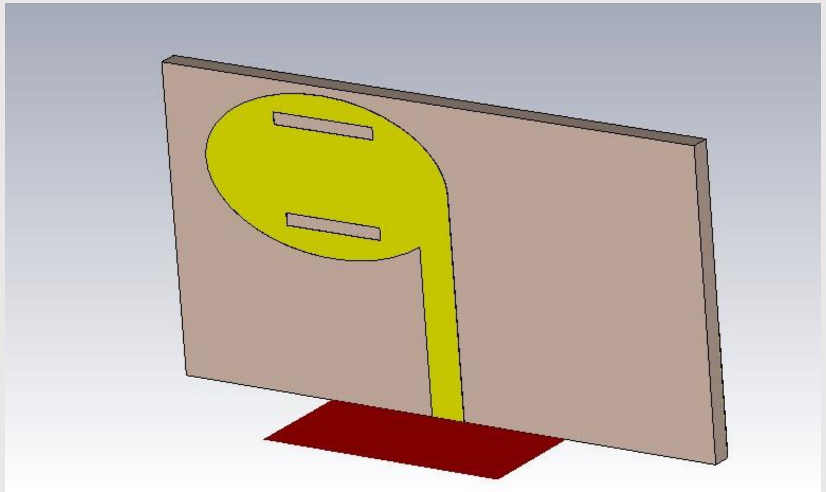


Fig: *Final Proposed E-MPA*

Parameters	Optimized Value
Frequency, 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, W_s (mm)	48
Feedline Length, (mm)	2.9
Feedline Width, (mm)	18
Ground Length, (mm)	48
Ground Width, (mm)	10
No. of Slots	2

Results and Discussion for Final Proposed E-MPA:

- **Return Loss or S_{11} parameter:**

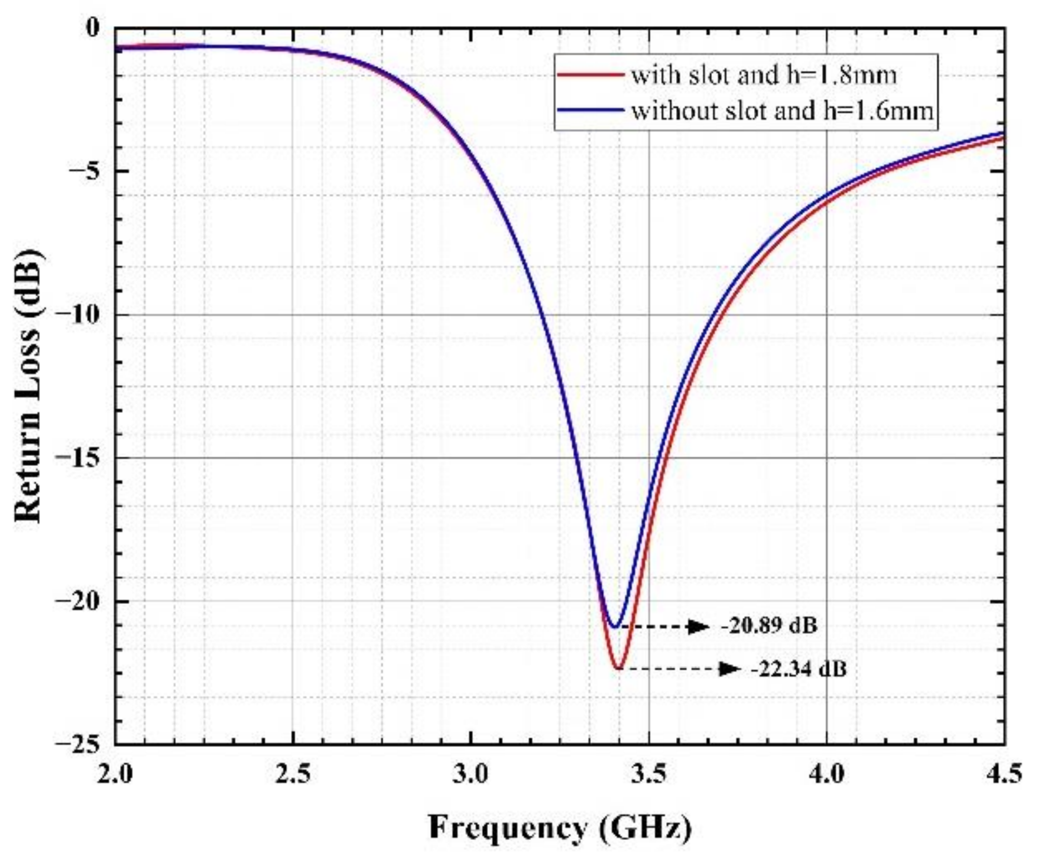


Fig: *Return Loss for Final E-MPA*

Antenna with Slot (1.8 mm height):

✓ S11 = –22.34 dB at ~3.45 GHz (better matching)

Antenna without Slot (1.6 mm height):

✓ S11 = –20.89 dB at ~3.45 GHz

Conclusion:

Slotted design offers improved impedance matching and more efficient transmission

Results and Discussion for Final Proposed E-MPA:

- **Bandwidth & Gain**

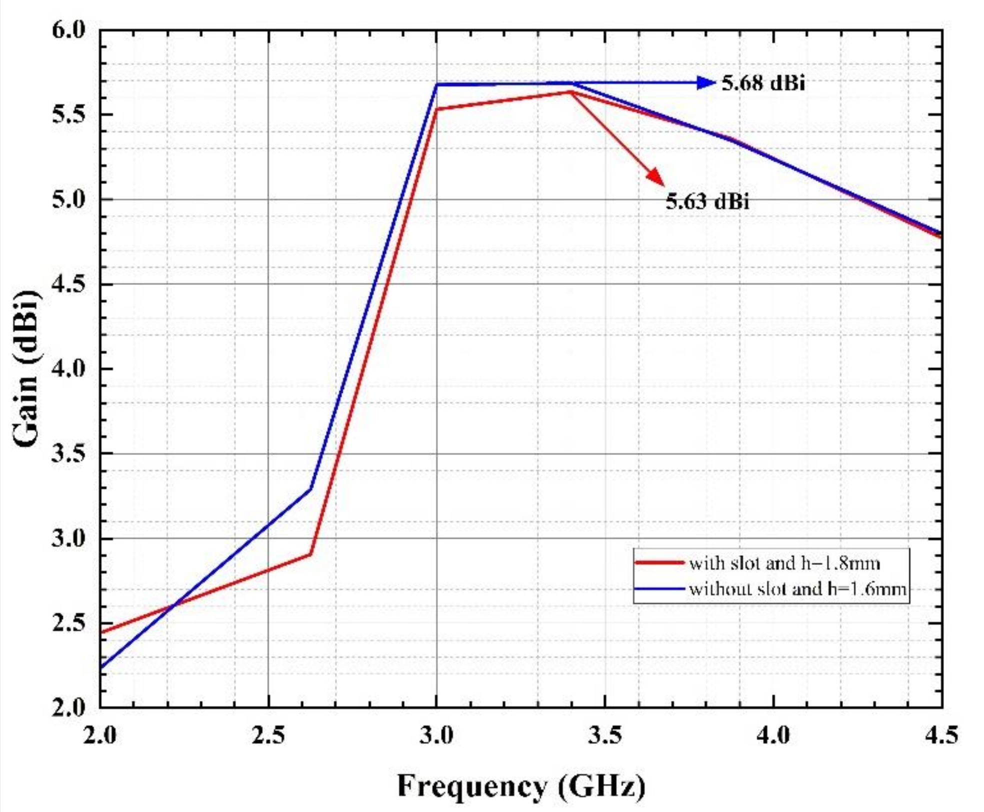


Fig: *Gain for Final E-MPA*

Gain Performance:

✓ Non-slotted (1.6 mm): Peak gain = 5.68 dBi

✓ Slotted (1.8 mm): Peak gain = 5.63 dBi

Both stable from 3.1–3.5 GHz; non-slotted slightly better directionality

Bandwidth (from CST):

✓ Slotted: 3.2 – 3.705 GHz → 505 MHz

✓ Non-slotted: 3.2 – 3.68 GHz → 480 MHz

Slotted antenna offers slightly wider bandwidth*

Conclusion:

Slotted design preferred for better bandwidth

Both support sub-6 GHz 5G with efficient performance

Results and Discussion for Final Proposed E-MPA:

- **Efficiency:**

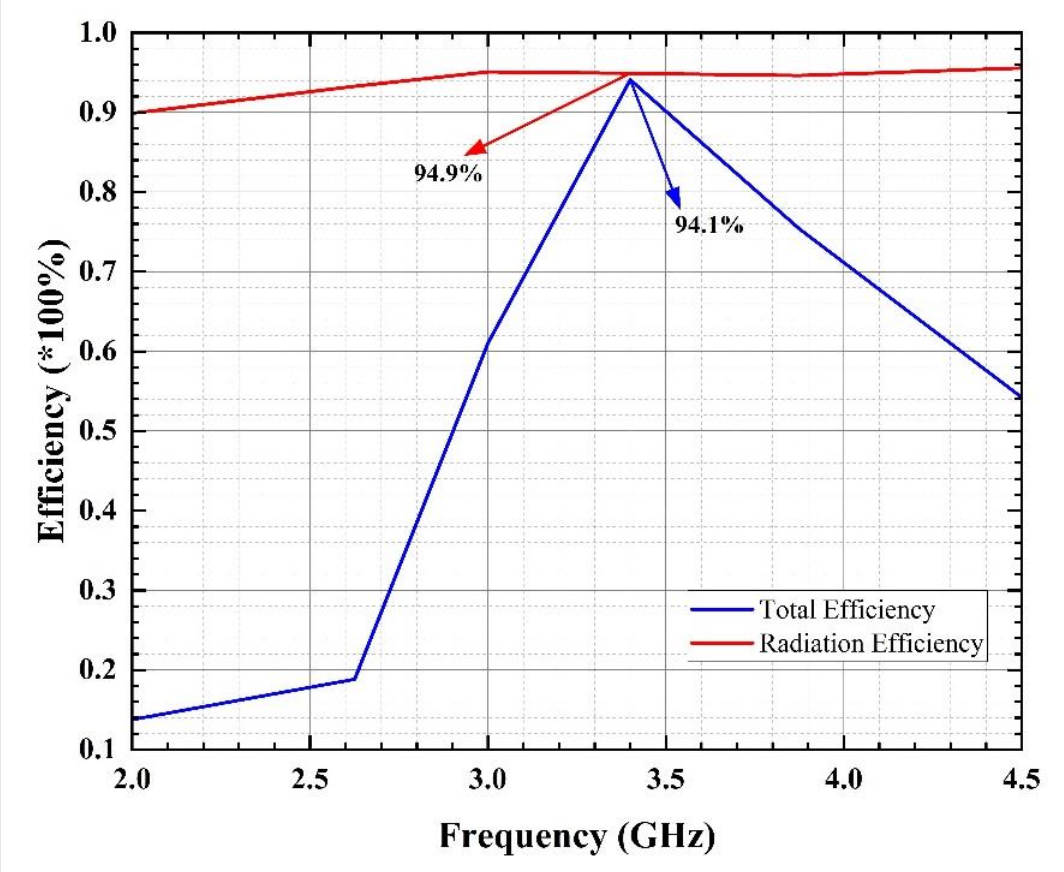


Fig: *Efficiency for Final E-MPA*

Radiation Efficiency:

✓ 94.9% at 3.45 GHz(resonant frequency)

✓ Consistently high conversion of input power to radiated energy

Total Efficiency:

✓ Peaks at 94.1% at 3.45 GHz(resonant frequency)

✓ Sharp rise followed by gradual drop beyond peak

Conclusion:

High efficiency due to slotted design and 1.8 mm substrate height

Well-suited for 5G applications with minimal power loss

Results and Discussion for Final Proposed E-MPA:

- **VSWR:**

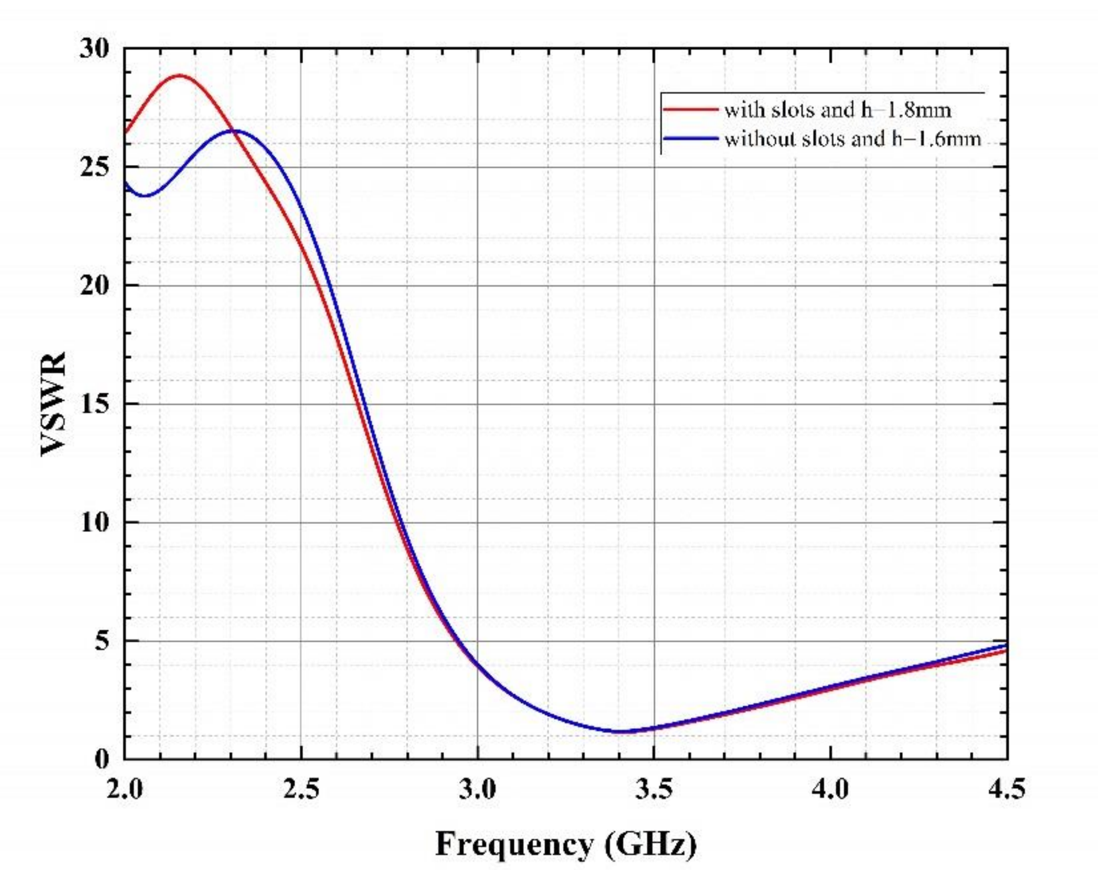


Fig: *VSWR for Final E-MPA*

Best at ~3.45 GHz:

✓ Both VSWR < 2 (good matching)

Slotted (1.8 mm):

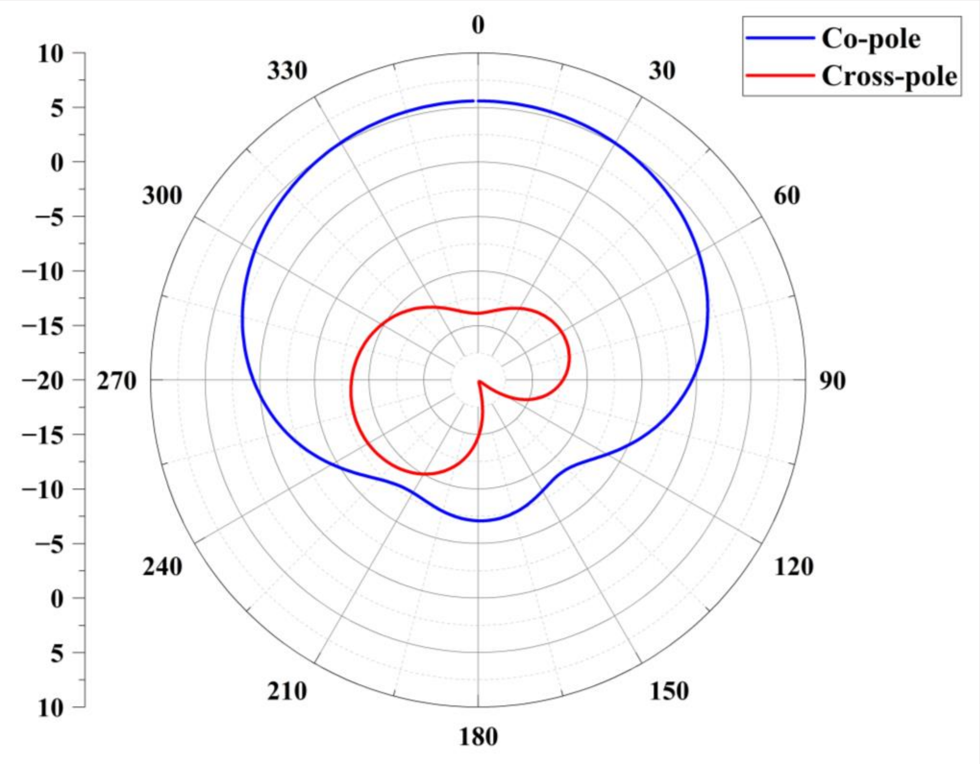
✓ Slightly lower VSWR → better efficiency

Conclusion:

Slotted design offers improved impedance matching

Results and Discussion for Final Proposed E-MPA:

- **Radiation Pattern:**



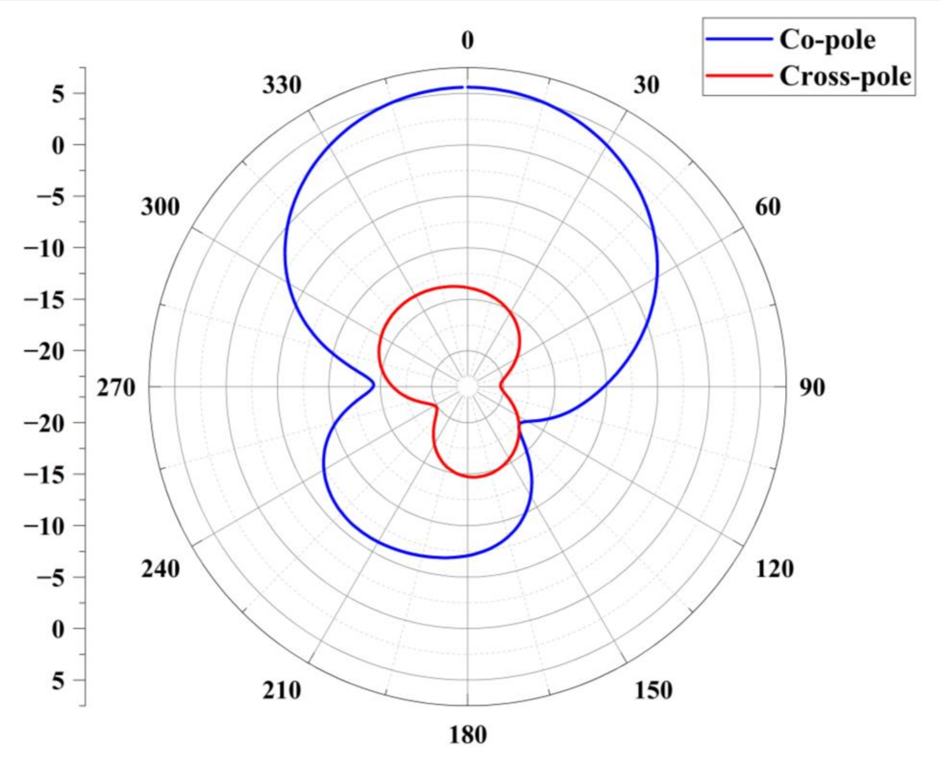


Fig: *Normalized H-plane Radiation Pattern at 3.4GHz*

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

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***

Conclusion

This project successfully demonstrates the design and optimization of an elliptical microstrip patch antenna using TLC30 substrate for sub-6 GHz 5G communication. The TLC30 material, with a dielectric constant of 3.0, offered an excellent trade-off between size, efficiency, bandwidth, and cost.

After introducing slots and increasing the substrate height to 1.8 mm, the final antenna achieved:

- **Return Loss of –22.34 dB at 3.4 GHz**
- **Gain of 5.63 dB**
- **Radiation Efficiency of 94.9%**
- **Bandwidth of 505 MHz**
- **Low VSWR at resonant frequency (3.45 GHz)**

The *radiation pattern* of the slotted design showed nearly *omnidirectional behavior*, ideal for mobile and base station scenarios in 5G networks. This ensures uniform coverage and reliable signal transmission across different directions.
These improvements over the non-slotted design confirmed better impedance matching, wider bandwidth, and suitability for modern 5G applications, all while maintaining cost-effectiveness through the use of TLC30.

Acknowledgement

We sincerely thank our guide, Prof. Nupur Chhaule, for her invaluable mentorship and support throughout our project. Our heartfelt gratitude goes to our HOD, Prof. Abhijit Banerjee, for providing resources and encouragement, and to our Director, Prof. Dilip Bhattacharya, for his inspiring leadership. This project’s success is a result of your collective guidance and support.

Reference

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Thank You