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Comparative Study of Patch Antenna Parameters for IoT and 5G Applications for Mobils

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***Abstract*— The rapid growth of Internet of Things (IoT) [1, 2, 3] applications, driven by the advent of 5G technology [3, 4, 5, 6], is transforming industries such as healthcare, logistics, and smart cities. A key challenge in this evolution is the design of miniaturized antenna arrays that meet the stringent requirements of bandwidth, coverage, and power consumption for IoT devices operating within 5G networks. This article provides a comprehensive review of recent advancements in the development of compact and efficient antennas for 5G IoT applications [7, 8, 9], emphasizing their critical role in enabling mass connectivity and enhancing the performance of modern communication networks. A comparative analysis of patch antennas, focusing on the use of two commonly employed substrates—FR4 and Rogers RT5880—is presented. Key parameters, including dielectric constant, loss tangent, frequency range, bandwidth, gain, efficiency, antenna size, and thermal stability, are evaluated. Rogers RT5880, with its low dielectric constant (εr ≈ 2.2) and low loss tangent (tan δ ≈ 0.0009), proves to be ideal for high-frequency 5G applications, offering compact designs with higher gain, broader bandwidth, and superior thermal stability. In contrast, FR4, with higher dielectric losses, is more suited to lower-frequency IoT applications where cost is a critical factor, though its performance is limited at higher frequencies. The findings underscore the importance of substrate selection in balancing performance, size, and cost for optimal antenna design in 5G IoT applications. Additionally, the study highlights the importance of compact patch antennas, which can be directly integrated into IoT [10, 11, 12]devices or placed nearby to optimize connectivity in 5G networks, particularly at 10 GHz.**

***Index Terms*—: IoT, 5G, Miniature, Patch antenna, FR-4, Rogers RT5880, Copper, Mobils.**

I. Introduction

The objective of this work is to design and implement a miniaturized antenna array for IoT applications in 5G [13, 14] networks, while highlighting the use of metamaterial cells such as Complementary Split-Ring Resonators (CSRR), as well as slot-based techniques on the patch and ground plane. These two miniaturization methods—based on slots and metamaterials—were introduced to demonstrate the advantages of metamaterial resonators over traditional slot techniques in achieving compact antenna structures. To further optimize the performance of the proposed antennas—particularly in reducing size and increasing gain—the Defected Ground Structure (DGS) technique was applied to the ground plane of the designs dedicated to emerging IoT 5G technologies.

Several parametric studies were conducted to enhance the performance of the designed geometries, considering key metrics such as reflection coefficient, gain, and bandwidth, while significantly reducing signal transmission interference. A comparative analysis between two substrate types was also carried out to evaluate their influence on antenna performance for the selected application. Specifically, we used FR-4 lossy (dielectric constant ε_r = 4.3, thickness = 1.58 mm, conductivity = 0.025) and Rogers RT5880 lossy (ε_r = 2.2, thickness = 0.8 mm, conductivity = 0.0009), with the latter aiding in further miniaturization.

The aim of our study is the complete design and simulation of a miniaturized antenna array, followed by the fabrication of a prototype system for 5G IoT [15, 16] applications. The goal of this innovation is to develop an antenna system operating at 10 GHz using CST software, achieving high performance in terms of reflection coefficient, radiation pattern, gain, and Voltage Standing Wave Ratio (VSWR). Antenna arrays of 2×2, 4×4, and 8×8 elements were designed using miniaturization techniques to reduce the overall size of the proposed structures. Simulation results and prototype measurements were compared and analyzed. By integrating these key features, a miniaturized antenna array for IoT can provide reliable, efficient, and energy-saving connectivity for smart devices in a 5G environment.

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II. Design and Simulation Comparison of Patch Antennas

A. *Initial antennas*

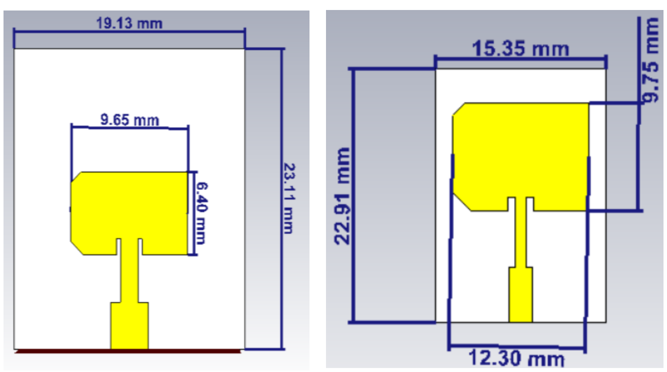
In this article, we design two patch antennas using different substrates to conduct a comparative study of various antenna parameters using the CST 2019 simulation environment. The goal is to operate at a target frequency of 10 GHz. The specifications defining the key characteristics of the antenna components are outlined as follows:

- Dielectric permittivity of substrate 1: ε_r = 4.3 (FR-4)
- Dielectric permittivity of substrate 2: ε_r = 2.2 (Rogers RT5880)
- Height of dielectric substrate 1: h = 1.58 mm
- Height of dielectric substrate 2: h = 0.508 mm
- Desired resonance frequency: f_r = 10 GHz
- Microstrip line matched to 50 Ω
- Feeding method: microstrip line
- Metallization (copper) thickness: h = 0.035 mm

The antenna dimensions are calculated using standard design equations. The first antenna is designed using FR-4 substrate, and the second one is based on Rogers RT5880 substrate [17, 18].

B. *Conception and Simulation*

Figure 1 shows the new structure of the two planar antennas after optimization, the first antenna (a) with the FR-4 substrate and the second antenna (b) with the Roger RT5880 substrate. The different parameters of the two patch antennas are shown in the following figures.



a-Antenna with FR4 substrat.
b-Antenna with Rogers RT5880 substrat.
Fig.1. Patch antenna with the new structure.

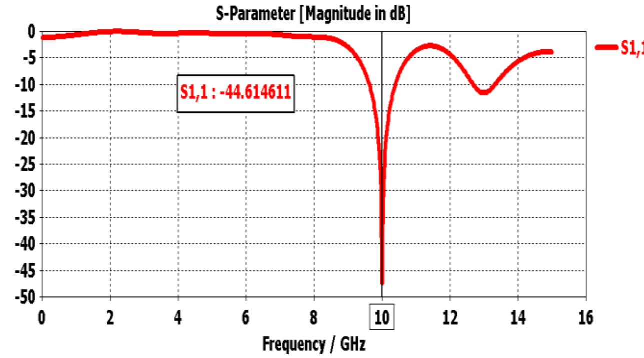


Fig.2. Reflection Coefficient S11 of the Patch Antenna with the New Structure (FR4 Substrate).

The antenna demonstrates excellent performance at its target frequency of 10 GHz, with an S11 value of -44.61 dB indicating superb impedance matching and minimal signal reflection—only about 0.0035% of the power is reflected. This far exceeds the typical design goal of S11 < -10 dB. The return loss plot shows a sharp dip, suggesting a narrow to moderate bandwidth, which is characteristic of patch antennas. Overall, the design is highly efficient and serves as a strong baseline for further optimization techniques such as CSRR or DGS.

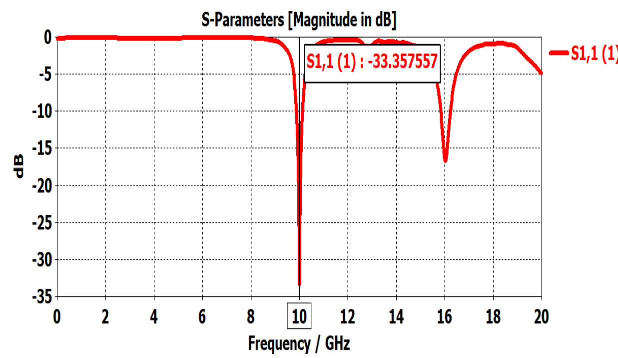


Fig.3. Reflection Coefficient S11 of the Patch Antenna with the New Structure (Roger RT5880 Substrate).

The S11 plot shows a strong resonance at 10 GHz with a deep return loss of –33.36 dB, indicating excellent impedance matching and efficient radiation—ideal for 5G or IoT applications. A secondary dip near 16 GHz suggests dual-band or wideband capability, possibly enabled by design features like slots, CSRR, or DGS. The sharper 10 GHz resonance implies a narrower bandwidth, while the broader 16 GHz response hints at additional functionality. Compared to the initial design, this version appears to offer enhanced multi-band performance with only a slight compromise in reflection at the primary frequency.

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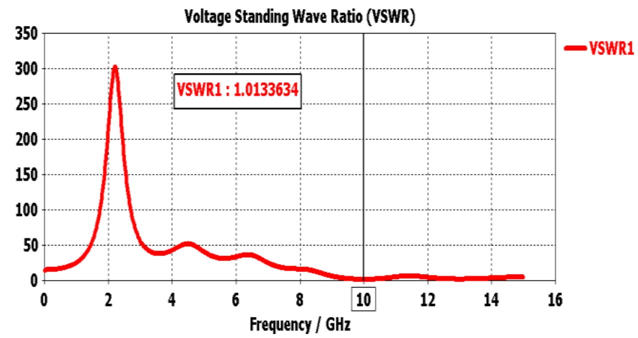

Fig.4. Voltage Standing Wave Ratio (VSWR) of the New Patch Antenna (FR4 Substrate).

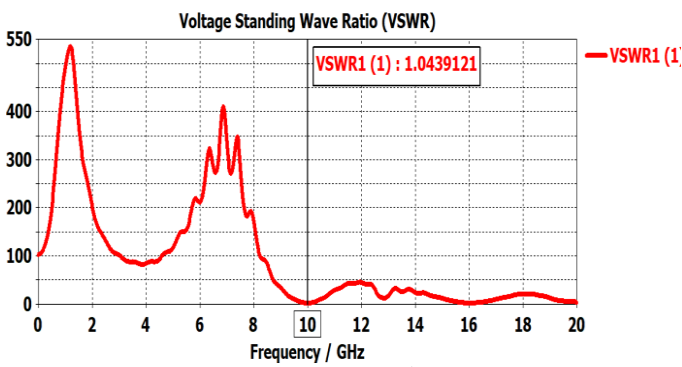

Fig.5.The Standing Wave Ratio (SWR) of the new patch antenna (Rogers RT5880).

Figures 4 and 5 show a Voltage Standing Wave Ratio (VSWR) of 1.013 for the FR4 substrate and 1.0439 for the Rogers RT5880 substrate [19], indicating excellent impedance matching at the target frequency of 10 GHz. A VSWR value close to 1 signifies that nearly all the power is being transmitted to the antenna with minimal reflection, which is essential for efficient performance. The extremely low VSWR values observed in both cases confirm that the antenna is well-matched to the transmission line, ensuring maximum power transfer and minimal signal loss. This level of impedance matching reflects careful design and optimization of the antenna structure for operation at 10 GHz. Consequently, the new antenna is highly effective at radiating energy at the desired frequency, making it well-suited for high-frequency applications such as 5G communication systems and advanced IoT networks [20] where signal integrity and efficiency are critical.

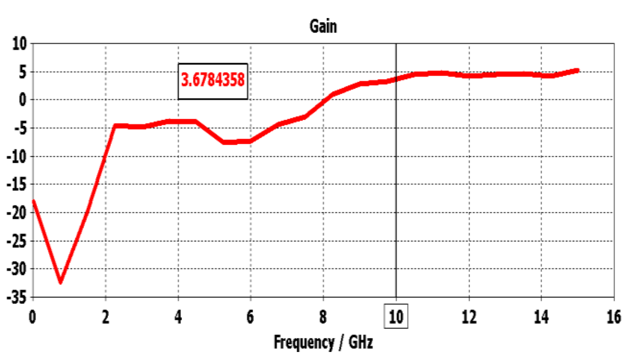

Fig.6. Gain of the patch antenna with new structure. (FR4).

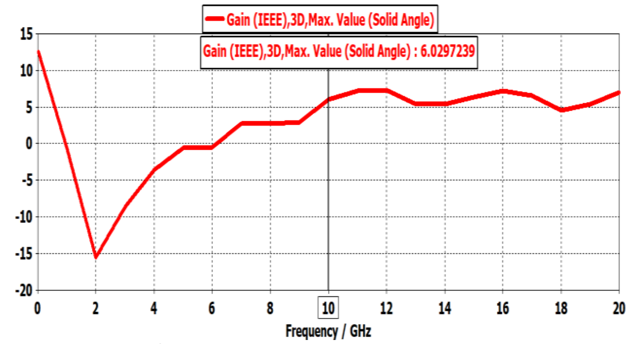

Fig.7. Gain of the patch antenna with new structure. (Roger RT5880).

Figure 6 shows that the gain of the new antenna using an FR4 substrate is 3.678 dBi, while Figure 7 illustrates that the same antenna, when implemented with a Rogers RT5880 substrate, achieves a significantly higher gain of 6.029 dBi. This clear improvement in performance is primarily due to the superior dielectric properties of Rogers RT5880, which features a lower loss tangent and more stable permittivity compared to FR4. These characteristics reduce dielectric losses and enhance the antenna's radiation efficiency, leading to a higher gain. The comparison highlights the substantial impact that substrate material can have on antenna performance, especially at high frequencies like 10 GHz. While the FR4-based antenna still performs adequately, the Rogers RT5880-based version offers enhanced signal strength and better overall efficiency, making it more suitable for demanding applications such as 5G and high-speed IoT communications where maximizing gain and minimizing losses are crucial.

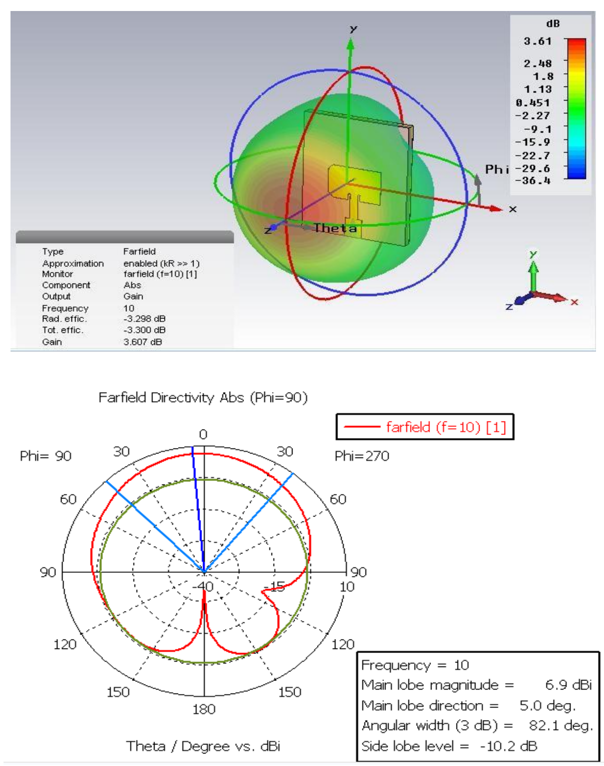

Fig.8..3D and polar gain radiation pattern of the new structure (FR4).

According to Figure 8, the radiation pattern of the antenna is omnidirectional, with a main lobe beamwidth of 82.1 degrees and a gain of 3.607 dB at the frequency of 10 GHz. This

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indicates that the antenna radiates energy uniformly in multiple directions, making it well-suited for applications that require broad coverage, such as wireless sensor networks or IoT deployments. The beamwidth of 82.1 degrees suggests a fairly wide angular spread of the main lobe, ensuring that the antenna maintains effective radiation across a large area. Although the gain of 3.607 dB is moderate, it is adequate for many practical applications and reflects a good balance between gain and coverage. The omnidirectional behavior, combined with a stable gain and broad beamwidth, supports the antenna's suitability for environments where consistent performance across various directions is essential. Overall, the radiation characteristics observed in Figure 8 confirm the antenna's effectiveness at 10 GHz, particularly when wide-area connectivity is prioritized over highly focused directional transmission.

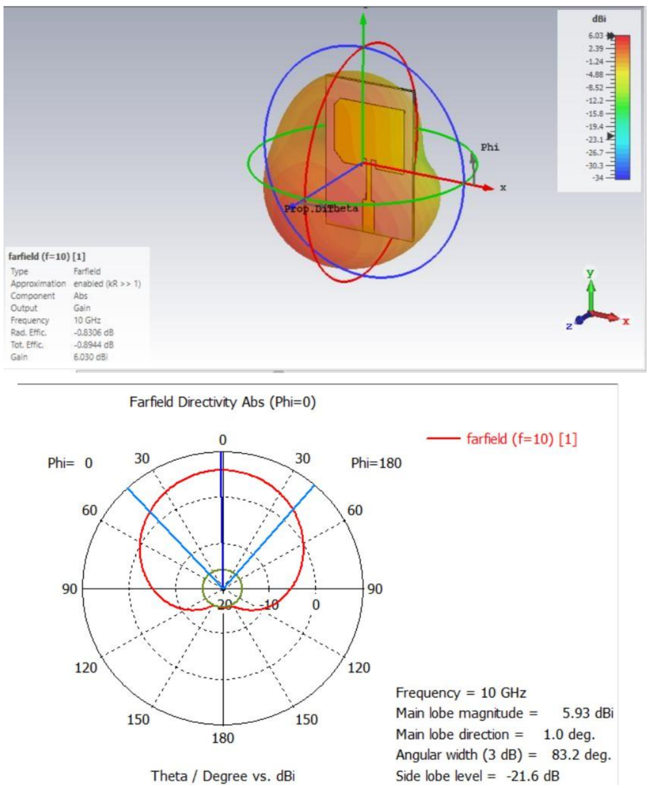

Fig.9.3D and polar gain radiation pattern of the new structure. (Roger RT5880).

According to Figure 9, the radiation pattern of the antenna exhibits an omnidirectional characteristic, which is desirable for applications requiring uniform coverage in multiple directions. The main lobe has a beamwidth of 83.2 degrees, indicating a moderately focused radiation in the desired direction while still covering a wide angular region. This beamwidth ensures that the antenna maintains a stable and consistent performance across a broad spatial area, which is advantageous for scenarios such as IoT networks or 5G small cells where connectivity to multiple devices in different orientations is necessary. The antenna achieves a gain of 6.030 dB at the design frequency of 10 GHz, demonstrating efficient radiation and good directivity. This level of gain, combined with the relatively wide beamwidth, suggests a well-balanced trade-off between directionality and coverage, making the antenna suitable for both point-to-multipoint communication and scenarios where consistent signal strength is required over a broad area.

III. COMPARAISON BETWEEN FR4 AND ROGERS TR5880 SUBSTRATS

When comparing FR4 and Rogers RT5880 as antenna substrates, Rogers RT5880 clearly outperforms FR4 in high-frequency applications. With a lower dielectric constant (εr ≈ 2.2) and significantly lower loss tangent (≈ 0.0009), RT5880 enables faster signal propagation, reduced dielectric losses, broader bandwidth, and higher gain and efficiency—making it ideal for 5G and IoT systems operating at 10 GHz or higher. In contrast, FR4 suffers from higher losses, limited frequency range, and reduced efficiency, making it better suited for low-cost, low-frequency designs. Additionally, RT5880 supports more compact, thermally stable, and reliable antenna designs, which is critical for modern, miniaturized, and outdoor applications [18, 19, 20].

Rogers RT5880 is generally the superior choice for high-frequency applications such as Cloud IoT and 5G, due to its excellent electrical properties—offering better bandwidth, higher gain, improved radiation efficiency, and strong thermal stability. These features are critical for maintaining reliable and fast wireless communication in demanding environments. However, its higher cost can be a limiting factor. For lower-frequency IoT systems or cost-sensitive deployments where ultra-high performance is not essential, FR4 remains a viable alternative. Although it has higher losses and limited high-frequency capability, FR4 still supports basic functionality at a much lower price point, making it suitable for budget-conscious or large-scale IoT implementations.

For patch antennas intended for IoT 5G applications, **Rogers RT5880** is strongly recommended due to its superior performance at high frequencies, despite being more expensive. In contrast, **FR4** can still be suitable for low-cost IoT applications operating at lower frequencies or where performance is less critical. The choice depends on the trade-off between performance, operating frequency, and cost.

Table1: comparaison parameters for Rogers RT5880 and FR4 for IoT 5G Patch Antennas.

Parameter	Rogers RT5880	FR4
Dielectric Constant (εr)	2.2	4.3–4.8
Loss Tangent (tan δ)	0.0009	0.02
Frequency Range	Suitable for frequencies up to 60 GHz	Suitable for frequencies below 6 GHz
Bandwidth	Wider bandwidth, better impedance matching	Narrower bandwidth, higher return loss
Gain and Efficiency	High gain and efficiency, better at high frequencies	Lower gain and efficiency, reduced at high frequencies

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Parameter	Rogers RT5880	FR4
Antenna Size	More compact due to lower εr	Larger due to higher εr
Thermal Stability	High thermal stability, reliable in harsh conditions	Less stable, potential performance degradation in extreme environments
Cost	Higher cost, suitable for high-performance applications	Lower cost, suitable for low-cost applications

This table provides a concise comparison of the two materials, helping to make an informed decision based on the specific needs of the IoT 5G applications [18, 19, 20].

IV. Conclusion

In conclusion, the design of compact and efficient antennas is paramount for the success of 5G IoT applications, which demand high bandwidth, low power consumption, and extensive coverage. This study has demonstrated that substrate selection plays a crucial role in determining the performance of patch antennas used in such applications. **Rogers RT5880** emerges as the superior choice for high-frequency 5G systems, offering advantages such as low dielectric constant, low loss tangent, and superior thermal stability, which enable smaller, high-performance antenna designs ideal for mmWave frequencies and high-speed IoT networks. On the other hand, **FR4**, with its higher dielectric losses, remains a cost-effective solution for lower-frequency IoT applications, where performance requirements are less stringent.

The comparative analysis emphasizes that the selection of substrates should align with the specific needs of the application, balancing factors like cost, performance, and size. As IoT networks continue to expand and evolve within 5G ecosystems, the importance of efficient and miniaturized antenna designs will only grow. Patch antennas, with their compact form factor, offer a promising solution for seamless integration into IoT devices and can be placed in strategic locations to optimize connectivity. Future advancements in antenna materials and designs will further drive the development of reliable, high-performance IoT networks, supporting the ever-expanding demands of the 5G era.

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