International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 9 Issue 2, Mar-Apr 2025 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Design, Simulation, and Performance Evaluation of 2.4 GHz Microstrip Patch Antenna Arrays with Power Divider for UAV and Drone Applications

Aremu, O. A.[1]; Ajao, O. S.[2]; Makinde, O. S.[3]; Adeniji J. A.[4]

[1,3,4]Physics Department, The Polytechnic, Ibadan, Oyo State, Nigeria
[2]Physics Department, The Oke Ogun Polytechnic, Saki, Oyo State, Nigeria

ABSTRACT

Single-element microstrip patch antennas face significant challenges, including low gain and narrow bandwidth, which restrict their broader applications. This paper focuses on the design and simulation of rectangular microstrip patch antenna (RMPA) arrays to enhance gain performance compared to a single-element RMPA for Drone and Unmanned Aerial Vehicle (UAV) applications. The process is done with the help of Computer Simulation Technology (CST) microwave studio. The resonant frequency, substrate material, and substrate height were first specified, followed by the design of a single-element RMPA as the initial step in the design process. The single element was excited by the quarter-wave feed line method for good impedance matching network. The two-element and four-element RMPA arrays were designed using the single-element RMPA as the fundamental building block. The performance of the designed and simulated antennas were evaluated and compared in terms of gain, return loss and radiated power. The results revealed that, the gain increased from 7.61 dB (single element) to 9.64 dB (2×1 array) to 10.7 dB (4×1 array). Compared to the single element RMPA the return loss of -23.61 dB, the 2×1 and 4×1 RMPA arrays achieved a return loss of -26.78 dB and -30.97 dB respectively. The radiated power analysis revealed that the 4×1 array achieved the highest transmission efficiency at 99.92%, surpassing the single-element (97.78%) and the 2×1 array (99.48%). The 4×1 array is the best performing configuration, with optimal impedance matching. This study confirms that increasing the number of elements enhances gain and directivity, leading to better radiation focus and power efficiency.

How to cite this paper: Aremu, O. A. | Ajao, O. S. | Makinde, O. S. | Adeniji J. A. "Design, Simulation, and Performance Evaluation of 2.4 GHz Microstrip Patch Antenna Arrays with Power Divider for UAV and Drone Applications" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-9 | Issue-2, April 2025, pp.716-724, URL: www.ijtsrd.com/papers/ijtsrd76329.pdf

IJTSRD76329

KEYWORDS: *Antenna arrays, Gain, Power divider, Return loss, Radiated power*

1. INTRODUCTION

The rapid advancements in wireless communication and aerial technologies have increased the demand for efficient and high-performance antennas, particularly in the **2.4 GHz** frequency band.

Microstrip patch antennas have emerged as a preferred choice due to their **lightweight, low profile, ease of fabrication, and compatibility with modern communication systems.** In applications such as **drones and unmanned aerial vehicles (UAVs)**, reliable and high-gain antenna arrays are essential for stable communication, navigation, and data transmission. Microstrip single antenna has several advantages, it also has several disadvantages such as low gain, narrow bandwidth with low efficiency [1,2]. These disadvantages can be overcome by constructing many patch antennas in array configuration. Many authors have anticipated quite a number of techniques to enhance the performance of microstrip patch antennas. As stated by [3], array configuration is usually adopted to improve the gain of microstrip patch antennas. Conversely, [4] in his work reported that the array feed, to a large extent, determines the gain improvement achieved.

Khraisat (2012) [5] reported the design of a single microstrip path antenna. The length, width, input impedance of the patch and the feed dimensions were evaluated without stating the formulae in the paper. Furthermore, the author showed the geometrical arrangement of 2x1 and 4x1 arrays. The same values specified for single MSA were used for the design of the antenna arrays. The design equations for the computations of the widths and lengths of the microstrip lines, and quarter wavelength transformer were not stated. The designs were tested with IE3D electromagnetic simulator.

This paper focuses on the **design, simulation, and performance analysis of single element and different microstrip patch antenna arrays with** design equations for the computations of the microstrip lines, and quarter wavelength transformer as well as power divider operating at **2.4 GHz**

2. METHODOLOGY

This paper intends to design and simulate a single rectangular microstrip patch antenna (RMPA) and arrays RMPA for Drone and UAV applications. To realize this, the choice of simulating software, design specifications and parameter (dimension) calculations to achieve a light weighted RMPA is considered as follows:

A. Choice of Antenna Simulation Software

In this study, the CST studio suit 2024 software is preferred for design and simulation, as it is based on the Finite Element Method (FEM) techniques. CST is Ideal for wideband antenna designs and fast transient analysis, such as impulse response and broadband scattering. It also combines multiple solvers to handle complex antenna systems, like an array inside an enclosure.

Step 1: Calculation of the Patch width (Wp)

In this study, the detailed procedure and design equations [6] [7] [8] for the proposed single element Microstrip patch antenna designed at the operating frequency 2.4 GHz for Drone and UAVs applications using Rogers RO3000 substrate are as follows $f_r = 2.4 \times 10^9\ Hz$, $c = 3 \times 10^8\ ms^{-1}, h = 1.6\ mm\ and\ \varepsilon_r = 3.55$.The patch width (Wp) of the antenna is computed based on (1) as:

$$W_P = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

Step 2: Design of effective dielectric constant, ϵ_{eff}

The effective dielectric constant ϵ_{eff} introduced to account for the fringing and the wave propagation in the line. ϵ_{eff} is obtained from (2)

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5} \quad (2)$$

Step 3: Design of Effective and actual length of the patch.

The effective length of the patch is calculated from (3):

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

The length extension (ΔL) is subtracted from the length of the patch with actual length of the pat()unchanged. The length extension is considered due to fringing field as seen in (4) while the actual length of the patch is obtained from [9] using (5)

$$\Delta L = 0.412h\frac{\left(\epsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

$$L_P - L_{eff} - 2\Delta L \quad (5)$$

Step 4:. Design of ground plane dimensions (Lg and Wg)

The length and width of the ground is computed using (6) and (7) respectively as:

$$L_g = 6h + L_P \quad (6)$$

$$W_g = 6h + W_P \quad (7)$$

Step 5:. Design of quarter-wave feedline dimensions

The conductance of a single slot of finite width is given by [10, 11] as follows.

$$G = \frac{W}{120\lambda_0}\left[1 - \frac{(k_0 h)^2}{24}\right] \quad \text{for } \frac{h}{\lambda_0} < {}^{1}/_{10} \quad (8)$$

$$B - \frac{W}{120\lambda_0}\left[1 - 0.636\ln(k_0 h)^2\right] \quad \text{for } \frac{h}{\lambda_0} < {}^{1}/_{10} \quad (9)$$

where λ_0 is the free space wavelength and $k_0$is the wave number given by,

$$k_0 = \frac{2\pi}{\lambda_0} \quad (10)$$

$$R_{in} = \frac{1}{2G} \quad (11)$$

The width of the quarter wave transformer feedline depends on its characteristics impedance. which is designed for impedance matching. For a patch input impedance $(R_{in} = 100\ \Omega)$ and a feedline output impedance (Z_0=50 Ω)

Z_1=√(Z_0 R_in) (12)

Step 6: Design of the width of Quarter wave section

The width of the quarter-wave feed line is computed using the mathematical expression given in [10, 12, 13] as follows

$$\frac{W_Q}{h} = {8e^A}/{e^{2A} - 2} \quad \text{for } \frac{W_Q}{h} < 2 \quad (13)$$

$$\frac{W_Q}{h} = {}^{2}/_{\pi}\left[B - 1 - \ln\left((2B-1) + \left({}^{\varepsilon_r - 1}/_{2\varepsilon_r}\right)\{\ln(B-1) + 0.39 - {}^{0.61}/_{\varepsilon_r}\}\right)\right] \quad \text{for} \quad \frac{W_Q}{h} > 2 \qquad (14)$$

where

$$A = \frac{Z}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + {}^{0.11}/_{\varepsilon_r}\right)$$

$$B = {}^{377\pi}/_{2Z\sqrt{\varepsilon_r}}$$

Solving iteratively, for $h = 1.6\,mm$ and $\varepsilon_r = 3.55$, the width W_Q of the quarter wave feed line is obtained.

Step 7: Design of length of the 50 Ω transmission line and quarter-wave feedline.

The length of 50 Ω transmission line and quarter-wave feedline are computed using (15) as:

$$L_{Q\,(50\,\Omega)} = {}^{\lambda}/_{4} = {}^{\lambda_0}/_{4\sqrt{\varepsilon_{reff}}} \qquad (15)$$

where $\lambda_0 = {}^{c}/_{f_0}$ and $\varepsilon_{reff} = 3.05$

Figure 1 illustrates the schematic diagram of the quarter-wave feed single-band microstrip antenna, highlighting the designed parameters while figure 2 depicts the. Model of Quarter wave-feed line of the antenna at 2.4 GHz using CST Studio. Table 1 provides a summary of the dimensions for the single-patch antenna designed at 2.4 GHz.

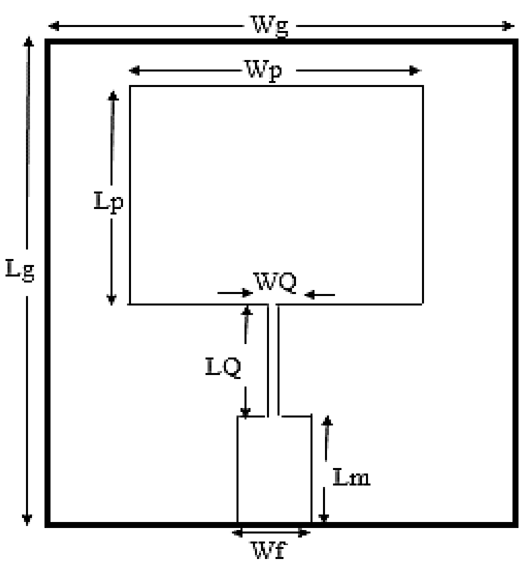

Fig 1 schematic diagram of the quarter-wave feed single-band microstrip antenna.

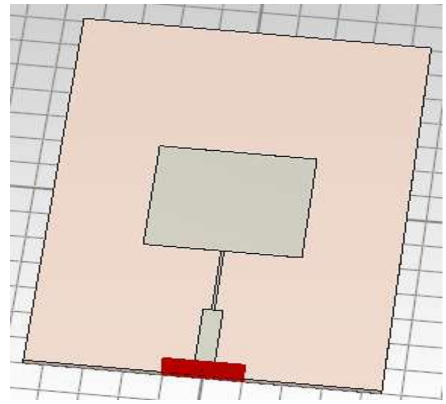

Fig. 2. Model of single element Patch antenna using CST Studio

Table 1 Dimensions for single element RMPA

Parameters	Values
(A) Patch dimensions	
Patch Length (L)	28.85 mm
Patch Width (W)	38.05mm
Height of substrate (hs)	1.6 mm
(B) Ground plane dimensions	
Ground Plane Length (L_g)	38.45 mm
Ground Plane width (W_g)	47.65 mm
(C) Dimensions of feedline	
Length of quarter-wave feedline	17.9 mm
Characteristics impedance of quarter-wave	70.7 Ω
Input edge impedance	100 Ω
Width of quarter-wave feed line	1.97 mm
Width of 50 Ω transmission line (Wf)	3.5 mm
Length of 50 Ω transmission line	17.9 mm

Step 8: Layout for N-element linear array

The edge to edge spacing S, between adjacent patches is $0.5\,\lambda_g$. Therefore, the spacing between the patches is computed using,

$$S = 0.5\frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \qquad (16)$$

Total array length is,

$$L_{array} = N \times L_{patch} + 3S \qquad (17)$$

where *N* is the number of array

Ground plane dimension for N-element array

For proper operation, the ground plane should extend by at least $6h = 6 \times 1.6 = 9.6\,mm$ beyond the patch edges in all directions. Hence, the ground plane length (L_g) and ground plane width (W_g) for N array is given depicts by equations (18) and (19) respectively,

$$L_g = L_{array} + 9.6N \qquad (18)$$

$$W_g = W_{array} + 9.6N \qquad (19)$$

Computation of Antenna efficiency (η) and reflection coefficient (Γ)

Antenna **efficiency** (η) is determined by converting the gain (G) and directivity (D) obtained after simulation into linear scale, the relationship is as shown in Equation (16)

$$\eta = \frac{10^{\left(G_{dBi}/10\right)}}{10^{\left(D_{dBi}/10\right)}} \quad (16)$$

The **Reflection Coefficient (Γ)** quantifies how much of the incident power is reflected due to impedance mismatch. It is related to **VSWR** using the Equation (17)

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \quad (17)$$

The reflected power (P_r) presents the **percentage of incident power that is reflected** due to impedance mismatch, it is computed using the expression given by (18)

$$P_r - \Gamma^2 \times 100 \quad (18)$$

The power radiated by the antenna can be estimated by subtracting the power reflected from antenna input power, equivalently as shown in (19)

$$P_{radiated} - (1 - |\Gamma|^2) \,.\, P_{input} \quad (19)$$

where Γ is the linear reflection coefficient given by,

$$\Gamma = 10^{RL/20} \quad (20)$$

Figure 3 depicts the. Model of Quarter wave-feed line of the 2 × 1 array antenna with power divider at 2.4 GHz using CST Studio while Table 2 provides a summary of the dimensions for the 2 × 1 array antenna designed at 2.4 GHz.

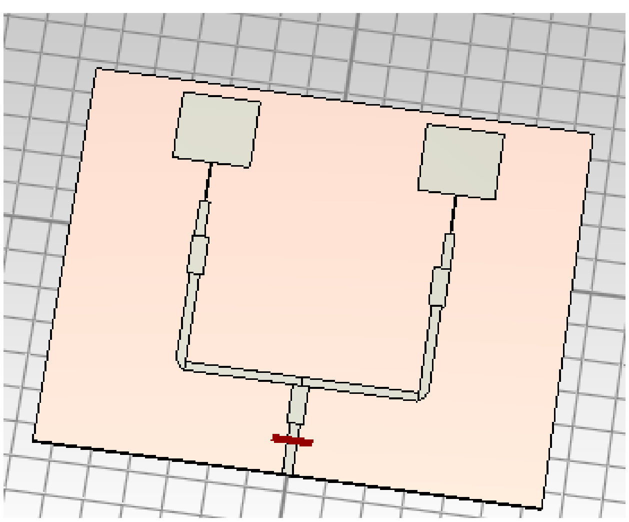

Fig. 3. Design of 2X1 array Patch antenna with power divider using CST Studio

Table 2 Design dimensions for the 2 × 1 array RMPA

Parameters	Values
(A) Patch dimensions	
Patch Length (L)	28.85 mm
Patch Width (W)	38.10 mm
Height of substrate (hs) Spacing between adjacent patches (S) Total array length (L_{array}) Total array width (L_{array})	1.6 mm 35.80 mm 92.80 mm A.10 mm
(B) Ground plane dimensions	
Ground Plane Length (L_g)	112.00 mm
Ground Plane width (W_g)	A.30 mm
(C) Dimensions of feedline	
Length of quarter-wave feedline	18.00 mm
Characteristics impedance of quarter-wave	35.35 Ω
Input edge impedance	50 Ω
Width of quarter-wave feed line	4.70 mm
Width of 50 Ω transmission line (Wf)	3.50 mm
Length of 50 Ω transmission line	20.00 mm

Figure 4 illustrates the. Model of Quarter wave-feed line of the 4 × 1 array antenna with power divider at 2.4 GHz using CST Studio while Table 3 provides a summary of the dimensions for the 4 × 1 array antenna RMPA.

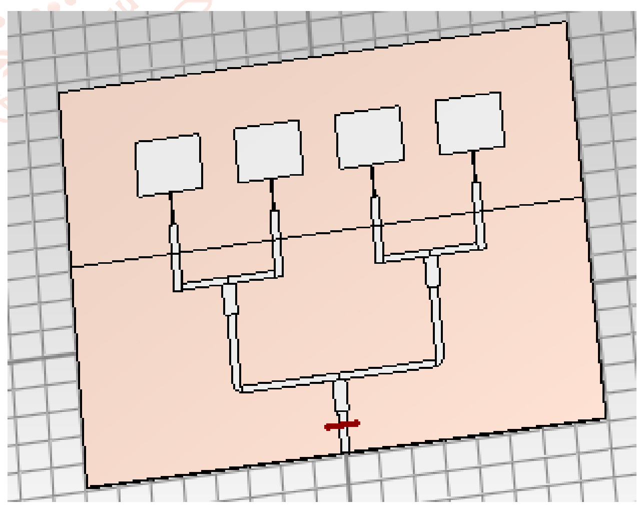

Fig. 4. Design of 4 × 1 linear array Patch antenna with power divider using CST Studio

Table 3 Design dimensions for the 4 × 1 array RMPA

Parameters	Values
(A) Patch dimensions	
Patch Length (L)	28.85 mm
Patch Width (W)	38.10 mm
Height of substrate (hs) Spacing between adjacent patches (S) Total array length (L_{array}) Total array width (L_{array})	1.6 mm 31.20 mm 171.90 mm A.10 mm
(B) Ground plane dimensions	
Ground Plane Length (L_g)	231.50 mm
Ground Plane width (W_g)	A.50 mm
(C) Dimensions of feedline	
Length of quarter-wave feedline	18.00 mm
Characteristics impedance of quarter-wave	35.35 Ω
Input edge impedance	250 Ω
Width of quarter-wave feed line	4.70 mm
Width of 50 Ω transmission line (Wf)	3.50 mm
Length of 50 Ω transmission line	20.00 mm

3. RESULTS AND DISCUSSION

This section presents the results for different microstrip antenna for single elements and linear elements array operating at 2.4 GHz. Estimation of different parameters such as return loss (S-parameter), VSWR, gain, bandwidth and half power beam width are presented.

3.1. Return loss and Bandwidth

Figures 5, 6, and 7 depicts the graphical representation of the return loss (S11) and the bandwidth of all kinds of proposed antennas designed and simulated. The values of S11 and bandwidth obtained are: (-23.62, -26.77, and -30.96) dB and (28.80, 30.40, and 31.20) MHz for single element, 2 X 1 array and 4 X 1 array respectively. The S11 and bandwidth results obtained for the single-element microstrip antenna and its array configurations (2 X 1 and 4 X 1) show interesting trends in impedance matching and bandwidth behavior as the number of elements increases. The 4 X 1 antenna array shows excellent impedance matching (-30.96) compared to a single patch and 2 X 1 array. This is a significant improvement, meaning that almost all the power is being transmitted rather than reflected. The return loss values obtained for the three antenna understudy were considered good since they are less than the -10 dB minimum specified value for a good practical microstrip patch antenna design, and signifies that minimum power is reflected from the antenna to the source input port.

The results also revealed a slight and **steady increase in bandwidth** as the number of elements increases. The slight increase in bandwidth suggests that the impedance matching across the array is improving, due to better coupling, increasing element and feed network adjustments.

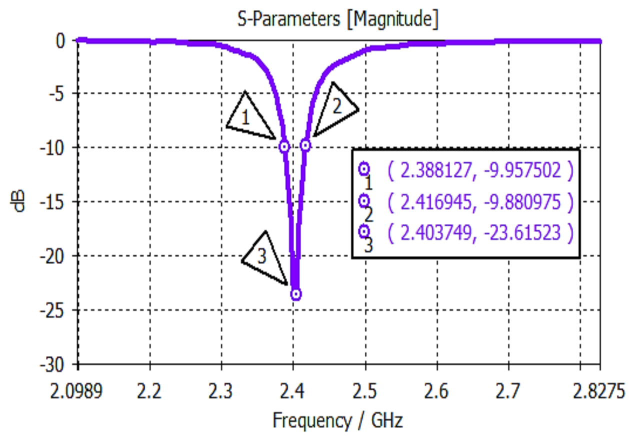

Fig. 5 Return loss and bandwidth of single element RMPA

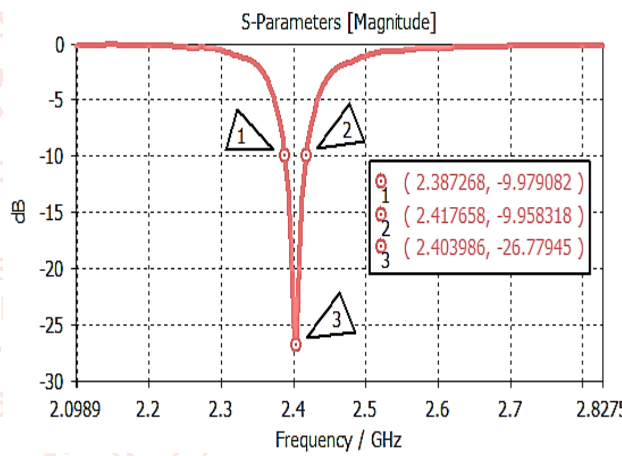

Fig.6. Return loss and bandwidth of 2 × 1 RMPA array

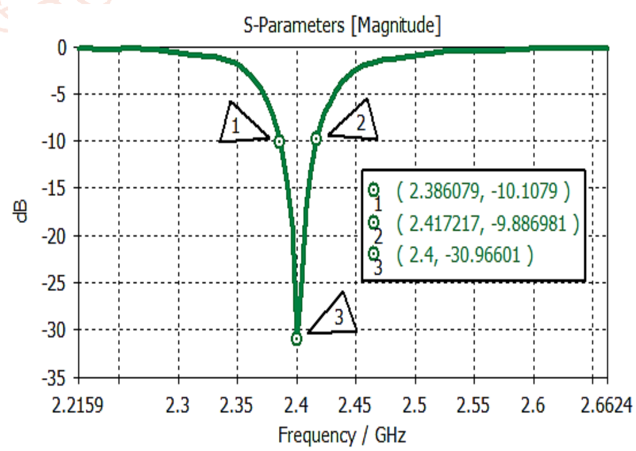

Fig. 7. Return loss and bandwidth of 4 × 1 RMPA array

3.2. VSWR

The results of the VSWR are depicts in Figures. (8, 9 and 10) for single element, 2 × 1 array and 4 × 1 array individually, which are (1.350, 1.156 and

1.058), respectively. The result revealed that, VSWR decreases (i.e., improving impedance matching) from a single element to a **2×1 array**, and then to a 4×1 array**.** The 4×1 array has the best VSWR (1.058), which is very close to the ideal value of **1.0** (indicating nearly perfect impedance matching, maximizing power transfer to the antenna).

The computed reflection coefficient, reflected power and the transmuted power gotten are: (0.149, 0.072 and 0.028), (2.22, 0.52 and 0.08) % and (97.78, 99.48 and 99.92) % for single element, 2×1 array and 4×1 array respectively. The results revealed that 4×1 array has minima reflection and highest radiating or transmitting power and the results further suggests that, the array designed is effective, and mutual coupling effects have contributed positively.

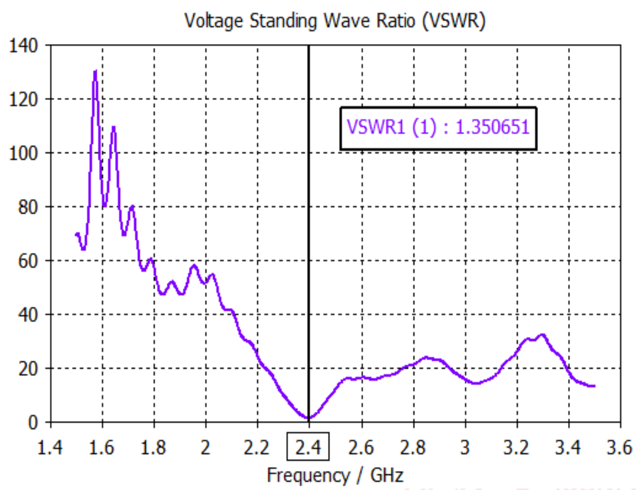

Fig. 8. VSWR of single element RMPA

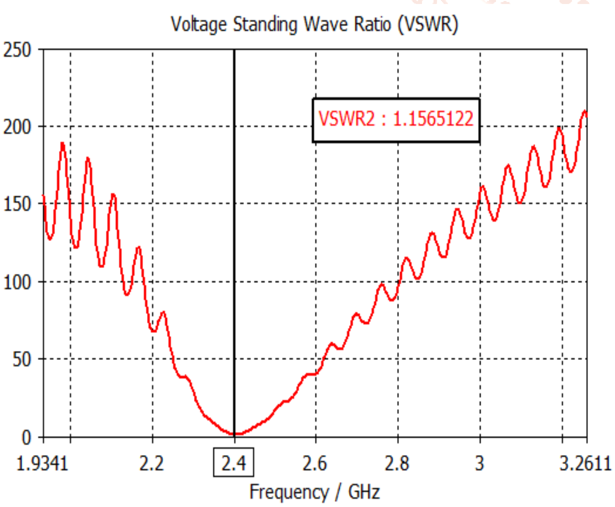

Fig. 9. VSWR of 2×1 RMPA array

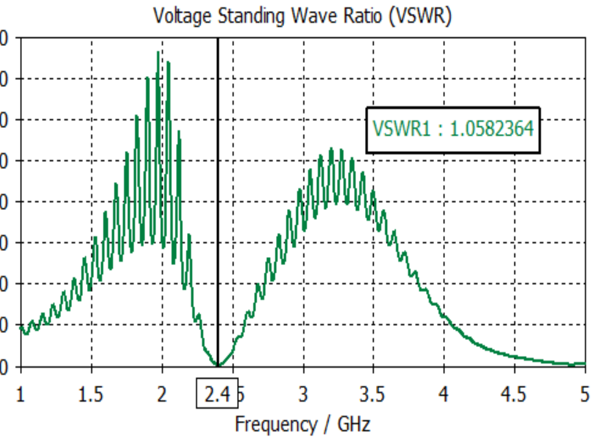

Fig. 10. VSWR of 4×1 RMPA array

3.3. GAIN AND RADIATION PATTERN

Figures 11, 12 and 13 depicts the three dimensional (3D) view, together with the gains achieved by the proposed single element, 2×1 array and 4×1 array respectively. The maximum gain of 10.9 dBi was achieved by 4×1 array while operating at the desired frequency of 2.4 GHz. Subsequently, single element and 2×1 array achieved gains of 7.61 dBi and 9.64 dB at the desired frequency respectively. The **gain follows a similar trend,** showing **significant improvement from single element to 2×1 array,** but **a smaller gain increment from 2×1 to 4×1 array** (1.06 dB) was noted. Therefore, **4×1 array is the best choice** for **directional applications** due **to its high gain, high efficiency, and good impedance matching.**

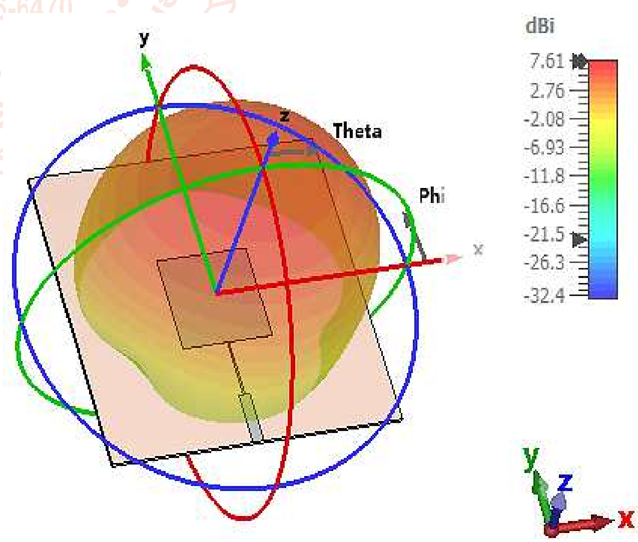

Fig. 11 3D gain and radiation pattern of single element RMPA

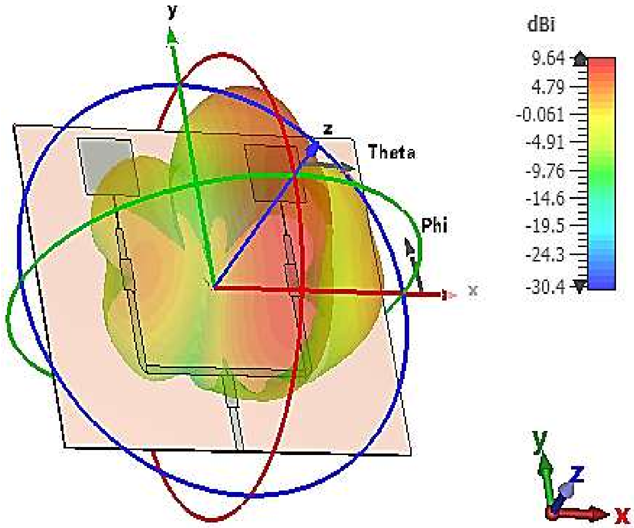

Fig. 12 3D gain and radiation pattern of 2 × 1 RMPA array

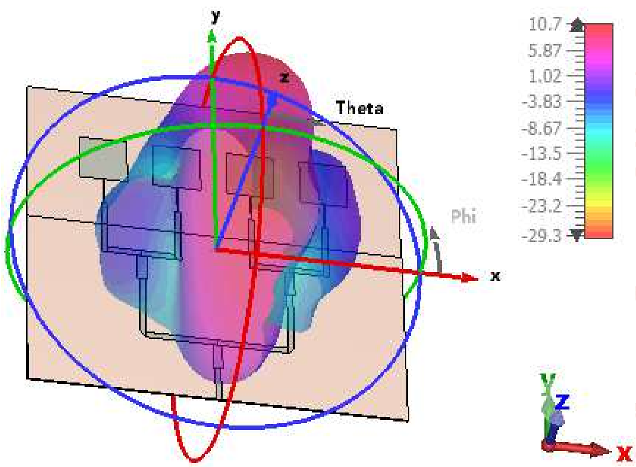

Fig. 13 3D gain and radiation pattern of 4 × 1 RMPA array

3.4. FAR FIELD DIRECTIVITY

Figures 14, 15, and 16 present the two dimensions far field directivity of the simulated single element, 2 × 1 array and 4 × 1 array. The achieved directivity values are respectively (8.23, 10.90 and 11.00) dB. The angular width corresponding to 3 dB (HPBW) of the single element antenna is 42.5° and of the 2 × 1 array is 62.4° while, it is 90.5 ° for 4 × 1 array. The study revealed that, the **directivity increases** with more elements because **arrays reinforce radiation in a preferred direction,** reducing unwanted spreading. The efficiency of the antenna designed was computed from the gain and directivity obtained using Equation (16). It was noted that, the **4×1 array has the highest radiation efficiency (93.3%) due to the fact that it would spreads power over more elements,** leading to **lower power dissipation per element** and **higher radiation efficiency.** The results are shown in Table 4.

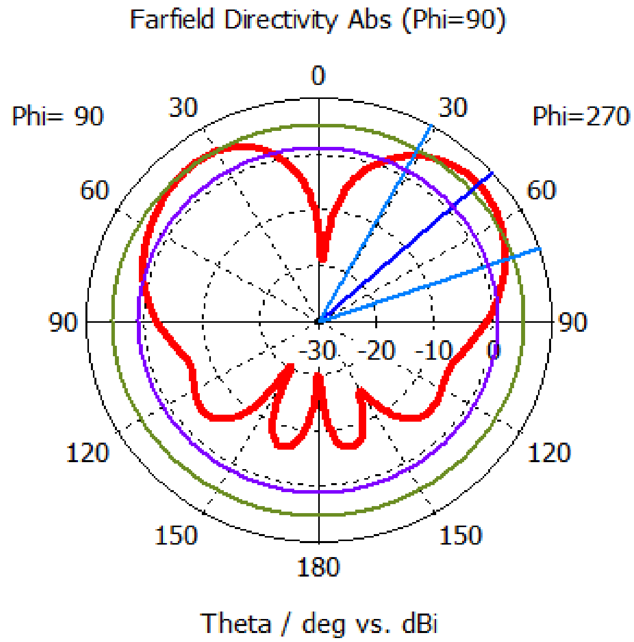

Fig. 14 Directivity and beam width of single element RMPA

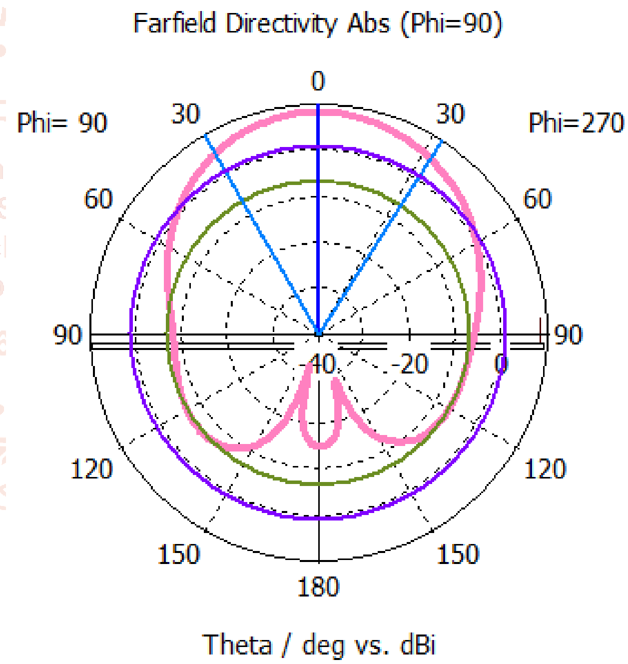

Fig. 15 Directivity and beam width of 2 × 1 RMPA array

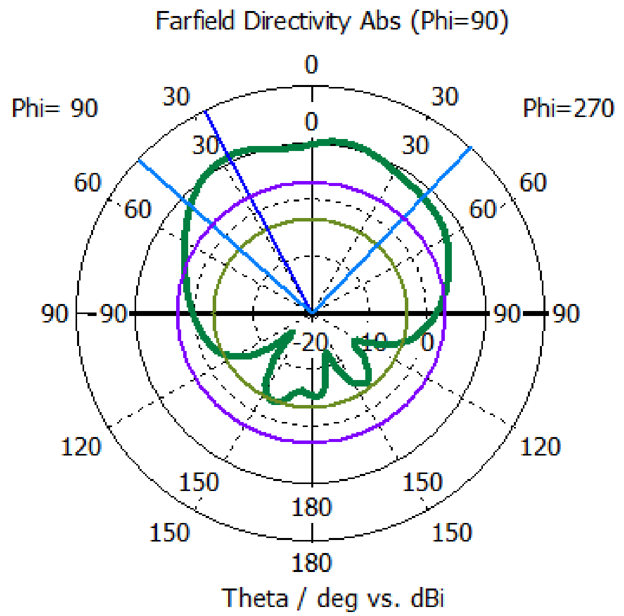

Fig. 16 Directivity and beam width of 4 × 1 RMPA array

Table 4 provides a summary of the simulation results for the **designed microstrip patch antennas**.(Single element, 2 × 1 array, and 4 × 1 array) It presents the key performance parameters of the antennas, including **resonant frequency, return loss (S11), VSWR, bandwidth, gain, directivity, reflected power (P_r), transmitted power (P_T), reflection coefficient (Γ), and efficiency (η)**, offering a comprehensive evaluation of its characteristics.

Table 4.

Parameters	Single element	Two array	Four array
Fr (GHz)	2.40	2.40	2.40
Gain (dBi)	7.61	9.64	10.70
Return loss, (dB)	-23.61	--26.78	-30.97
Bandwidth MHz)	28.80	30.40	31.20
VSWR	1.350	1.156	1.058
Directivity (dBi)	8.23	10.90	11.00
η (%)	86.7	75.0	93.3
Γ	0.149	0.072	0.028
P_r (%)	2.22	0.52	0.08
P_T (%)	97.78	99.48	99.92

CONCLUSION

This paper analyzed and compared the performance of **three microstrip patch antenna configurations:** Single element, 2 × 1 array and 4 × 1 array at 2.4 GHz resonant frequency using Rogers's substrate. Through **simulation in CST Studio Suite 2024,** key parameters such as **VSWR, reflection coefficient, gain, directivity, efficiency, transmitted power, reflection coefficient and mutual coupling effects** were evaluated. The simulation results revealed that, the **gain** increased from **7.61 dB (single element) to 9.64 dB (2×1 array) to 10.7 dB (4×1 array).** The directivity followed the similar trend. It was also discovered that, the **radiation efficiency improved as more elements were added** due to **better impedance matching, reduced surface wave losses, and more effective power distribution.** This study confirm that increasing the number of elements enhances **gain and directivity,** leading to **better radiation focus and power efficiency.** The **4×1 array is the best performing configuration,** with **optimal impedance matching (VSWR = 1.058)** and **highest gain and directivity.** However, further work would be needed for better feeding techniques and spacing adjustments to improve the efficiency of the proposed antennas, in particular to enhance the gains and bandwidth while having a smaller antenna dimension

References

[1] Osman, M. A. R (2006). "Microstrip Array Antenna For Automobile Radar System," Master of Electrical-Telecommunication Engineering Master's Thesis, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, May,2006.

[2] IEEE Std 802.16-2004, "IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems", March 2004.

[3] Khraisat YSH. (2011). Design of 4 elements rectangular microstrip patch antenna with high gain for 2.4 GHz applications. Mod. Appl. Sci. 2011;6(1):68–74.

[4] Alsager A. F. (2011). Design and analysis of microstrip patch antenna arrays. Msc. Thesis, Univ. Coll. Boras, Sch. Eng. 2011;1:1–80.

[5] Khraisat, Y. S. (2012). Design of 4 Elements Rectangular Microstrip Patch Antenna with High Gain for 2.4GHz Applications. Modern Applied Science, 6(1): 68 - 74.

[6] Naveen K, Dasari K, Swapnasri G, Swetha R, Nishitha S, Anusha B. Microstrip patch antenna array with gain enhancement for WLAN applications. Int. Conf. Adv. Smart, Secur. Intell. Comput. Nov. 2022;1–5.

[7] Huang Y, Boyle K. Antennas from theory to practice, 1st ed. West Sussex, United Kingdom: John Wiley & Sons; 2008.

[8] Chemkha H, Belkacem A. Design of new inset fed rectangular microstrip patch antenna with improved fundamental parameters. DTS 2020 -

IEEE Int. Conf. Des. Test Integr. Micro Nano-Systems. 2020;4:9–12.

[9] Chon, N. L. (2010). Photonic Antenna for Wireless Local Area Network backhaul Application, Unpublished Masters Thesis, Universiti Teknologi,. Malaysia, Malaysia.

[10] Balanis, C. A. (2005). Antenna Theory: Anaysis and Design. 3rd ed. New Jersey: John Wiley and Sons, Inc. pp. 1 - 144, 811 - 876.

[11] Martin, M. A., & Sayeed, A. I. (2011). A Design Rule for Inset-fed Rectangular Microstrip Patch Antenna. WSEAS Transaction on Communication, 1(9), 63 - 72.

[12] Pozar DM. Microwave engineering, 4th Edition," John Wiley &Sons, Inc. 2012;1– 756.

[13] Ajay VG, Parvathy AR, Mathew T. Microstrip antenna with DGS based on CSRR array for WiMAX applications," Int. J. Electr. Comput. Eng. 2019;9(1):157. DOI:10.11591/ijece.v9i1.pp157-162