Design and Optimization of Rectangular Microstrip Patch Antenna using Duroid Substrate For 5G Application in Nigeria

O. OLABISI[1], A. G EBISEMIJU[2], S.O AREO[3], D. E ELEYELE[4]
[1, 2, 3]Department of Science Laboratory Technology, Ladoke Akintola University of Technology
[4]Department of Physics, Ladoke Akintola University of Technology

***Abstract-* This paper deals with the design and optimization of rectangular microstrip patch antennas (MPAs) for 5G applications using RTDuroid substrate. The performance of such an antenna is analyzed based on single rectangular MPA return loss, bandwidth, Gain and Voltage Standing Wave Ratio. Thereafter, array configurations (1x2 and 1x4 arrays) have been examined for their effect on antenna performance. With the optimization that has been done on these arrays, there is a significant increase in their gain and radiation patterns, that is, the main lobe magnitude has increased, the beamwidth is reduced, and side lobes are at a lower level. The results demonstrated the promise of optimized rectangular MPAs and arrays that could meet the requirements imposed by 5G networks such as high gain, wide bandwidth, and such.**

***Indexed Terms-* Microstrip Patch Antenna, RT duroid substrate, 3.5GHz**

I. INTRODUCTION

Mobile communication systems such as the first generation (1G), second generation (2G), third generation (3G), fourth generation (4G) and fifth generation (5G) cellular networks enables mobile connection to mobile devices. Fifth generation (5G) technology serves as basesfor the smart phones, smart buildings, smart cities, and many applications in the future, thus requiring a 5G antenna with low latency, high gain, low path loss, and stable radiation pattern [1]. However, under-requisites promised by 5th Generation is beset with issues such as coverage and propagation characteristics, output power, and unwanted emissions attenuation among others [2]. To overcome these challenges, different types of antennas have been designed, such as monopole antenna, dipole antenna, loop antenna, and microstrip [3]. Microstrip antennas are said by research and literature to be the cutting-edge antenna to work for 5G because it uses less power, is high gain, wide bandwidth, lightweight, easy to fabricate, and inexpensive [4]. There are various types of microstrip antennas, but in this research, the focus is on the design and optimization of rectangular microstrip antennas.

II. ANTENNA DESIGN

The beginning of the design process is selecting a relevant substrate material. For the substrate material, RT Duroid 5880 having a low loss tangent and easy processing was chosen [5], because this choice is crucial in performance characteristics of the antenna, as it influences the antenna's performance characteristics. Optimal patch dimensions are established during critical steps. The length and width are calculated so as to have a resonating feature at the required 5G frequency band which typically falls around 3.5 GHz. These calculations consider the factors needed for the design.

Measurement of patch width (w_p)

The width [w] of the patch is calculated using the equation below;

$$w = \frac{c}{2fr} \sqrt{\frac{2}{\epsilon_{r+1}}}$$

Effective dielectric constant (ϵ_{reff})

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-1/2} \text{ for } \frac{w}{h} \geq 1$$

Measurement of Δl

$$\Delta l = \frac{0.412(\epsilon_{eff}+0.3)[\frac{wp}{h}+0.264]}{(\epsilon_{eff}-0.258)[\frac{wp}{h}+0.8]} \ \epsilon_{reff}$$

Actual length of the patch is determined by the Equation 3.20;

$$l = l_{eff} - 2\Delta l$$

L_{reff} isthe effective length that is given by the Equation 3.21 below

$$l_{eff} = \frac{c}{2fo\sqrt{\epsilon_{reff}}}$$

$f_0$is the resonant frequency that can be calculate by the Equation 3.22;

$$f_0 = \frac{c}{2\sqrt{\epsilon_{eff}}} = \frac{1}{2l\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}}$$

Where ϵ_{reff} is the effective dielectric constant
ϵ_r is the relative permittivity of the dielectric material
h is the thickness of the dielectric layer
W is the width of the conductor

The preferred feeding method is coaxial probe feeding. Such a method is simple and flexible in achieving the most appropriate impedance matching between the feeding line and the antenna [6]. With careful consideration, the feed point is located on the patch, leading to low reflection losses and high power transfer. The antenna design process makes use of electromagnetic simulation software like HFSS for analyzing and optimizing antenna performance. Major performance parameters are simulated and analyzed in return loss, bandwidth, and radiation pattern. Parameter sweeps and optimization algorithms are used to optimize antenna dimensions and feeding configurations toward the desired parameters of performance. The design also embarks on investigating possible array configurations to improve performance considering the rigorous demands imposed by 5G communication. Arrays include a number of linear, like 1x2 and 1x4, explored for better gain and directivity. This involves ensuring that several antenna elements are placed strategically with respect to inter-element spacing so that mutual coupling can be minimized and patterns optimized.

III. RESULTS AND DISCUSSION

Return Loss

The simulated return loss of the rectangular MPA at the resonant frequency of 3.5 GHz was found to be -28.85 dB as shown in Figure 1.This exceptionally low return loss value signifies a high degree of impedance matching between the antenna and the feeding line [7]. This implies minimal power reflection back to the source, resulting in efficient power transfer to the radiating element. This characteristic is crucial for 5G applications, as it minimizes signal losses and ensures maximum power is utilized for effective communication.

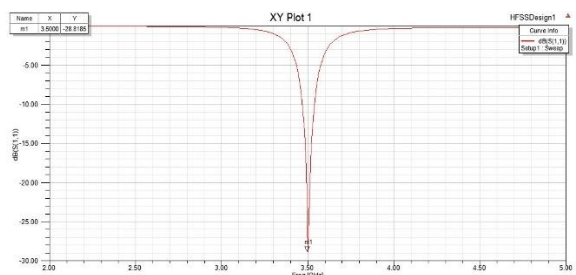

Figure 1: Return Loss of the Rectangular MPA

Bandwidth

The simulated bandwidth of the rectangular MPA shown in Figure2 was determined to be 188 MHz at the center frequency of 3.5 GHz. While this value falls within the typical range for microstrip patch antennas [7], it is crucial to consider that 5G applications often demand wider bandwidths to accommodate high data rates and diverse communication services. Further optimization efforts, such as incorporating matching networks or exploring alternative substrate materials, can be explored to increase the bandwidth and enhance the antenna's suitability for demanding 5G application

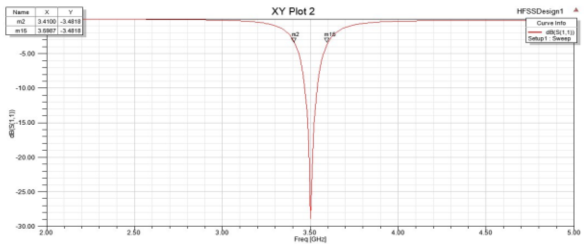

Figure 2: Bandwidth of the Rectangular MPA

Voltage Standing Wave Ratio (VSWR)

The simulated VSWR of the rectangular MPA shown in Figure 3 was 0.6297, indicating excellent impedance matching with minimal power reflection. A low VSWR is highly desirable as it minimizes signal losses within the transmission line, ensuring maximum power delivery to the antenna [8]. This is particularly important for 5G applications, where efficient power transfer is crucial for maximizing coverage and minimizing interference.

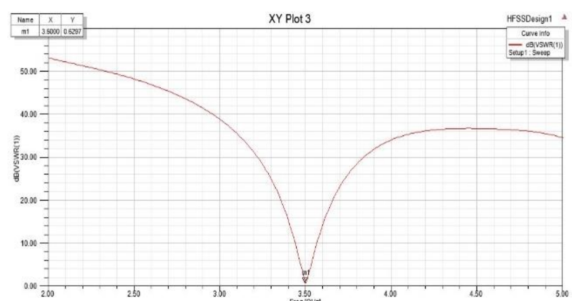

Figure 3: Voltage Standing Wave Ratio of rectangular MPA

Radiation Pattern

Simulation results shown in Figure 4 indicated a directivity of 2.5882 dB for the rectangular MPA. This characteristic is beneficial for 5G applications, where directional signal propagation is often preferred to enhance coverage and minimize interference with other communication systems. The focused radiation pattern can also contribute to improved link quality and reduced power consumption.

Figure 4: Radiation pattern in 3D of Rectangular MPA

Gain

The simulated peak gain of the rectangular MPA at 3.5 GHz was 7.8059 dB as shown in Figure 5. This level of gain is sufficient for many 5G applications, enabling effective communication over reasonable distances. Higher gain is particularly advantageous for applications that require long-range communication or operation in areas with challenging propagation conditions.

Figure 5: Gain plot for rectangular MPA

IV. OPTIMIZATION

Further optimization efforts can be explored to enhance these characteristics and improve overall performance. This may include investigating alternative substrate materials, exploring different feeding techniques, and optimizing the array configuration to achieve higher gain and wider bandwidth.

Return Loss

The single patch antenna demonstrated superior performance with an excellent return loss of -37.812 dB, indicating strong impedance matching. The 1x2 array exhibited a lower return loss of -12.543 dB, while the 1x4 array configuration as shown in Figure 6 showed multiple return loss peaks, suggesting potential for multi-band operation. While the array configurations offer flexibility in frequency response, they exhibit a trade-off in terms of reduced return loss at the center frequency compared to the single patch antenna. These findings suggest that the choice between single patch and array configurations depends on the specific application requirements, prioritizing either optimal impedance matching or broader frequency operation for 5G applications.

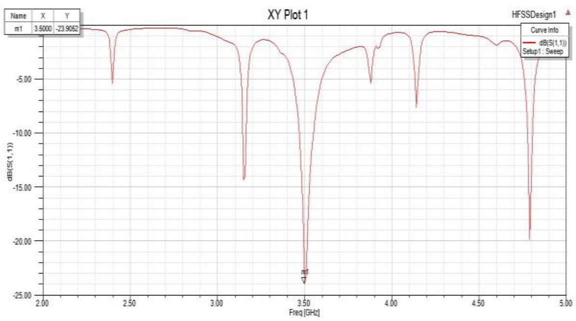

Figure 6: 1x4 rectangular array return loss

Bandwidth

The single patch antenna demonstrated a bandwidth of 73.2 MHz. The 1x4 array configuration exhibited a slightly narrower bandwidth of 66.5 MHz. While a slight reduction in bandwidth is observed with the array configuration, it still falls within the acceptable range for 5G applications. Optimization techniques, such as incorporating matching networks (e.g., stub tuning, slot loading) and adjusting the dimensions of the patch elements, can be explored to potentially increase the bandwidth of the array configuration while maintaining acceptable performance.

Voltage Standing Wave Ratio (VSWR)

Analysis of Figures 4.7 revealed acceptable VSWR values (below 2) for both 1x2 and 1x4 array microstrip antennas at 3.5 GHz. While the single patch antenna demonstrated superior impedance matching at the center frequency with a VSWR close to 1, the optimized array configurations exhibited promising results, offering a trade-off between achieving broader operational bandwidth and maintaining acceptable impedance matching. This suggests that with further optimization, array configurations can provide a viable alternative with enhanced performance across a wider frequency range."

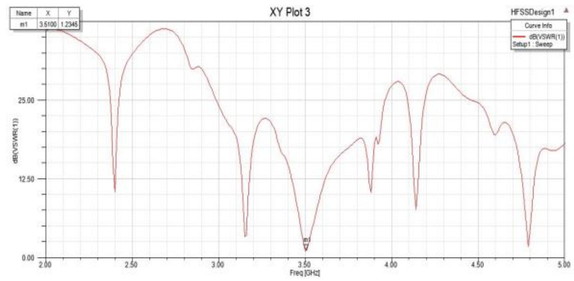

Figure 7: 1x4 Array for Voltage Standing Wave Ratio

Radiation Pattern

The 1x4 array configuration demonstrated significant improvements in the radiation pattern compared to the single patch antenna. The main lobe magnitude increased from 7.8059 dB for the single patch to 12.32 dB for the 1x4 array as shown in Figure 8, indicating a substantial gain enhancement. The 1x4 array also exhibited a narrower angular width (3dB) of 82.6 degrees compared to the single patch, indicating improved directivity and a more focused radiation pattern. Additionally, the lower sidelobe levels (-16.5 dB for the 1x4 array compared to -14.2 dB for the 1x2 array) suggest reduced interference and improved signal clarity. These results underscore the significant performance enhancements achievable through array optimization techniques.

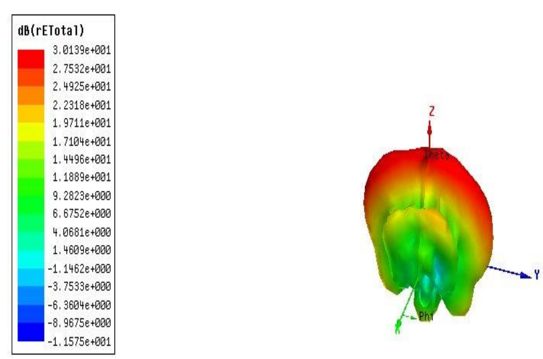

Figure 8: 3-D Radiation Pattern 1x4Antenna Array

Gain

Analysis of the gain characteristics, depicted in Figures 9, revealed significant performance variations among the single patch, 1x2 array, and 1x4 array microstrip antenna configurations at the 3.5 GHz operating frequency. While the single patch antenna exhibited a gain of 5.4668 dB, the 1x2 array demonstrated a slight improvement, reaching 5.5051 dB. However, the 1x4 array configuration exhibited a substantial gain enhancement, achieving 12 dB at the operating frequency. This substantial gain increase in the 1x4 array configuration positions it favorably for 5G applications demanding higher gain for robust signal propagation and extended coverage. Furthermore, the single patch antenna's gain values at the band edges exhibited a slight decrease, falling below the generally considered optimal threshold for 5G performance. In contrast, the 1x4 array's higher gain at 3.5 GHz underscores the potential of array optimization to achieve the gain levels necessary for reliable and efficient 5G network operation. These findings emphasize the significance of exploring array configurations, such as the 1x4 array, as a promising avenue for enhancing antenna performance in demanding 5G applications."

Figure 9: 1x4 Array for gain

CONCLUSION

This work entailed designing and optimizing a relatively conventional microstrip patch antenna for 5G applications. It is worth mentioning that RT Duroid 5880 is used as substrate material. However, its low loss characteristics make it an ideal substrate material. The design processes included patch dimensions, feeding techniques, and desired array configurations that led to the performance improved. Simulation results are a promising show of performance characteristics including good values of return loss, bandwidth, and gain. As attested by the 1x4 array configuration, considerable increase in gain and directivity is achieved when moving from a single patch antenna to an array. This shows the significant influence of array configurations on performance improvement for 5G applications. This research is a useful introductory study into designing and optimizing rectangular microstrip patch antennas for 5G communication systems. Further improvements may entail more research and optimization such as trying other substrate materials or feeding techniques or most likely array configurations. These will give further performance optimizations and the adaptability of these antennas to the emerging requirements of 5G and future wireless communications.

REFERENCES

[1] Andrews, J.G. (2014). "What Will 5G Be?" *IEEE Journal on Selected Areas in Communications*, 32(6), 1065-1082.

[2] Li, *et al*. (2021). "A Comprehensive Survey of 5G Security: Research Challenges and Solutions." *IEEE Communications Surveys & Tutorials*, 23(1), 470-512.

[3] Balanis, C. A. (2021). Antenna Theory: Analysis and Design (3rd ed.), 981-1011

[4] Charkraborty, U., Chatterjee, S., Chowwdhury S.K. and Sarkar, P.P. (2011). A Compact microstrip patch antenna for wireless communication. *Progress in Electromagnetic Research* 18, 211-220.

[5] Hassan, R. and Suman, A. (2012). Substrate height and dielectric constant dependent performance of circular microstrip patch array anenna for broadband wireless access. *Journal of Emerging Trends in Computing and Information science*3, 1392-1397.

[6] James, J. R. (2022). Handbook of microstrip antennas. *Peter Peregrinus Ltd*, 815-850

[7] Suganthi, S., Shashikumar, D., Chand, E. (2022). Experimental Verification of Gain and Bandwidth Enhancement of Fractal Contoured Metamaterial Inspired Antenna. *Advanced Electromagnetics*, *11*(3), 42-49.

[8] Nakar, P. S. (2004). Design of a compact microstrip patch antenna for use in wireless/cellular devices.