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Design of Circular and Rectangular Patch Antennas Using Teflon and Rogers Substrates for 5G Applications at 25 GHz

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Abstract

This paper presents a comprehensive study on the design and performance evaluation of circular and rectangular microstrip patch antennas tailored for 5G applications, operating at 25 GHz. Utilizing Teflon and Rogers substrates with superior dielectric properties, the antennas are meticulously crafted and rigorously analyzed. The study explores the design methodology, and simulation outcomes, and compares circular and rectangular patch antennas, focusing on their suitability for 5G systems. Through iterative simulations and optimizations, the antennas are fine-tuned to achieve optimal performance parameters, including impedance matching, radiation efficiency, and bandwidth, ensuring their efficacy in high-frequency communication environments.

The design methodology involves precise calculations for optimal antenna dimensions, considering substrate material properties, dielectric constants, and desired radiation characteristics. Performance metrics such as peak directivity, gain, efficiency, and bandwidth are comprehensively evaluated and compared for both Teflon and Rogers substrates. This investigation contributes to advancing microstrip patch antenna design for 5G, elucidating the interplay between substrate materials, antenna geometries, and performance characteristics. The findings not only enhance our understanding of antenna design principles but also lay the groundwork for further optimization and refinement of microstrip patch antennas for future high-frequency communication systems.

Keywords- Circular and rectangular microstrip patch antennas, 5G technology, High-Frequency Structure Simulator (HFSS), Roger's substrates, Teflon, Wireless communication

INTRODUCTION

Microstrip patch antennas have emerged as indispensable components in modern wireless communication systems due to their compact size, low profile, and seamless integration capabilities [1]. They facilitate high-speed data transfer, enabling connectivity across a wide range of devices and applications. The choice of substrate material significantly impacts the performance of microstrip patch antennas [2], with Teflon and Rogers substrates being preferred for their superior dielectric properties, especially in high-frequency applications.

In the era of 5G technologies, characterized by the ever-growing demand for faster data transmission and enhanced connectivity, the design and optimization of microstrip patch antennas have become paramount [3-6]. This paper presents a comprehensive comparative analysis of microstrip patch antennas, focusing on circular and rectangular geometries fabricated using Teflon and Rogers's substrates, operating at 25 GHz [7].

Microstrip patch antennas offer several advantages over traditional antenna designs, including their lightweight construction, cost-effectiveness, and versatility in design [8]. Typically consisting of a radiating patch suspended above a ground plane, with a dielectric substrate sandwiched in between, these antennas are highly adaptable for integration into various devices [9], spanning from smartphones and tablets to IoT devices and automotive systems.

This study aims to delve into the intricate details of microstrip patch antenna design for 5G applications [3-6, 10]. By systematically evaluating antenna performance based on substrate materials, geometries, operating frequencies [5], and key performance metrics such as S-parameters, VSWR (Voltage Standing Wave Ratio), peak directivity, gain, efficiency, and bandwidth, this research endeavours to offer valuable insights into the best design and deployment of microstrip patch antennas in 5G communication systems [11].

Through a meticulous examination of the performance disparities between antennas fabricated using Teflon and Rogers's substrates [7], as well as circular and rectangular geometries, this study seeks to address pertinent queries regarding substrate material and antenna geometry selection for optimal performance in 5G applications [1]. By illuminating the intricate interplay between substrate material, antenna geometry, and performance metrics [2], this research aims to contribute to the ongoing advancement and refinement of microstrip patch antenna technology within the realm of 5G communication systems.

Frequency of Operation: This parameter defines the central frequency at which the antenna operates optimally. It delineates the frequency range within which the antenna demonstrates its highest performance in transmitting and receiving electromagnetic signals efficiently. The selection of an appropriate operating frequency is crucial for ensuring compatibility with the intended application and communication standards.

Bandwidth: Bandwidth characterizes the frequency range over which the antenna maintains efficient operation. A wider bandwidth signifies the antenna's ability to accommodate a broader range of frequencies, allowing it to adapt to diverse communication standards and environmental conditions. A comprehensive bandwidth is essential for robust communication systems to mitigate interference and support multiple communication protocols simultaneously.

Peak Directivity: Directivity represents the antenna's ability to concentrate radiated power in specific directions. It quantifies the antenna's effectiveness in focusing electromagnetic energy towards desired areas while minimizing radiation in undesired directions. Peak directivity is instrumental in enhancing signal strength, achieving longer communication distances, and reducing interference from surrounding sources.

Peak Gain: Gain measures the antenna's efficiency in transmitting and receiving electromagnetic signals in a particular direction compared to an ideal isotropic radiator. It denotes the amplification of signal strength provided by the antenna system, facilitating improved communication performance, increased coverage area, and enhanced signal reception sensitivity.

Total Efficiency: Total efficiency encompasses all losses incurred within the antenna system, including conductor, dielectric, and mismatch losses. It evaluates the antenna's ability to convert input power into radiated power effectively, providing insights into the overall performance and energy efficiency of the antenna design.

Radiation Efficiency: Radiation efficiency quantifies the proportion of input power that is converted into radiated electromagnetic waves. It excludes losses associated with resistive heating and non-radiative losses, focusing solely on the antenna's ability to emit electromagnetic energy. High radiation efficiency is desirable for maximizing the antenna's effectiveness in transmitting signals and minimizing energy wastage.

Return Loss: Return loss quantifies the amount of power reflected from the antenna due to impedance mismatches. It serves as a critical metric for evaluating the impedance matching between the antenna and the transmission line or feed network. A low return loss indicates efficient power transfer and optimal impedance matching, essential for maximizing signal transmission and minimizing signal loss.

Voltage Standing Wave Ratio (VSWR): VSWR evaluates how well the antenna is matched to the transmission line or feed network. It measures the ratio of the maximum voltage to the minimum voltage along the transmission line, indicating the magnitude of reflected power compared to the transmitted power. A low VSWR signifies good impedance matching and efficient power transfer, essential for minimizing signal degradation and ensuring reliable communication performance.

ANTENNA DIMENSIONS

Rectangular Microstrip Patch Antenna

Determination of Patch Width: The width of the patch is crucial as it affects the resonant frequency and impedance matching of the antenna. Calculating the patch width ensures that

the antenna operates at the desired frequency and exhibits optimal performance.
The width of the patch is calculated using the formula given in [4]

$$W = \frac{C}{2F0\sqrt{(\epsilon r+1)/2}} \tag{1}$$

Where F0 =Operating Frequency
€r=Dielectric Constant
C=3*10^8 m/s

Determination of Effective Dielectric Constant: Accurate calculation of the effective dielectric constant accounts for fringing fields, ensuring precise tuning of the antenna for resonance at the operating frequency.
It is calculated using the equation is given as [5]

$$\epsilon erff = \frac{(\epsilon r+1)}{2} + \frac{(\epsilon r-1)}{2}\left[1 + \frac{1}{\sqrt{\left((1)+12\frac{H}{W}\right)}}\right] \tag{2}$$

Determination of Effective Length (Leff): The effective length accounts for electrical lengthening due to fringing fields, enabling precise adjustment of the patch dimensions for resonance.
It is calculated using the formula given as [4, 5]

$$Leff = \frac{C}{2F0\sqrt{\epsilon erff}} \tag{3}$$

Normalized Extension in Length: This parameter ensures accurate adjustment of the patch length to achieve optimal resonance and radiation characteristics.
It is calculated using the formula given as [6]

$$\Delta L = 0.412H \cdot \frac{(\epsilon erff+0.3)\cdot\left(\frac{W}{H}+0.264\right)}{(c-0.258)\cdot\left(\frac{W}{H}+0.8\right)} \tag{4}$$

Length of the Patch: Calculating the patch length ensures proper resonance and determines radiation characteristics such as beam width and directivity [7].
The length of the patch is given as

$$L = Leff - 2\Delta L \tag{5}$$

Determination of Substrate Length and Width: Proper substrate dimensions ensure optimal alignment and mounting of the patch antenna, accounting for substrate effects on performance.
Substrate length and width are given by the formulae [12]

$$Lg = L + 6h \tag{6}$$
$$Wg = W + 6h \tag{7}$$

h: here h is not the height of the substrate

$$h = \frac{0.0606\lambda}{\sqrt{\epsilon r}} \tag{8}$$

Feed Line Length: Determining the feed line length ensures efficient impedance matching and power transfer between the transmission line and the antenna.
The length of the feed line is determined using formulae [12]

$$Lf = \frac{\lambda g}{4} \tag{9}$$
$$\lambda g = \frac{\lambda}{\sqrt{\mathcal{E}reff}} \tag{10}$$

Circular Microstrip Patch Antenna

Physical Radius of Patch (a): The physical radius determines the overall size and shape of the circular patch antenna. It influences the resonant frequency, bandwidth, and radiation characteristics of the antenna [13].

$$a = \frac{F}{\sqrt{\left(1+\frac{2h}{\pi\cdot\epsilon r\cdot F}\cdot\ln\left[\left(\frac{\pi\cdot F}{2h}+1.7726\right)\right]\right)}} \tag{11}$$

Here, $F = \frac{8.791e9}{fr\sqrt{\epsilon r}}$ (12)

Effective Radius (a_e): The effective radius accounts for the fringing fields and substrate effects, providing a more accurate representation of the patch size. It ensures precise tuning of the antenna for optimal performance and resonance at the operating frequency [13].

$$ae = a \cdot \sqrt{\left(1 + \frac{2h}{\pi\cdot\epsilon r\cdot a}\cdot\ln\left[\left(\frac{\pi\cdot a}{2h}+1.7726\right)\right]\right)} \tag{13}$$

Table 1 summarizes the key design parameters and specifications for the antennas studied in this research. The table includes details such as the antenna type, permittivity of the substrate, operating frequency in Gigahertz (GHz), patch dimensions in millimetres (mm), feed dimensions in mm, and substrate dimensions in mm.

Table 1: *Antenna design parameters and specifications.*

Antenna Type	**Permittivity**	**Operating Frequency (GHz)**	**Patch Dimensions (mm)**	**Feed Dimensions (mm)**	**Substrate Dimensions (mm)**
Rectangular (Rogers 4003)	3.55	34.5	2.76 x 3.97 x 0	3 x 0.3	6 x 6 x 0.8
Rectangular (Teflon)	2.1	23.8	3.57 x 4.82 x 0	3 x 0.3	6 x 6 x 0.8
Circular (Teflon)	2.1	21.85	Radius: 2.4	5 x 0.4	10 x 10 x 0.8
Circular (Rogers RT/Duroid 5880)	2.2	20.85	Radius: 2.4	5 x 0.4	10 x 10 x 0.8

METHODOLOGY

The design methodology encompasses precise calculations tailored to achieve optimal dimensions for circular and rectangular patch antennas operating at the frequency of 25 GHz. These calculations are based on established equations governing microstrip patch antennas, ensuring that the antennas resonate efficiently at the desired frequency.

To determine the dimensions of the patch, substrate, and feeding mechanism, rigorous analysis is conducted, considering factors such as substrate material properties, dielectric constants, and desired radiation characteristics. This process ensures that the antennas are meticulously engineered to meet the stringent requirements of 5G applications, as illustrated in Fig. 1.

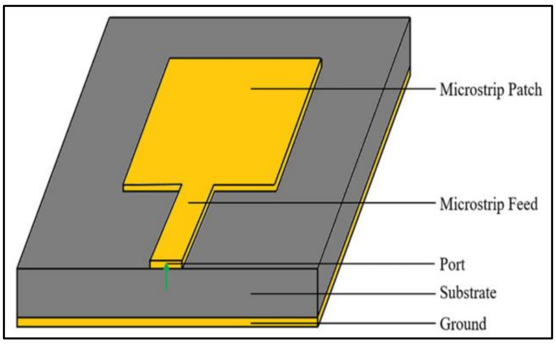

Figure 1: *General diagram of the microstrip patch antenna.*

Through iterative simulations and optimizations, the antenna designs are fine-tuned to achieve optimal performance metrics, including impedance matching, radiation efficiency, and bandwidth. This iterative approach, as depicted in Fig. 2, identifies and mitigates potential design challenges, ensuring that the final antenna configurations meet or exceed the performance expectations for 5G communication systems.

By integrating theoretical calculations with advanced simulation tools, the design methodology ensures that the circular and rectangular patch antennas are meticulously engineered to deliver superior performance at the 25 GHz operating frequency.

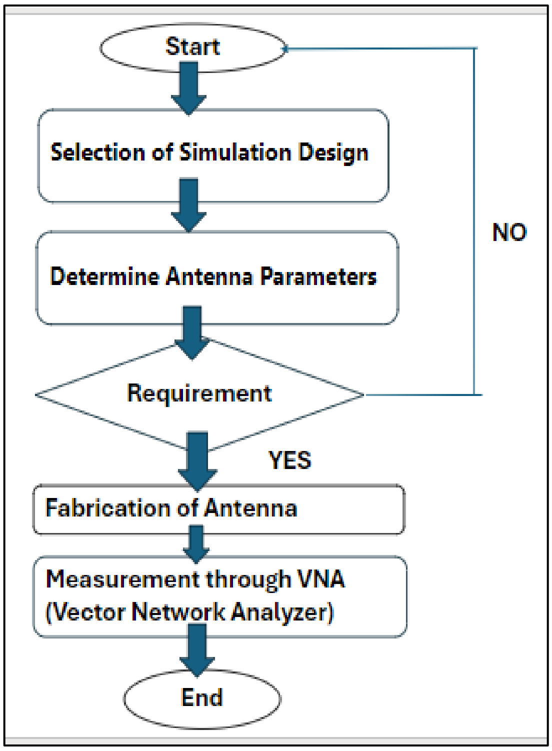

Figure 2: *Flow chart for microstrip patch antenna design.*

This systematic approach facilitates the development of high-performance antennas optimized for 5G technologies, poised to meet the evolving demands of wireless communication in the 5G era.

RESULTS AND DISCUSSION

Simulation results demonstrate the performance of circular and rectangular patch antennas on Teflon and Rogers substrates at 25 GHz. Comparative analyses evaluate the impact of substrate material and patch geometry on antenna characteristics. The study sheds light on the strengths and limitations of each design, providing valuable insights for antenna engineers and researchers. As illustrated in Fig. 3a and 3b, the simulation designs depict the performance characteristics of the rectangular and circular patch antennas, respectively.

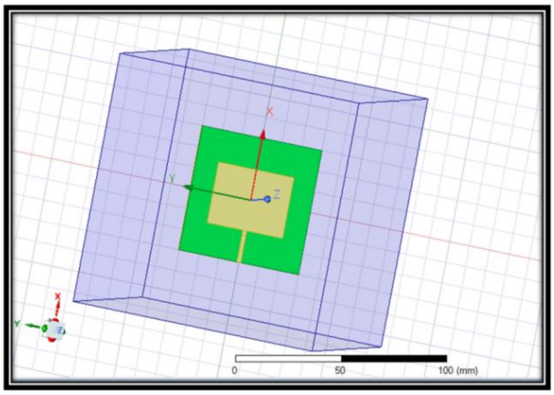

Figure 3a: *Rectangular patch design.*

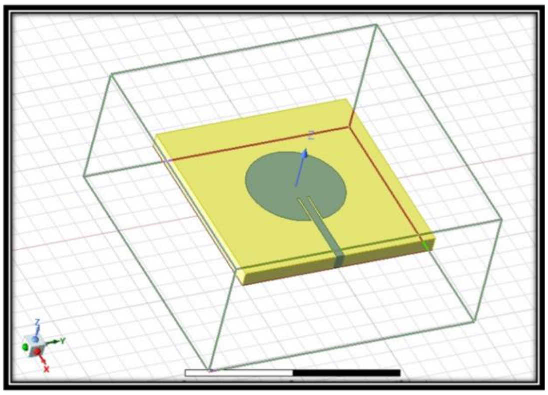

Figure 3b: *Circular patch design.*

Performance Evaluation

Rectangular Patch Antennas

The rectangular patch antenna fabricated on Rogers's 4003 substrate exhibits a peak directivity of 0.565728, gain of 0.5642, total efficiency of 0.927480, and radiation efficiency of 0.997434. It operates at 34.5 GHz with an S-parameter of -12.8 dB and a VSWR of 1.54. The antenna achieves a bandwidth of 2.3 GHz.

The rectangular patch antenna fabricated on Teflon substrate demonstrates a peak directivity of 4.491314, gain of 4.6183, total efficiency of 0.882649, and radiation efficiency of 1.028291. It operates at 23.8 GHz with an S-parameter of -13.9 dB and a VSWR of 1.58. The antenna achieves a bandwidth of 1.0 GHz [14].

Circular Patch Antennas

The circular patch antenna fabricated on Teflon substrate exhibits a peak directivity of 5.569213, a gain of 5.443, a total efficiency of 0.939920, and a radiation efficiency of 0.977501. It operates at 21.85 GHz with an S-parameter of -14.06 dB and a VSWR of 1.487. The antenna achieves a bandwidth of 1.25 GHz.

The circular patch antenna fabricated on Rogers RT/Duroid 588 substrate demonstrates a peak directivity of 5.579727, gain of 5.4776, total efficiency of 0.969431, and radiation efficiency of 0.981699. It operates at 20.85 GHz with an S-parameter of -19.03 dB and a VSWR of 1.25. The antenna achieves a bandwidth of 1.05 GHz.

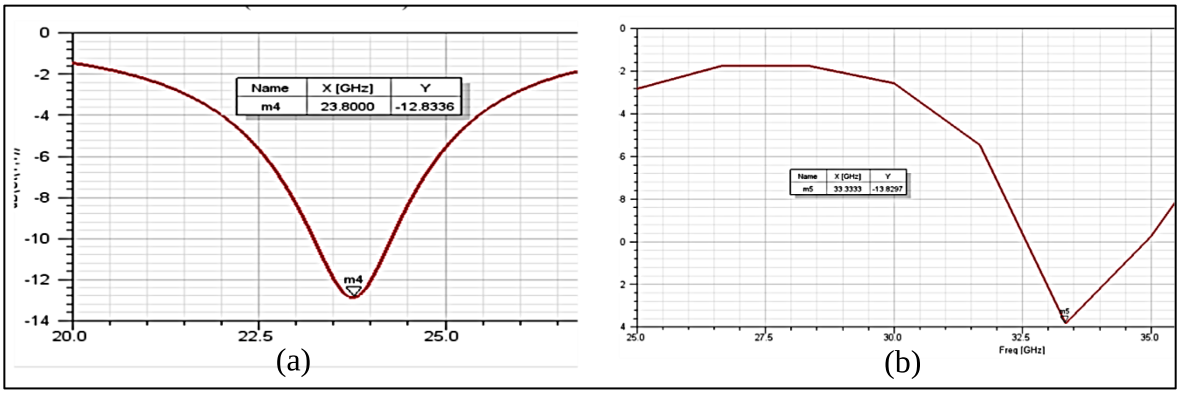

Figure 4: *(a) S Parameter (Teflon) of rectangular patch design (b) S Parameter (Rogers 4003) of rectangular patch design.*

Fig. 4 (a and b) depicts the S-parameter graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The S-parameter values for the Teflon antenna and Rogers RT/Duroid antenna are -13.9 dB and -13.6 dB, respectively.

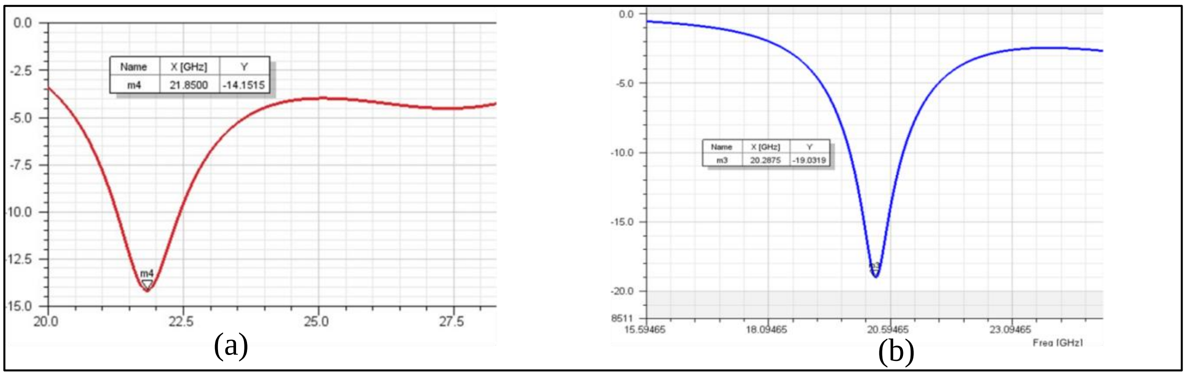

Figure 5: *(a) S Parameter (Teflon) of circular patch design (b) Parameter (Rogers RT/ Duroid 5880) of circular patch design.*

Fig. 5 (a and b) illustrates the S-parameter graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The S-parameter values for the Teflon antenna and Rogers RT/Duroid antenna are -14.06 dB and -19.03 dB, respectively.

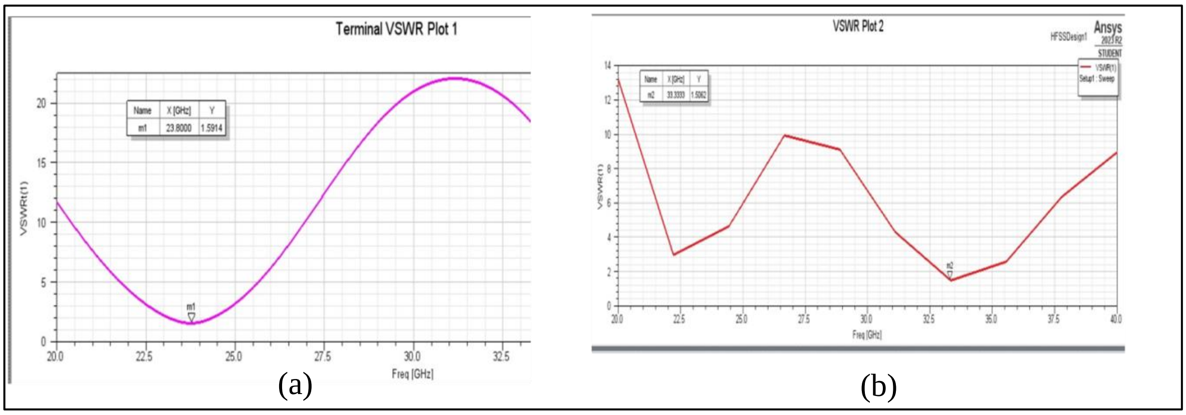

Figure 6: *(a) VSWR (Teflon) of rectangular patch antenna design (b) VSWR (Regers 4003) of rectangular patch antenna design.*

Fig. 6 (a and b) illustrates the VSWR graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The VSWR values for the Teflon antenna and Rogers RT/Duroid antenna are 1.58 and 1.54, respectively.

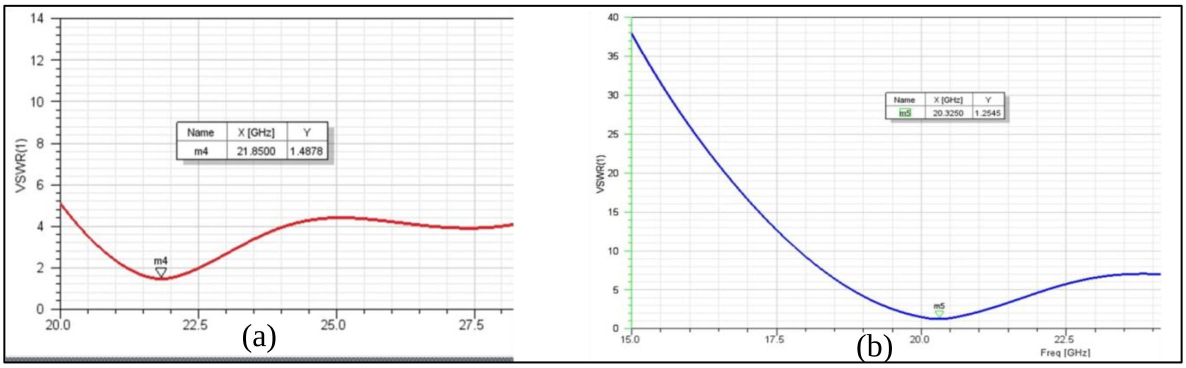

Figure 7: *(a) VSWR (Teflon) of circular patch antenna design (b) VSWR (Rogers RT/ Duroid 5880) of circular patch antenna design.*

Fig. 7(a and b) displays the VSWR graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The VSWR values for the Teflon antenna and Rogers RT/Duroid antenna are 1.487 and 1.25, respectively.

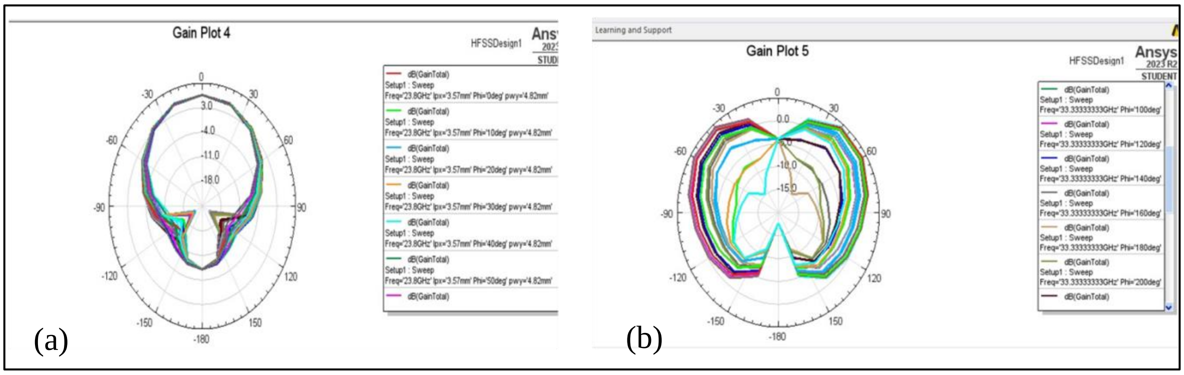

Figure 8: *(a) Gain Plot of Teflon Rectangular patch antenna design (b) Gain plot of Rogers 4003 rectangular patch antenna design.*

Fig. 8(a and b) shows the Gain graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The gain values for the Teflon antenna and Rogers RT/Duroid antenna are 4.6183 and 0.5642, respectively.

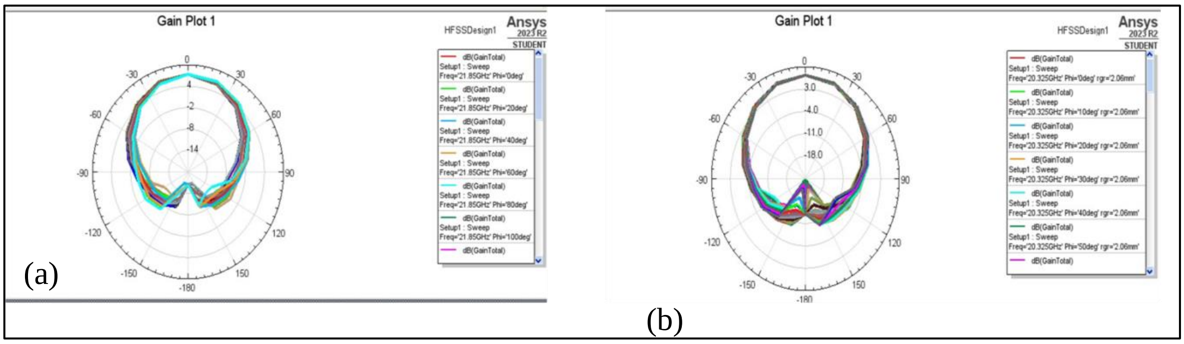

Figure 9: *(a) Gain plot of Teflon circular patch antenna design (b) Gain plot of Rogers RT/ Duroid 5880 circular patch antenna design.*

Fig. 9(a and b) showcases the Gain graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The gain values for the Teflon antenna and Rogers RT/Duroid antenna are 5.443 and 5.4776, respectively.

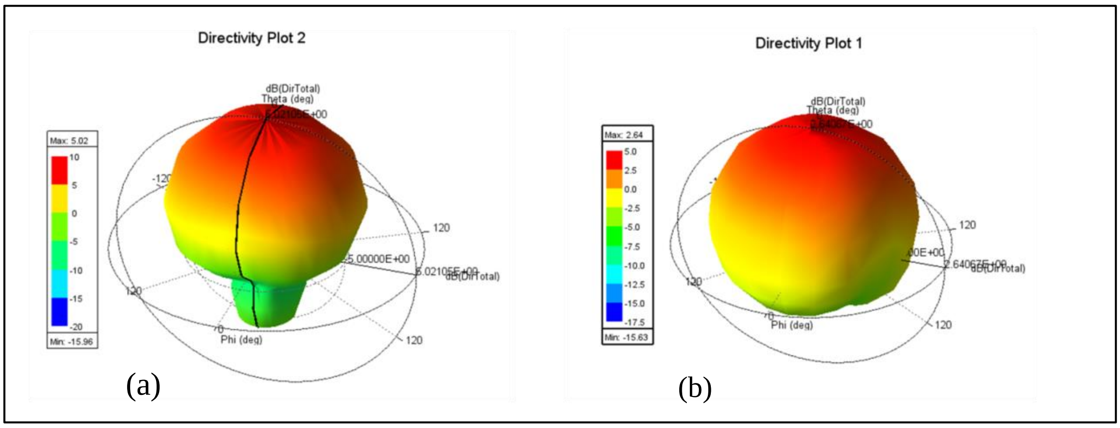

Figure 10: *(a) Directivity plot of Teflon rectangular patch antenna design, (b) Directivity plot of Rogers 4003 rectangular patch antenna design.*

Fig. 10 (a and b) exhibits the Directivity graphs of the Teflon and Rogers RT/Duroid antennas for rectangular patch antennas. The directivity values for the Teflon antenna and Rogers RT/Duroid antenna are 4.491314 and 0.565728, respectively.

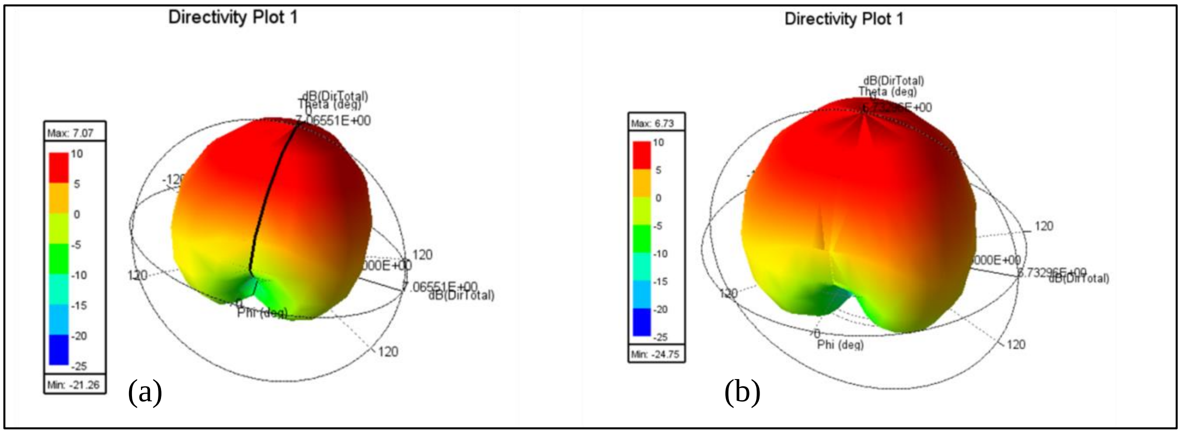

Figure 11: *(a) Directivity plot of Teflon circular patch antenna design, (b) Directivity plot of Teflon circular patch antenna design.*

Fig. 11(a and b) exhibits the Directivity graphs of the Teflon and Rogers RT/Duroid antennas for circular patch antennas. The directivity values for the Teflon antenna and Rogers RT/Duroid antenna are 5.569213 and 5.579727, respectively.

Table 2 summarizes the characteristics of distinct types of antennas fabricated with various materials, along with their corresponding peak directivity, peak gain, total efficiency, radiation efficiency, and bandwidth.

Table 2: *Comparison of antenna parameters at 25 GHZ*

Antenna Type	S-parameter (dB)	VSWR	Peak Directivity	Peak Gain	Total Efficiency	Radiation Efficiency	Bandwidth
Circular (Teflon)	-14.06	1.487	5.569213	5.443	0.939920	0.977501	1.25 GHz
Circular (Rogers RT/Duroid)	-19.03	1.25	5.579727	5.4776	0.969431	0.981699	1.05 GHz
Rectangular (Teflon)	-13.9	1.58	4.491314	4.6183	0.882649	1.028291	1.0 GHz
Rectangular (Rogers 4003)	-12.8	1.54	0.565728	0.5642	0.927480	0.997434	2.3 GHz

CONCLUSION

In conclusion, this study underscores the promising performance exhibited by circular and rectangular patch antennas crafted from Teflon and Rogers substrates operating at 25 GHz. Capitalizing on the distinctive dielectric properties inherent to these substrates, the study successfully realizes efficient antenna designs, thus showcasing their potential to bolster communication systems in the 5G landscape. The utilization of Teflon and Rogers substrates not only facilitates the attainment of desirable antenna characteristics but also underscores their viability in meeting the demanding requirements of contemporary high-frequency communication scenarios.

Furthermore, the study advocates for continued research and optimization endeavours to tailor these antenna designs for specific applications within the realm of high-frequency communication. Such initiatives are crucial for ensuring that these antennas can seamlessly integrate into and optimize the performance of evolving 5G networks. By refining microstrip antenna technology through ongoing exploration and optimization, we can effectively address the burgeoning demands of next-generation wireless communication systems.

In essence, the findings of this study not only validate the efficacy of circular and rectangular patch antennas employing Teflon and Rogers substrates but also underscore the significance of ongoing research efforts in advancing antenna technology for the 5G era. Through sustained innovation and refinement, the evolution of microstrip antennas holds tremendous promise in enhancing the efficiency, reliability, and performance of future wireless communication networks.

REFERENCES

1. Ding, Z., Zhang, D., & Ma, C. (2020). Broadband antenna design with integrated CB-CPW and parasitic patch structure for WLAN, RFID, WiMAX, and 5G applications. *IEEE Access*, *8*, 42877-42883. https://doi.org/10.1109/ACCESS.2020.2977616
2. Khan, I., & Gunjal, R. (2018). Review of MSP antenna design for various substrates. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3230632
3. Thatere, A., Khade, S., & Lande, V. S. (2021). A modified rectangular mid-band microstrip slot antenna for WLAN, WiFi and 5G applications. *Journal of University of Shanghai for Science and Technology*, *23*(1). https://jusst.org/wp-content/uploads/2021/01/A-Modified-Rectangular-Mid-band-Microstrip-Slot-Antenna-for-WLAN-WiFi-and-5G-Applications-1.pdf
4. Didi, S. E., Halkhams, I., Fattah, M., Balboul, Y., Mazer, S., & El Bekkali, M. (2022). Design of a microstrip antenna patch with a rectangular slot for 5G applications operating at 28 GHz. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, *20*(3), 527-536. http://telkomnika.uad.ac.id/index.php/TELKOMNIKA/article/view/23159
5. Abdulmajid, M. F. (2021). Study and analysis of rectangular microstrip patch antenna at 28GHz for 5G applications. *WSEAS Transactions on Communications*, *20*, 6-11. https://wseas.com/journals/articles.php?id=53
6. Shereen, M. K., Khattak, M. I., & Nebhen, J. (2022). A review of achieving frequency reconfiguration through switching in microstrip patch antennas for future 5G applications. *Alexandria Engineering Journal*, *61*(1), 29-40. https://doi.org/10.1016/j.aej.2021.04.105
7. Borel, R. T. T. S. (2023). A Microstrip Patch Antenna Designed for 25 GHz Applications. *Int. J. Res. Anal. Rev*, *10*(1), 134-139.
8. Bansal, A., & Gupta, R. (2020). A review on microstrip patch antenna and feeding techniques. *International Journal of Information Technology*, *12*(1), 149-154. https://doi.org/10.1007/s41870-018-0121-4
9. Grilo, M., Hiroaki Seko, M., & Salete Correra, F. (2016). Wearable textile patch antenna fed by proximity coupling with increased bandwidth. *Microwave and Optical Technology Letters*, *58*(8), 1906-1912. https://doi.org/10.1002/mop.29942
10. Al-Janabi, F., Singh, M. J., & Pharwaha, A. P. S. (2021). Development of Microstrip Antenna for Satellite Application at Ku/Ka Band. *Journal of Communications*, *16*(4), 118-125. https://www.jocm.us/uploadfile/2021/0319/20210319050317478.pdf
11. RANI, M. K. L., BHAGYASRI, K., MADHURI, K. N. L., VENKATA, K., & HEMALATHA, M. (2022). Design and implementation of Triple Frequency Microstrip patch antenna for 5G communications. *International Journal of communication and computer Technologies*, *10*(1), 11-17. https://ijccts.org/index.php/pub/article/view/149
12. Maheswari, T., Sankar, V. U., Reddy, S. S., Kumar, B. P., & Rushendrababu, K. (2019). Design of a microstrip patch antenna for 5G wireless applications. *IJRAR-International Journal of Research and Analytical Reviews (IJRAR)*, *6*(1), 510-515. https://ijrar.org/papers/IJRAR19H1227.pdf
13. Kumar, B. L. V., Pramod, C. B., Nagendram, S., & Kalyan, S. S. S. (2021, February). Design and Analysis of Circular Patch Antenna. In *Journal of Physics: Conference Series* (Vol. 1804, No. 1, p. 012200). IOP Publishing. https://iopscience.iop.org/article/10.1088/17

42-6596/1804/1/012200/pdf
14. Prachi, V. G., & Vijay, S. (2020). A novel design of compact 28 Ghz printed wideband antenna for 5G applications. *International Journal of Innovative Technology and Exploring Engineering*, *9*(3), 3696-3700.

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