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Comparative Analysis of Different Feeding Techniques and Different Substrates on the Performance of 5G Micro-strip Patch Antenna

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Wireless communication is evolving rapidly to meet growing demands for higher data rates and seamless connectivity, especially with the rise of the Internet of Things (IoT). Among the latest advancements, 5G technology stands out by enabling ultra-fast data transmission, high capacity, and efficient spectrum utilization through millimeter-wave frequencies. This study presents a comparative analysis of six Microstrip Patch Antennas (MPAs) designed for 5G applications, addressing the challenge of limited space and increasing performance demands. The novelty of this work lies in the evaluation of how substrate materials and feeding techniques influence MPA performance, providing insights not thoroughly addressed in prior research. The antennas were designed using three substrates1: FR-4 (εr = 4.4), 2-Rogers RT5880 (εr = 2.2), and 3- Taconic RF-35TC (εr = 3.5), and two feeding techniques: Microstrip line feed and coaxial probe feed. All antennas were tuned to resonate at 38 GHz, suitable for 5G millimeter-wave applications. Feeding technique also significantly affects impedance matching and Gain. It is found out that using Roggers RT Duroid 5880 substrate with Microstrip feedline technique provides the highest gain whereas the largest bandwidth is achieved using coaxial feed with FR4 substrate. A quarter-wave transformer was additionally implemented for optimal impedance matching between the source and antenna. The findings guide substrate and feed selection in compact 5G antenna designs.

Keywords: 5G; Microstrip Patch Antenna; Millimeter Wave; Substrate Material; Feeding Technique

Introduction:

As the demand for high-speed wireless connectivity continues to grow exponentially, current communication systems are increasingly challenged by limited bandwidth and space constraints, especially in densely populated regions [1]. Traditional antenna designs often fall short of meeting the requirements of next-generation wireless standards like 5G, which demands compact, high-gain, and efficient antennas operating at millimeter-wave frequencies [2]. Consequently, there is a pressing need to develop compact antenna systems that can support high data rates and ensure stable performance within the 5G frequency spectrum. In a study [3], microstrip antennas are developed using Epoxy_kevlar_xy (εr = 3.6) and FR4_epoxy (εr = 4.4) substrates. At 7.58 GHz, the FR4-based design shows a return loss of −31.24 dB, gain of 9.97 dB, and 5.07 GHz bandwidth, while the Epoxy_kevlar_xy design resonates at 8.01 GHz with −22.24 dB return loss, 1.07 dB gain, and 5.26 GHz bandwidth. In [4], a patch antenna on Rogers RT Duroid 5880 operates at 38 GHz and 54 GHz, achieving return losses of 15.5 dB and 12 dB with respective bandwidths of 1.94 GHz and 2 GHz. In [5], an FR-4 based antenna resonates at 10.15 GHz, with 4.46 dBi gain, −18.27 dB return loss, and 9.95–10.35 GHz bandwidth.

A comparative analysis in [6] revealed that coaxial feeding offered greater bandwidth, while microstrip line feeding yielded improved gain and return loss. The dual-band antenna in [7] utilized two rectangular patches and a T-shaped patch, producing a narrow 5.1% and a wide 60.6% bandwidth. Authors in [8] evaluated coaxial and microstrip feeding for Bluetooth applications; coaxial feed exhibited better performance in return loss, bandwidth, efficiency, and impedance, with gain slightly favoring the microstrip line. In [9], an antenna using Rogers RT5880 is analyzed for both microstrip line and coaxial feed techniques at 9.3 GHz. The microstrip line feed shows a return loss of −18.9 dB, gain of 7.622 dB, directivity of 7.850 dBi, efficiency of 94.89%, and a VSWR of 1.258. In contrast, the coaxial feed exhibits a return loss of −14.209 dB, gain of 7.548 dB, directivity of 7.773 dBi, efficiency of 94.95%, and a VSWR of 1.485. In [10], a rectangular patch antenna on an FR-4 substrate with a microstrip feed is evaluated to analyze the influence of various parameters. Simulations yield a directivity of 4.154 dB, a beamwidth of 2.6515%, and a gain of 2.059 dB. In [11], a circular patch antenna with a line feed resonates at 2.4 GHz, demonstrating a return loss of −16.515 dB at 2.4018 GHz, a VSWR of 1.2069 at 2.4222 GHz, and a bandwidth of 6.4622%. This research paper presents the design and simulation of six microstrip patch antennas (MPAs) intended for 5G applications. Three substrate materials, namely, FR-4 (εr = 4.4), Rogers RT5880 (εr = 2.2), and Taconic RF-35TC (εr =3.5), as well as two feeding schemes in the form of coaxial probe feed (PF) and microstrip line feed (MF) are considered in the study.

All antenna configurations are modeled and simulated in CST (Computer Simulation Technology) to resonate at 38 GHz, a widely proposed frequency band for 5G applications. The characteristics of the antennas are analyzed in terms of S11 magnitude (return loss), bandwidth and gain. A quarter-wave transformer is also proposed to improve impedance matching. Simulation results are compared to evaluate the influence of substrate and feed type on antenna performance.

Objectives:

The objectives of this research are:

- To investigate the effect of different substrate materials and feeding techniques on MPA performance at 38 GHz,
- To optimize antenna design for enhanced gain and compactness in 5G applications.

Novelty Statement:

The novelty of the current study lies in the integrated comparison of multiple substrates and feed methods, providing design insights that have not been thoroughly explored together in existing literature. The research helps to offer a unique guideline for selecting the most suitable substrate-feed combination for efficient 5G antenna implementation.

Methodology:

CST Microwave Studio was used for all simulations, providing a robust platform for 3D electromagnetic analysis. It supports various solvers, with the Transient Solver and Frequency Domain Solver being the most utilized. The Transient Solver was primarily used to simulate high-frequency antenna structures, while the Frequency Domain Solver provides accurate, frequency-specific results. The Eigenmode Solver assisted in identifying the natural resonant modes of the designs. CST's parametric sweep feature was employed to optimize design parameters and to observe the effects of variations in substrate properties and feed configurations. After opening CST studio, New Template was selected. Then Microwave & RF/optical section, antennae was selected. After that planer (patch,slot) is clicked on. After that Time Domain was selected, and units were provided. This opened up CST environment for antenna design. Additional performance metrics such as bandwidth, gain, and directivity were used to evaluate each antenna's performance. The flowchart is shown is shown in Figure 1.

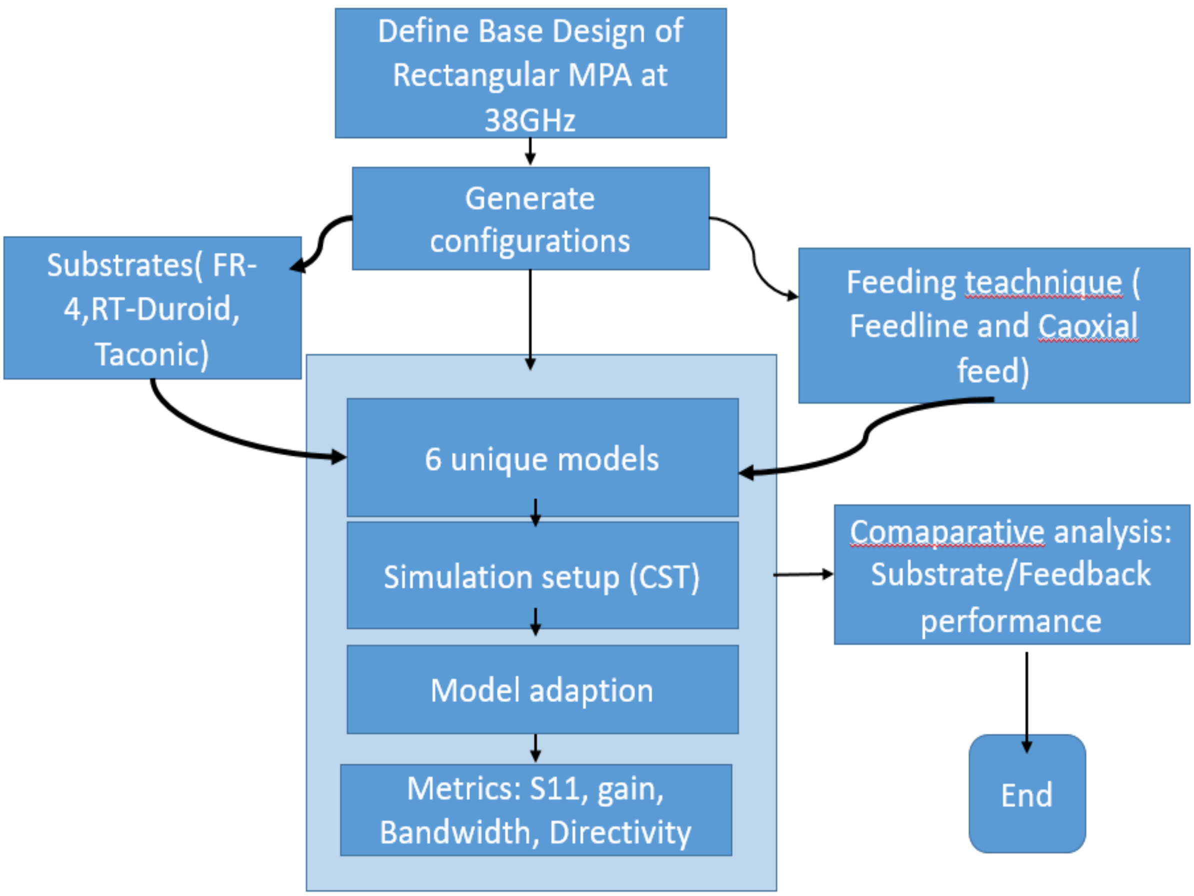

Figure 1. Workflow for 38 GHz MPA design, simulation, and performance comparison

The front view of the MPA with line feed is shown in Figure 1. Three different substrates were used: FR-4, Rogers RT-Duroid, and Taconic RF-35TC. The dimension of substrate is 4.5×7×0.787mm and dimension of patch is 1.5×3.425×0. 035mm.

A substrate was placed on top of the ground plane with a thickness of 0.787 mm, and a rectangular patch, serving as the radiating element of the antenna was designed on top of the substrate. To design the line feed, a quarter-wave transformer was first created and used for impedance matching. n Figure 3, the coaxial feeding technique is used. The substrate has dimensions of 4.5 × 4.2 × 0.787 mm^3, while the patch measures 1.48 × 1.776 × 0.035 mm^3.

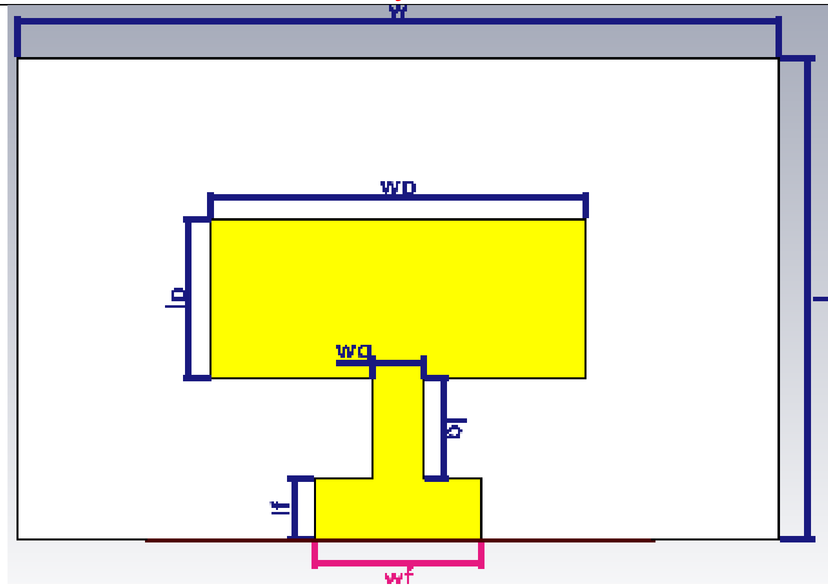

Figure 2. MPA with Feedline Technique

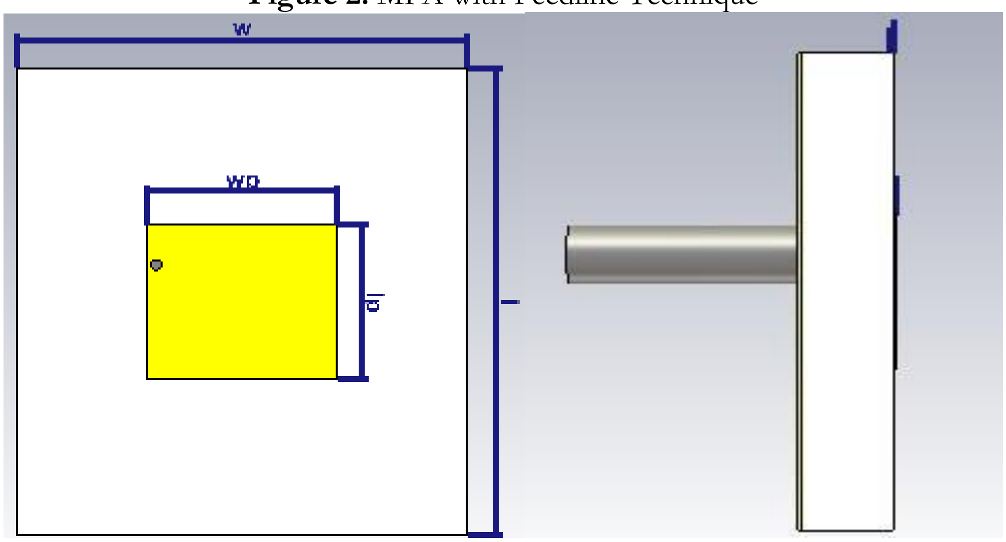

Figure 3. Microstrip Patch Antenna with Feedline Technique

Results:

S-parameters, or scattering parameters, described how radio frequency signals behaved in a network. An S11 value of −10 dB indicated that 10% of the power is reflected, while 90% was transmitted through the antenna. After designing antennas and providing feeding, the S11 results were obtained after simulation using 1D results and then clicking on S-parameters following by clicking on S11. The more negative the S11 value (in dB), the better the impedance matching. Its value depended on the degree of matching between the load and the source impedance. The S11 magnitudes of the six MPAs designed using different substrates and feeding methods are compared, as shown in Figure 4.

The Voltage Standing Wave Ratio (VSWR) also indicates the amount of matching. The value of 1 indicates perfect matching, which means no power was reflected from the antenna. Figure 5 shows VSWR for 6 different MPAs scenarios. At resonant frequency of 38GHz MPA using Fr4 with line feed has VSWR of 1.0359, using Rogers with line feed line has VSWR of 1.002, using Taconic with line feed has VSWR of 1.0035, using Fr4 with coaxial feed has VSWR of 1.0029, using Rogers with coaxial Feed has VSWR of 1.008 and using Taconic with coaxial Feed has VSWR of 1.02.

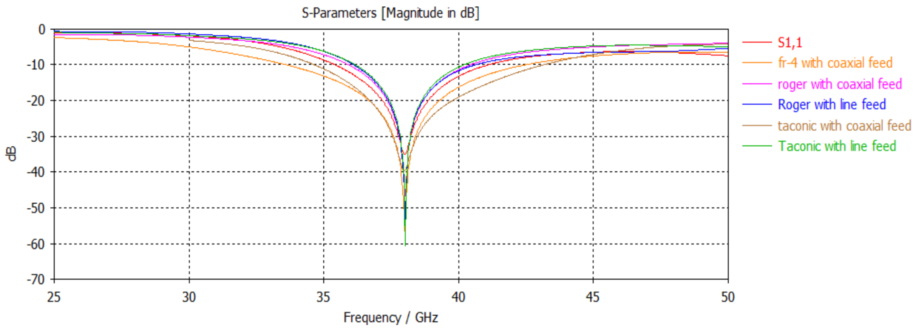

Figure 4. S-Parameters Comparison of different MPAs

The bandwidth is antenna is calculated looking at the points where VSWR is less than 2 and S11 magnitude is less (more negative) than -10dB. The absolute bandwidths for all 6 MPA's is provided in Table 1. The VSWR results are also given in 1D results in CST.

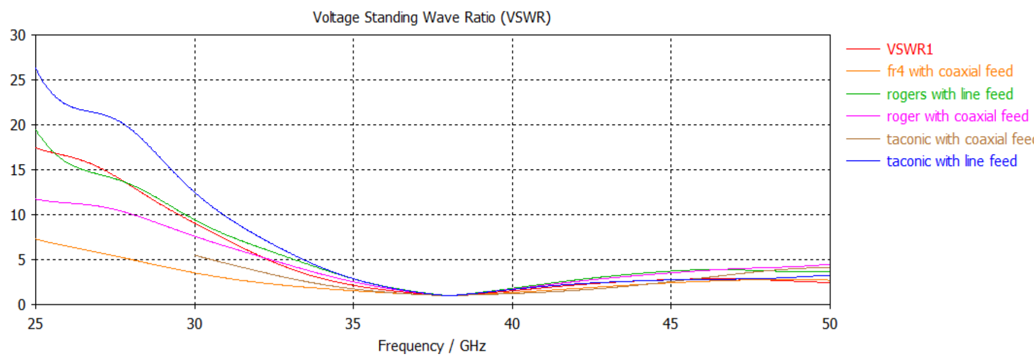

Figure 5. VSWR Comparison of different MPAs

The Gain of antenna is the ability of antenna to increase radiation in a desired direction by decreasing radiation in other/undesired directions. For isotropic antenna, which emits the same power in all directions, the gain is 0 dBi. The Gain of all six MPA's are shown in Figures 6-11. Gain of MPA with Line feed using substrate yields a gain of 3.67dB as shown in Figure 6. Changing substrate to Roggers RT Duroid 5880 provides a gain of 7.4 dB as shown in Figure-7. This shows significant increase as compared to using FR-4 though both used the same feed line technique. When RF-35 TC subsrate is showed the Gain is increased slightly to 7.71dB as shown in Figure-8. Now the feeding technique is changed to coaxial feed. The FR-4 substrate coaxial feed MPA yields a gain of 5.76 dB as show in Figure-9. The Roggers RT Duroid 5880 MPA with coaxial feed provides a gain of 6.93 as shown in Figure-10 whereas RF-35TC substrate MPA with coaxial feed provides a gain of 6.4 as shown in Figure 11.

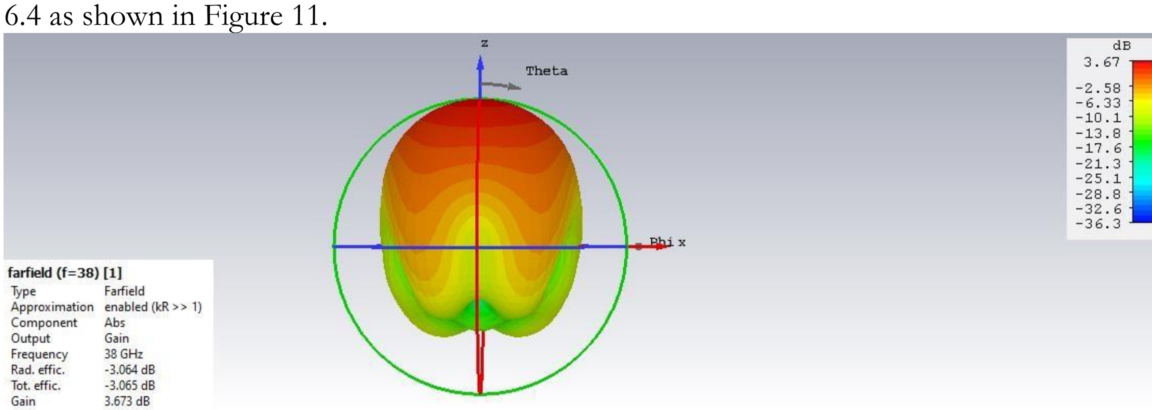

Figure 6. Gain of MPA with Line feed using FR-4 substrate. The gain is 3.67dB

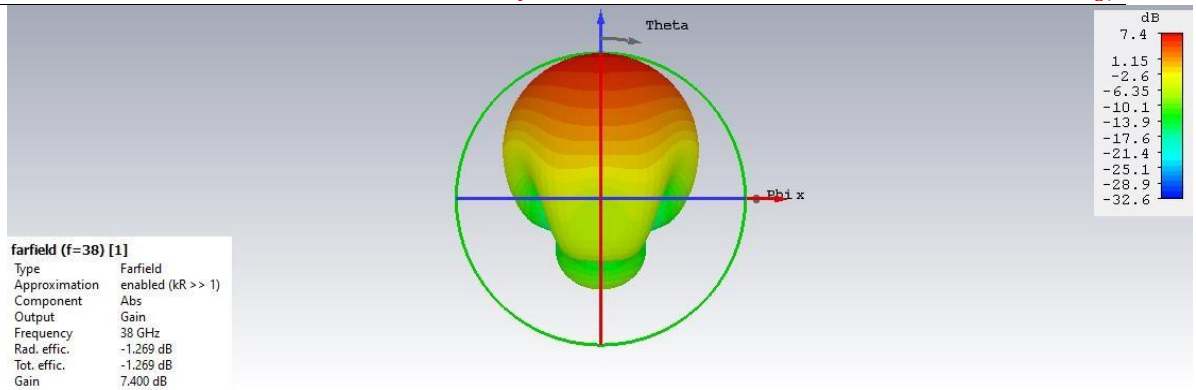

Figure 7. Gain of MPA with Line feed and Roggers RT Duroid substrate. The gain is 7.4dB

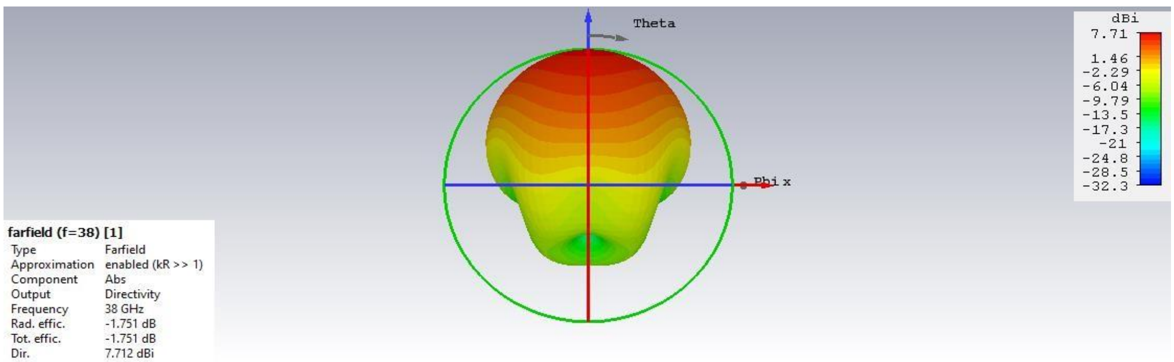

Figure 8. Gain of MPA with line Feed and Taconic RF-35TC substrate. The gain is 7.71dB

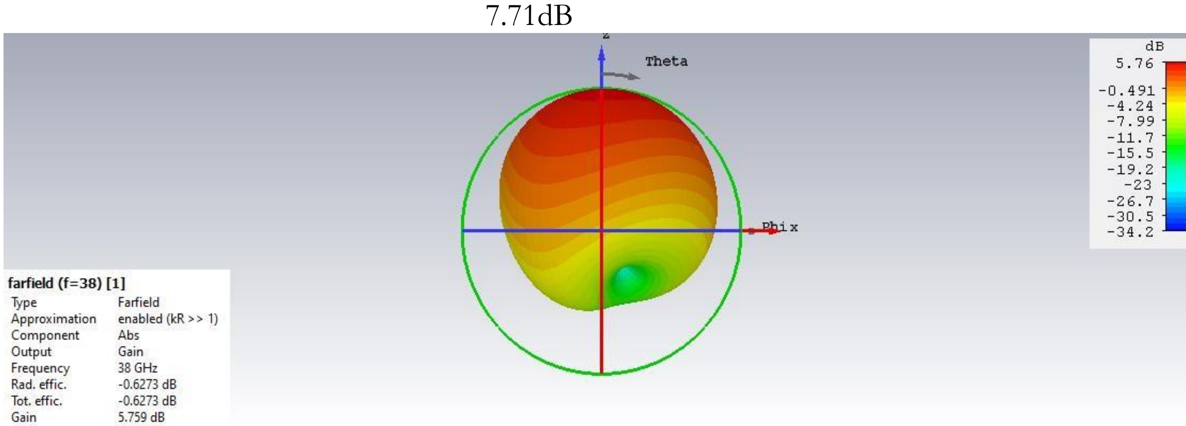

Figure 9. Gain of MPA with coaxial feed technique and Fr-4 substrate.

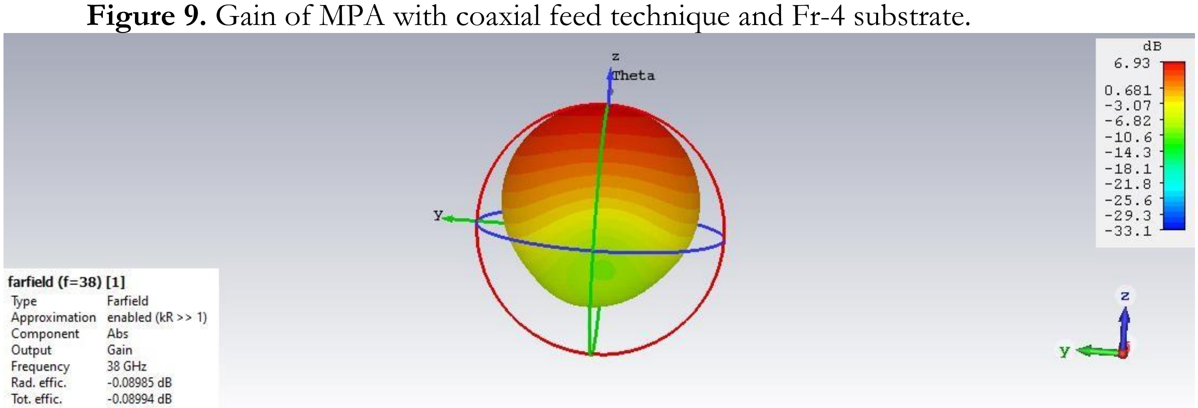

Figure 10. Gain of MPA with coaxial feed technique and Roggers RT Duroid 5880 substrate

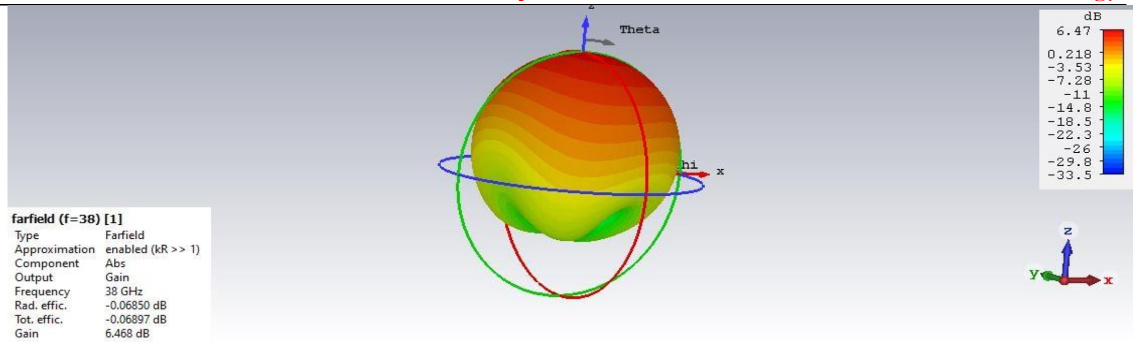

Figure 11. Gain of MPA with coaxial feed technique and Taconic RF-35C substrate

Discussion:

The comparative analysis of all the results was provided in Table 1. In all cases the antenna resonates at 38 GHz which is a 5G communication range. The microstrip feedline technique combined with Rogers RT Duroid substrate provides greatest Gain and Directivity. Whereas FR4 with coaxial feeding technique provides the highest absolute bandwith of 8.88GHz. Table 1 demonstrates the comparative analysis of 2 different feeding techniques and 3 different substrates. Table-2 presents a comparative analysis of the proposed work with existing studies. Unlike previous works that used fewer substrates and antenna variations, this study employs three substrates, six unique MPA designs, and targets the 5G 38 GHz band with improved performance in gain, bandwidth, and return loss.

Table 1. Comparative Analysis Microstrip Patch Antennas

Microstrip Patch Antennas	Gain (dB)	Directivity (dBi)	Return Loss (dB)	Bandwidth (GHz)	VSWR (dB)
Fr4 with line feed	3.672	6.737	-35	5.7	1.0359
Rogers with line feed	7.4	8.7	-60	4.03	1.002
Taconic with line feed	5.9	7.7	-55	4.5	1.0035
Fr4 with coaxial feed	5.76	6.386	-56	8.88	1.0029
Rogers with coaxial Feed	6.93	7.02	-47	8.2	1.008
Taconic with coaxial Feed	6.4	6.5	-39	8.5	1.02

Table 2. Comparison of Results with Existing studies

Reference	No of substates used	Simulation Tool	Feeding Techniques	5G Antenna Designs	No of unique MPA	Frequency Band	Performance metrics
[3]	2	HFSS	1	No	2	2-8 GHz	Gain, Bandwidth and efficiency
[6]	1	CST	2	No	2	5G (38 GHz and 58 GHz)	Gain, Bandwidth and efficiency
This work	3	CST	2	Yes	6	5G (38GHz)	Gain, Bandwidth and Return Loss

Conclusion:

This work presented the design and performance evaluation of Microstrip Patch Antennas using two feeding techniques; Microstrip Line Feed and Coaxial Probe Feed, with three different substrates: FR4, Rogers RT Duroid, and Taconic, targeting 38 GHz for future 5G applications. Among the configurations, the Rogers RT Duroid substrate with Microstrip feedline demonstrated the highest gain (7.4 dB) and directivity (8.7 dBi), while FR4 with coaxial feed achieved the maximum absolute bandwidth of 8.88 GHz.

Future recommendations:

Future work may involve the integration of all 4-feeding techniques and comparative analysis of all feeding techniques may be performed. Also, many other substrate materials can be utilized and their performance can be monitored in antenna design.

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Author's Contribution. Kifyat Ullah and Arshad Bangash proposed the methodology and presented the simulated results. Bilal Ur Rehman provided results and discussions. Muhammad Amir provided a Literature review. Muhammad Kashif and Humayun Shahid proofread the paper and provided critical edits.

Conflict of interest. The authors show no conflict of interest.

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