Radiation Pattern Reconfigurable Arch-Shaped Dual-Band Antenna for Wi-Fi and WLAN Applications

Esraa M. Salah[1], Hany A. Atallah[2*], Ahmed Abdelaziz[1], Hesham A. Mohamed[3], and Ehab K. I. Hamad[4]

[1] Electronics & Comm. Engineering Dept., Luxor Higher Institute of Engineering & Technology, Luxor 85834, Egypt
[2] Electrical Engineering Department, Faculty of Engineering, South Valley University, Qena 83523, Egypt
[3] Microstrip Circuits Department, Electronics Research Institute (ERI), Elnozha, Cairo 11843, Egypt
[4] Electrical Engineering Department, Faculty of Engineering, Aswan University, Aswan 81542, Egypt

Corresponding author: Hany A. Atallah (e-mail: h.atallah@eng.svu.edu.eg).

ABSTRACT This paper describes the design and analysis of a reconfigurable radiation pattern dual-band antenna for Wi-Fi and WLAN applications. The antenna patch comprises two parts: the upper part, which consists of three symmetrical oval rings, and the lower part, which is shaped like a lotus flower. The proposed pattern-reconfigurable antenna achieves three reconfigurable states by controlling the ON and OFF states of lumped p-i-n switches to control the direction of the radiation beams. The beam's direction change is performed by two switches that are connected in the gap between the feedline and the arch. The proposed antenna operates at 2.4 and 5.5 GHz, covering the bands from 2.1882 to 2.55 GHz and from 5.31 to 5.96 GHz, respectively. Additionally, the directivity over the working bands is about 1.92 to 4 dBi while the gain lies in the range of 1.66 to 3.5 dB. Moreover, the voltage standing wave ratio (VSWR) varies from 1 to 1.20. The size of the antenna is 47×59.5 mm^2 which is printed on a 1.6 mm thickness FR-4 substrate of 4.4 relative permittivity. Computer simulation technology Microwave Studio is utilized to design and optimize the recommended constructions. The proposed design achieves an acceptable value of VSWR, stable gain, and good directivity, which makes it a suitable choice for future radiation pattern reconfiguration applications. The proposed antenna is distinguished by a simple shape, compact size, respectable return loss, good radiation characteristics, and high efficiency. Furthermore, the novelty of this compact structure lies in simultaneously achieving pattern diversity at the dual bands of operation with noteworthy performance. The obtained results from measurements are matched well with simulations.

INDEX TERMS Monopole antenna, Radiation pattern, Reconfiguration, Wi-Fi, WLAN.

I. INTRODUCTION

One of the reconfigurable antennas that may emit in the desired various directions is the pattern-reconfigurable antenna. Focusing the energy in the direction to goals and minimizing the gain in undesired directions, which is an effective technique to increase the system gain and security [1], [2], [3]. Studies in [4] describe a unique pattern of the reconfigurable planar antenna, which is based on a top-loaded monopole antenna supplied by 50 Ω CPW line and PIN diodes are incorporated into the antenna. Researchers in [5] propose a pattern reconfigurable antenna with five switchable beams in the elevation plane. The ability to switch beams is obtained by reconfiguring parasitic strip lines surrounding the radiating dipole and reflecting metal components beneath the dipole. A wideband rectangular microstrip patch antenna with customizable radiation patterns, which includes two symmetrically inverted U-slots and two coaxial probes along the patch's length, is presented in [6]. In [7], a novel antenna with a programmable radiation pattern is simulated and examined utilizing eight hexagonal-shaped radiation cells. For 5G applications, a unique radiation pattern reconfigurable antenna is put forth in [8]. Two switches that link the patch to the hollow rectangular structure give three distinct radiation patterns, or modes, depending on the ON and OFF states of the switches. By keeping an eye on the states of the MEMS switches, the antenna in [9] operated in six different states. Additional to the pattern reconfigurability; it is might desired to increase the antenna bandwidth. In [10], a low-profile pattern-configurable antenna is suggested. A metallic ground plane with a coupling slot, a metasurface patch superstructure with two parasitic strips and two sets of PIN diodes make up the antenna. In [11], a phased array with adjustable antennas is suggested. For large-angle beam scanning, slanted beams are produced by combining the TM11 and TM20 modes of the circular and annular patches with various phase differences. Various antennas appropriate for microwave applications have been constructed and examined in [12]. There, a four-directional beam antenna with a maximum gain of 6.92 dBi operating at 5.07 GHz, a bandwidth of 0.3 GHz from 4.89 GHz to 5.18 GHz, and four center-fed PEC arms are investigated. The substrate of the antenna is covered with variable-height transformer oil, enabling frequency reconfigurability.

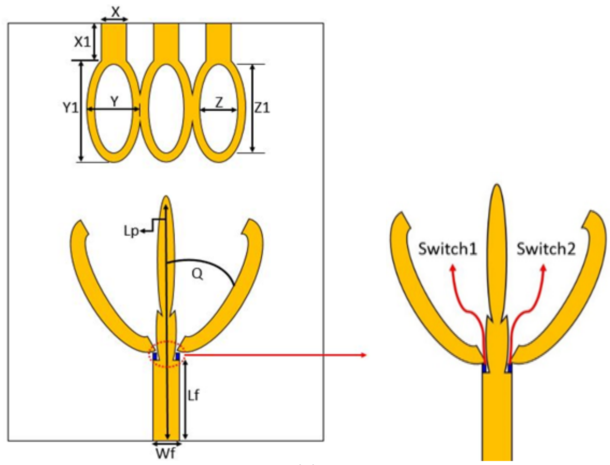
In this paper, a design of monopole antenna with a pattern reconfiguration is proposed to operate at constant frequencies of 2.4 GHz and 5.5 GHz for Wi-Fi and WLAN applications, respectively. The proposed antenna achieves high gain, high directivity, realistic VSWR, and significant reflection coefficients. The uniqueness of the suggested design lies in the fact that it could be easily manufactured and will resonate at a constant frequency between 2.4 and 5.5 GHz while having a variety of radiation patterns at the two operating bands. Additionally, three modes are offering a variety of radiation patterns based on the ON and OFF states of the attached switches. This paper is structured as follows: Section 2 presents the design methodology, while Section 3 discusses the measured and simulated results. Finally; the whole work is concluded in Section 4.

II. DESIGN METHODOLOGY

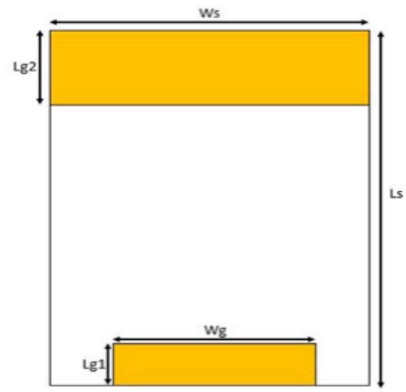
The proposed antenna is printed on a 1.6 mm thicker FR-4 substrate of 4.4 relative permittivity and 0.02 loss tangent. The proposed antenna has the geometry of $47\times59.5\times1.6$ mm^3. Figure 1 illustrates the proposed antenna configurations. Table 1 lists the values of various parameters employed in the proposed antenna. A partial ground plane measuring Ws = 47 mm by $Lg2$ = 8.5 mm is part of the designed antenna. It is supplied through a stripline with an orifice that is X = 3 mm wide. The modified three-symmetrical oval ring-shaped monopole of the radiating patch measures $Y1$ = 8 mm in length and Y = 4 mm in width. The microstrip line used to feed the reconfigurable antenna has an aperture of Wf = 3.1 mm wide. The size of the antenna's partial ground is Wg = 23 mm by $Lg1$ = 4 mm. Two printed monopoles that are slanted 30 degrees away from the vertical axis make up the reconfigurable radiating patch.

TABLE 1. The proposed antenna parameters.

Para meter	Values (mm)	Para meter	Values (mm)	Para meters	Values (mm/degree)
WS	47	*X*	3	*Z*	2
LS	59.5	*X1*	5	*Z1*	7
Lg1	4	*Y*	4	*Q*	28°
Lg2	8.5	*Y1*	8	*Lf*	6.5
Wg	23	*Lp*	11.5	*Wf*	3.1



(a)



(b)

FIGURE 1. Schematic diagram of the proposed antenna. (a) Top view, (b) Bottom view.

The radiation pattern reconfiguration of the antenna is achieved by attaching two switches; Switch 1 and Switch 2 between the antenna feedline and each Arch (arm) of the printed monopoles as shown in Fig. 1(a). When all of the switches are turned off (Case 1), the aerial will resonate with dual bands at 2.4 and 5.5 GHz. The antenna resonates at 2.4 and 5.5 GHz when Switch 1 is turned on and the other switch is turned off (Case 2). In other cases, the antenna resonates at 2.4 and 5.5 GHz. Figure 2 depicts the proposed antenna's reflection coefficients in the ON and OFF modes of Switch 1 and Switch 2.

TABLE 2. The proposed antenna parameters.

Case Number	Switch 1	Switch 2
1	OFF	OFF
2	ON	OFF
3	OFF	ON

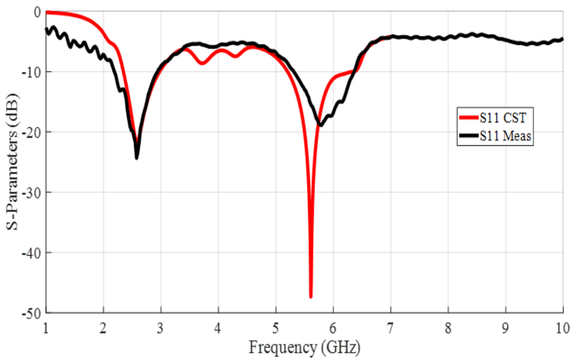
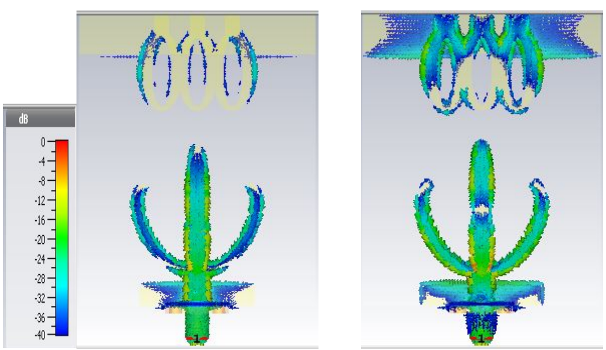


FIGURE 2. The reflection coefficients of the proposed antenna at Case 1.

The microwave studio computer simulation technology was used to develop and research the proposed structure (CST MWS). The Mini-Circuits RC-8SPDT-A18 RF switch matrix controls mode switching, which could be replaced by PIN diodes or RF-MEMS switches. The modes of the reconfigurable radiation pattern are achieved by using the two switches (Switch 1 and Switch 2) that are connected in the gap between the feedline and each Arch (arm) of the printed monopole antenna to regulate the beam's direction and to create the radiation pattern reconfigurable modes as described in Table 2.

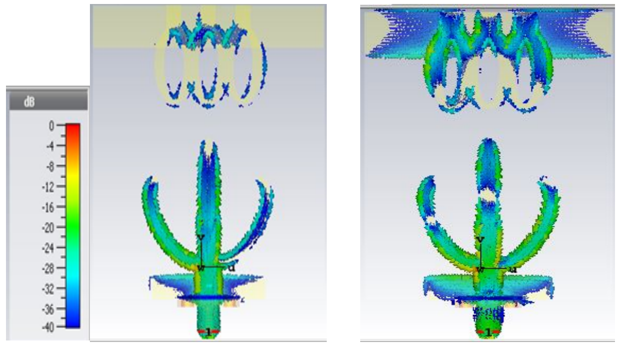
III. RESULTS AND DISCUSSIONS

Figure 2 depicts the S11 reflection coefficients of the proposed aerial in the OFF and ON states of the switches. Figures 3, 4, and 5 show the surface current distributions for cases 1, 2, and 3 at 2.4 and 5.5 GHz, respectively. Figure 6 demonstrate the comparison of the simulated realized gain using CST: (a) Case 2; (b) Case 3.



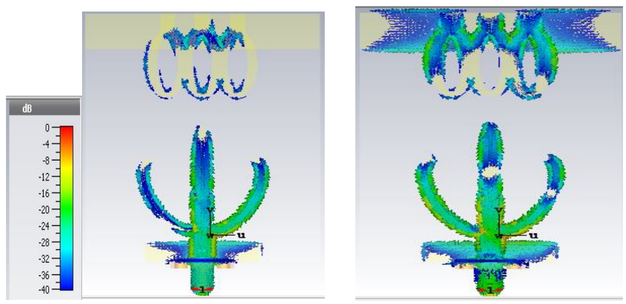
(a) (b)

FIGURE 3. The surface current distributions of the proposed antenna of Case 1 at (a) 2.4 GHz, and (b) 5.5 GHz



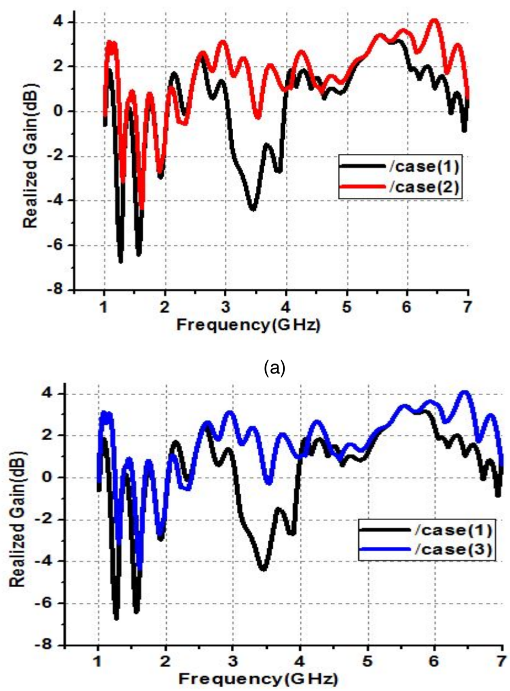
(a) (b)

FIGURE 4. The surface current distributions of the proposed antenna of Case 2 at (a) 2.4 GHz, and (b) 5.5 GHz



(a) (b)

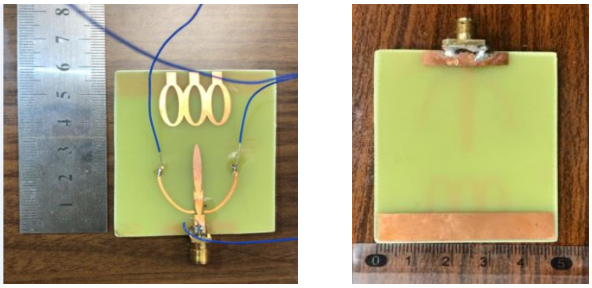
FIGURE 5. The surface current distributions of the proposed antenna of Case 3 at (a) 2.4 GHz, and (b) 5.5 GHz



(b)

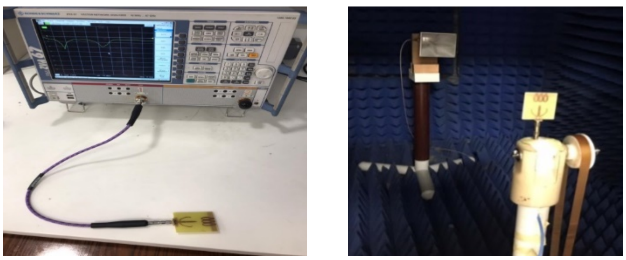
FIGURE 6. Comparisons between the simulated realized gains of the different cases of the proposed antenna using CST.

The photolithographic fabrication process is used to create the radiation pattern reconfigurable arch-shaped dual band antenna system prototype. The radiation pattern and gain are measured at the Electronics Research Institute (ERI) in Cairo using an anechoic chamber NSI 700S-30. A Rohde and Schwarz ZVA 67 Vector Network Analyzer (VNA) is used to determine the input reflection coefficients. Figures 7 and 8 depict the fabricated prototype of the designed antenna as well as the measurement setup for the proposed antenna system.



(a) (b)

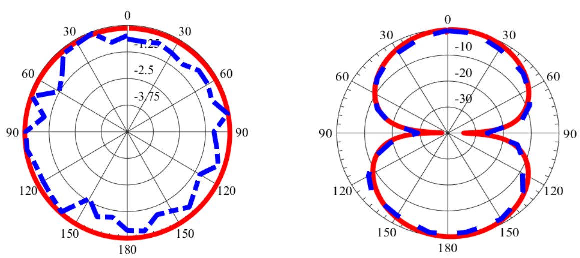
FIGURE 7. Prototype of the proposed antenna: (a) Top view, and (b) Bottom view.



(a) (b)

FIGURE 8. Measurements setup: (a) S-parameters measurement setup, and (b) Far-field measurement setup.

Figure 9 shows the radiation patterns for Case 1 when Switches 1 and 2 are turned off. Figure 9(a) shows that the proposed antenna's main lobe is oriented towards 180 at 2.4 GHz for φ = 0, whereas Figure 9(b) shows that the antenna's main lobe is oriented towards -173 at 2.4 GHz for φ = 90. Figure 9(c) shows that the proposed antenna's main lobe is directed towards -145 for φ = 0 at 5.5 GHz, whereas Figure 9(d) shows that the antenna's main lobe is directed towards -138 for φ = 90 at 5.5 GHz.



(a) (b)

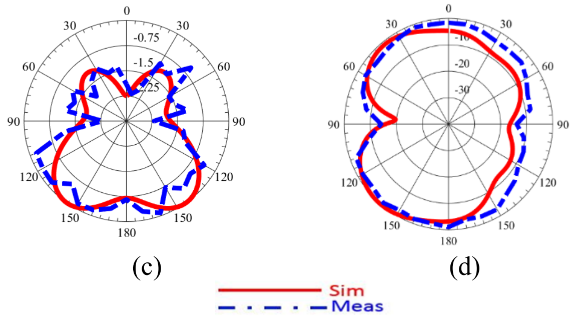


FIGURE 9. Radiation pattern of Case 1: (a) φ = 0˚ at 2.4 GHz, (b) φ = 90˚ at 2.4 GHz, (c) φ = 0˚ at 5.5 GHz, and (d) φ = 90˚ at 5.5 GHz.

Figure 10 depicts the radiation patterns for Case 2 when switch 1 is turned on and switch 2 is turned off. Figure 10(a) shows that the proposed antenna's main lobe is oriented towards -168 at 2.4 GHz for φ = 0, whereas Figure 10(b) shows that the antenna's main lobe is oriented towards -174 at 2.4 GHz for φ = 90. Figure 10(c) shows that the proposed antenna's main lobe is aimed at 137 for φ = 0 at 5.5 GHz, whereas Figure 10(d) shows that the antenna's main lobe is aimed at -140 for φ = 90 at 5.5 GHz.

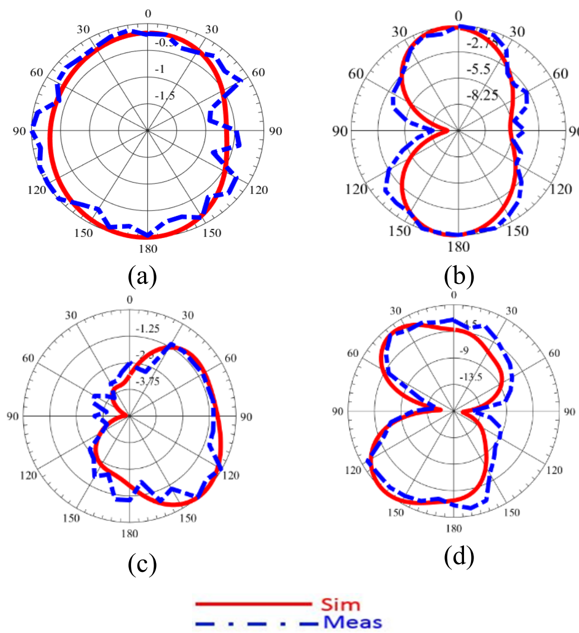


FIGURE 10. Radiation pattern of Case 2 (a) φ = 0˚ at 2.4 GHz, (b) φ= 90˚ at 2.4 GHz, (c) φ = 0˚ at 5.5 GHz, and (d) φ = 90˚ at 5.5 GHz.

Figure 11 shows the radiation patterns for Case 3 when Switch 1 is off and Switch 2 is on. Figure 11(a) shows that the proposed antenna's main lobe is oriented towards 168 at 2.4 GHz for φ = 0, whereas Figure 11(b) shows that the antenna's main lobe is oriented towards -174 at 2.4 GHz for φ = 90. Figure 11(c) shows the proposed antenna's main lobe, which is oriented towards -137 for φ = 0 at 5.5 GHz, whereas Figure 11(d) shows the antenna's main lobe, which is oriented towards -140 for φ = 90 at 5.5 GHz.

Figures 12, 13, and 14 show the simulated directivity of the proposed antenna for cases 1, 2, and 3 at 2.4 and 5.5 GHz, respectively.

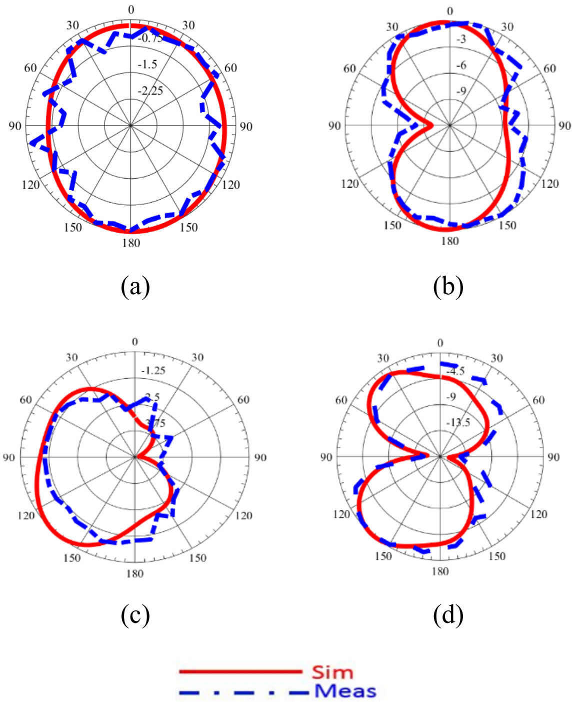


FIGURE 11. Radiation pattern of Case 3 (a) φ = 0˚ at 2.4 GHz, (b) φ = 90˚ at 2.4 GHz, (c) φ = 0˚ at 5.5 GHz, (d) φ = 90˚ at 5.5 GHz.

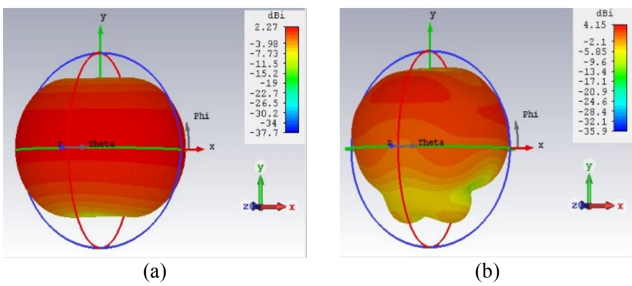


FIGURE 12. Directivity of the proposed antenna of Case 1 at (a) 2.4 GHz, and (b) 5.5 GHz

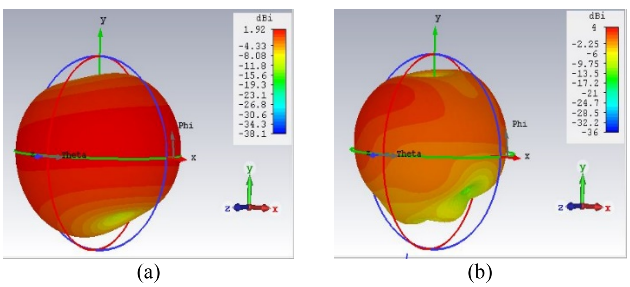


FIGURE 13. Directivity of the proposed antenna of Case 2 at (a) 2.4 GHz, and (b) 5.5 GHz

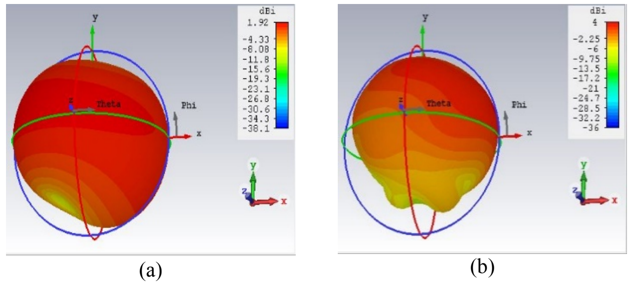


FIGURE 14. Directivity of the proposed antenna of Case 3 at (a) 2.4 GHz, and (b) 5.5 GHz

Table 3 describes the proposed antenna's ability to change its pattern by varying the switching states. Table 4 compares Cases 1, 2, and 3 in terms of frequency, gain, directivity, and radiation efficiency. From there, it can be inferred that the antenna has reasonable gain and reliable efficiency in each of the three scenarios. Table 5 compares the performance of the proposed antenna to that of some recently mentioned antenna in the literature. The proposed antenna's innovative features are its simple design and effective beam reconfiguration capabilities. The proposed antenna is smaller in size than the antennas described in the literature. Furthermore, the proposed aerial makes use of as few switches as possible, reducing both the complexity of the design and the losses caused by the switches.

TABLE 3. Summary of the switches' conditions and the corresponding major lobe directions

Case Number	Switch 1	Switch 2	Main Lobe Direction at φ = 0˚ at 2.4 GHz	Main Lobe Direction at φ = 0˚ at 5.5 GHz
1	OFF	OFF	180˚	-145˚
2	ON	OFF	-168˚	137˚
3	OFF	ON	168˚	-137˚

TABLE 4. Summary of all cases in terms of gain, directivity, efficiency, and VSWR at both bands of the proposed antenna

Case	Freq. (GHz)	Gain (dBi)	Directivity (dBi)	Efficiency (%)	VSWR
1	2.4 5.5	1.953 3.499	2.271 4.148	93.43 85.88	1.19 1.015
2	2.4 5.5	1.660 3.428	1.922 4.005	94.28 87.12	1.20 1.0023
3	2.4 5.5	1.660 3.428	1.922 4.005	94.28 87.12	1.20 1.0023

TABLE 5. Comparison between proposed design and previous designs from recent literature

Ref.	Size (mm^2)	Reconfigurability	Actuators	Peak Gain (dBi)
[1]	40×50	Frequency and Pattern.	2 PIN diodes	NG
[4]	85×90	Pattern	2 PIN diodes	4.8-4.05
[5]	70×55	Pattern	5 switches	5.2-6.5
[7]	18.9×6	Pattern	8 PIN diodes	8.46

[8]	3.34×6.73	pattern	2 switches	5.4-6.4
[13]	120×120	pattern	4 PIN diodes	7
[14]	5.4×5.4	Pattern	2 switches	3.9/4.8
[15]	40×30	Freq. and Pattern	4 PIN diodes	2.24-2.67
[16]	34×36	Freq. and Pattern	2 switches	4/5.6
[17]	23×31	Freq. and Pattern	3 PIN diodes	4.01/4.60
[18]	130×160	Freq. and Pattern	11 switches	5.6/4.6/3.3
This work	47×59.5	Pattern	2 switches	1.66-3.43

IV. CONCLUSION

In this paper, radiation pattern-reconfigurable monopole antenna has been presented and examined. Compact printed antennas with radiation pattern reconfiguration capability were designed and experimentally validated in this work. Moreover, this proposed design succeeds in concurrently accomplishing pattern diversity at two bands of operation. Additionally, three modes of operation offer a variety of radiation patterns based on the ON and OFF states of two switches. When Switch 1 and Switch 2 are OFF, the first mode pattern emitted at 2.4 GHz for Wi-Fi and 5.5 GHz for WLAN applications in directions with angles of 180˚ and -145˚ for φ = 0˚, respectively. In the second mode; when Switch 1 is ON and Switch 2 is OFF, the pattern radiated at 2.4 and 5.5 GHz with an angle of -168˚ and 137˚ for φ = 0˚, respectively. When Switch 1 is OFF and Switch 2 is ON; the third mode radiated in a radiating plane exact opposite to the direction of the first mode with an angle of 168˚ for φ = 0˚ at 2.4 GHz and -137˚ for 5.5 GHz. In terms of radiation patterns and reflection coefficients; there are good agreements between the measured and simulated results. The proposed antenna provides satisfactory VSWR value, which ranges from 1 to 1.20, which make the proposed antenna is good candidate for wireless communications applications.

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