A Polarization Reconfigurable Cockroach Shaped Microstrip Patch Antenna for WLAN Applications

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***Abstract*—This work designs and analyzes a cockroach-shaped microstrip patch antenna on a Teflon Glass Fiber substrate for polarization reconfigurability. Hind leg of the cockroach is considered for microstrip feed line and antenna of the cockroach body is used as stub. Two diodes are inserted between cockroach head and stub. Depending on the diode and input port variations, the antenna can switch between four polarization states. The findings demonstrate that the suggested antenna can produce $\pm 45^0$ linear polarization as well as right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) at specified frequencies with a 3 dB axial ratio bandwidth of $> 1.6\%$. The antenna is well-matched and has a 23% impedance bandwidth for less than -10 dB return loss. The antenna has a gain of more than 5 dBi in all polarization states across the designed frequency ranges.**

***Keywords*—Cockroach shape, Polarization diversity, Linear polarization, Microstrip patch, Right-hand circular polarization, Left-hand circular polarization**

I. Introduction

Among pattern, frequency, and polarization reconfigurable antennas, polarization reconfigurable antennas have many advantages in wireless communication, particularly in portable devices, because they can switch between polarization states of a device based on necessity, as an antenna needs to multifunction in this ever-growing era of communication [1]–[4], and microstrip patch as a polarization reconfigurable antennas have attracted the attention of researchers due to their inexpensive nature, minimum weight and having the capability of reducing multi-path losses [5]–[7].

Using PIN diodes or switch to toggle between polarization states in a microstrip patch is a common option, and several studies have been conducted to achieve polarization diversity in a microstrip patch using diodes or switch. To create polarization variety, [8] uses a cross slot on the ground plane and four diodes in each arm of the slot. Switching two of the diodes on and off the circular patch antenna can produce right hand circular polarization and left hand polarization. A circular patch with no defects in the ground plane can also change the linear polarization states by cutting a C-shaped slot into the patch and using diodes to control the states, and notches on the edge of the same patch along the diameter can change the circular polarization states by switching the diodes on and off [9]. Isolating a small square section by a narrow slit from the corner of a square patch and utilizing diodes in lieu of the narrow slit can change the circular polarization states of a square microstrip patch antenna [10]. Using diodes along the diagonal edges or along the axis edges of a square patch can also produce polarization reconfigurability but results in the use of a total of four diodes rather than two diodes [11]. It is worth noting that numerous microstrip patch forms, such as slotted H-shape [12], modified star shape [13], and fan blade shape [14], have been proposed for use in antenna construction over the years.

In this study, a cockroach-shaped microstrip patch antenna for polarization reconfigurability is presented, with the hind leg of the cockroach serving as the feed line and the antenna of the cockroach serving as the patch's open stub. Diodes and feeding ports are utilized to have altercation among polarization states. Section II describes the antenna design and working procedure and section III analyses the simulated results and confirms the polarization switchability. And finally section IV summerises the study.

II. Antenna Design

A. Antenna Geometry

A Cockroach shaped patch is placed on top of a Teflon Glass Fiber substrate. The cockroach's hind leg is used for the microstrip feed line, and the antenna is used for the stub that sticks out from the cockroach's head. D1 and D2 diodes are inserted between the cockroach head and the two stubs. The length of the patch for a horizontally held antenna is 21.7 mm, and the maximum width of the cockroach shaped patch is 12 mm. Fig. 1 depicts the geometry of the proposed

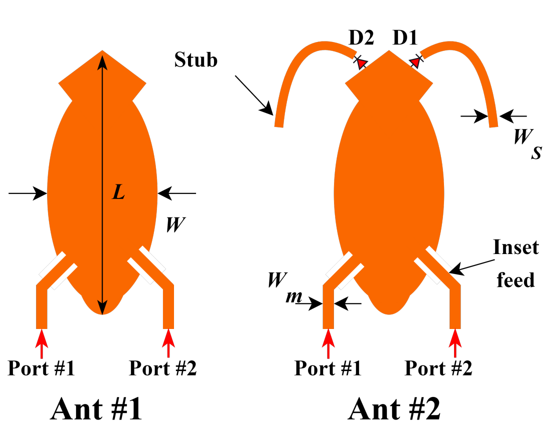

Fig. 1: Geometry of proposed cockroach shaped microstrip patch antenna.

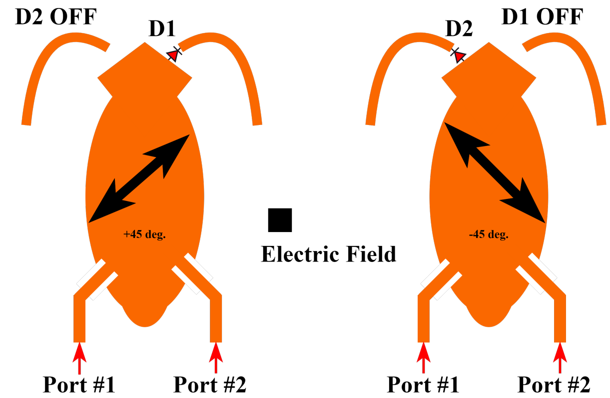

Fig. 2: Working principle of the antenna for linear polarization operation.

patch antenna, with Ant #1 created without the stub (cockroach antenna) and simulated, and Ant #2 designed with stubs and diodes between stubs and cockroach head and simulated using Advanced Design (ADS) software. The dimension and parameter of the antenna is given in I.

TABLE I: Design parameters of the proposed microstrip antenna

Parameter	Value
Substrate	Teflon Glass Fiber
Relative dielectric constant, ϵ_r	2.15
Patch length , L	21.7 mm
Patch width, W	12 mm
Microstrip line width, w_m	2.1 mm
Substrate height	0.8 mm
Stub line width, w_s	0.7 mm

B. Operating Principle

The operating concept of the antenna is demonstrated in this section. The functioning of linear polarization is illustrated first, followed by a description of how the antenna transitions between circular polarization states.

1) Linear Polarization Operation: When diode D1 is turned on and the input is supplied to both ports, +45^0 linear polarization is accomplished. When the patch is supplied from both ports and D1 is turned on, the stub connected with D1 begins to work. The stub excites the patch in such a way that the electric field lines align along the patch's +45^0 axis and are capable of emitting +45^0 linear polarization. As illustrated in Fig. 2, -45^0 linear polarization (LP) is accomplished by turning on the diode D2, which causes the other stub of the patch to operate and excites the electric field along the -45^0 axis of the patch, radiating -45^0 linear polarization.

2) Circular Polarization Operation: Circular polarization of both senses, namely right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) can be achieved in a manner almost similar to linear operation, with the exception that the input signal is routed to only one port at a time. As seen in Fig. 3, when a signal is put into

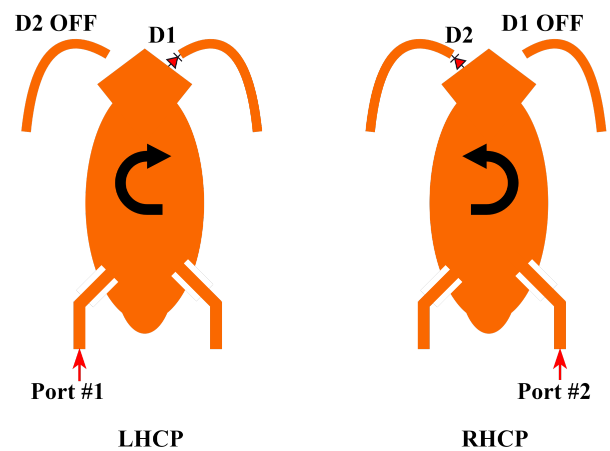

Fig. 3: Working principle of the antenna for circular polarization operation.

port #1 and diode D1 is turned on, the patch is capable of creating two orthogonal linear electric fields, and the stub length provides the patch with the dimension to produce a quarter wavelength phase difference between the electric field vectors. left-hand circular polarization is therefore produced in this case. Similarly, providing input to port #2 and turning on Diode D2 while leaving Diode D1 off generates RHCP. The polarization states depending on diode condition and input feed is given in Table II.

III. Result And Discussion

Ant #1 is first simulated and the results are analyzed to see if the antenna is appropriately matched. Ant #2 is then simulated with feeding to both ports and switching on either one of the diodes, and the results are hypothesized. Following

TABLE II: Polarization states of the antenna for several diode and input conditions

Input Port	D1	D2	Polarization State
Port #1 & #2	ON	OFF	+45^0 LP
Port #1 & #2	OFF	ON	-45^0 LP
Port #1	ON	OFF	LHCP
Port #2	OFF	ON	RHCP

that, a condition is examined when both diodes are turned on and feeding just one port at a time. The findings suggest that the antenna is capable of generating CP under these conditions. Finally, the effect of altering port feed and diode condition on CP is investigated and the results are analyzed. This section contains all of the simulation findings to justify the idea, as well as a study of the influence on the CP for various stub lengths.

A. Return Loss and Gain

Fig. 4 displays the return loss for the proposed antenna for several condition. The graphic clearly shows that the suggested antenna are properly matched in the frequency range over 4.8 GHz to 6.25 GHz. The antenna shows a maximum -10 dB impedance bandwidth of 23%.

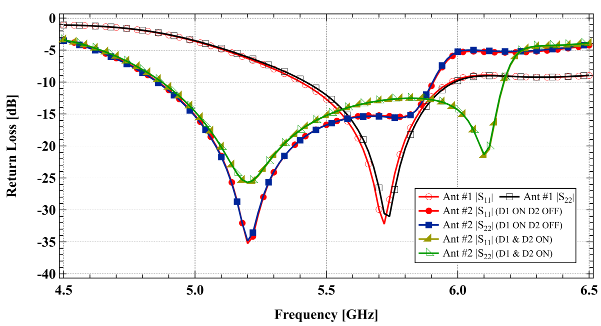

Fig. 4: Simulated return loss of the proposed antenna.

The proposed microstrip antenna's gain pattern is shown in Fig. 5. The antenna exhibits a very well gain greater than 5 dBi over the frequency range.

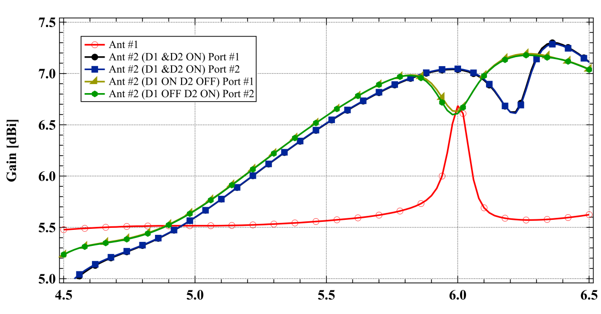

Fig. 5: Simulated gain versus frequency curve of the proposed antenna for several diode and input feed conditions.

B. Polarization Reconfigurability

1) Linear Polarization: When an input signal is supplied into both ports and one of the diodes is turned on, linear polarization of $\pm45^0$ is established. When diode D2 is turned on, Fig.6 and Fig. 7 illustrate the polarization angle and relative power for co-polarization and cross-polarization graphs, respectively, for linear polarization.

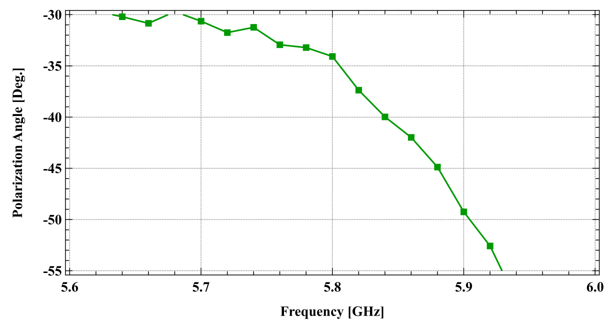

Fig. 6: Polarization angle versus frequency curve of the antenna.

The polarization angle is -45^0, at 5.88 GHz is clearly indicated by the graph in Fig. 6, indicating that the antenna is capable of producing -45^0 linear polarization. The cross polarization level for linear polarization is shown in Fig. 7, and it is obvious that the cross polarization level is more than 50 dB, confirming appropriate linear polarization. The same

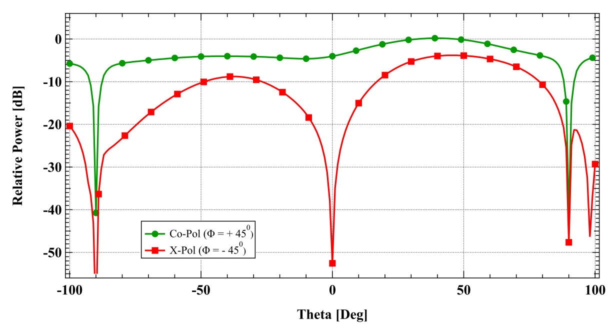

Fig. 7: Relative power of the proposed antenna for -45^0 linear polarization.

happens when diode D1 is ON while keeping D2 OFF and the antenna produces $+45^0$ linear polarization.

2) Circular Polarization: When both diodes are turned on and a signal is put into any of the ports, the antenna may produce circular polarization. The port #1 feed generates LHCP, whereas the port #2 feed generates RHCP. When only one port is supplied by an input signal, but not at the resonance frequency, both stubs make the patch radiate circularly. Because both stubs function as an antenna unit, the feed makes the input diagonal input, and the excitation of the patch creates CP. As isolation takes effect, the resonance frequency shifts owing to both diode activation.

Fig. 8 and Fig. 9 illustrate the cross polarization level for both left-hand and right-hand circular polarization. The figure

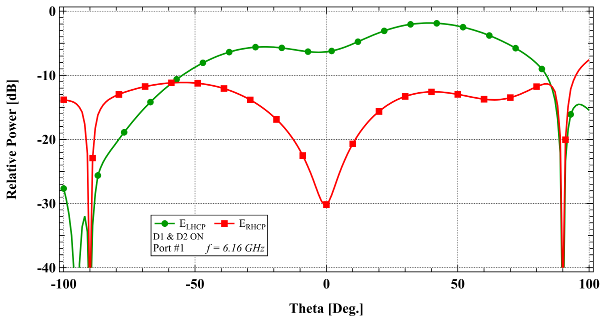

Fig. 8: Relative power for LHCP mode.

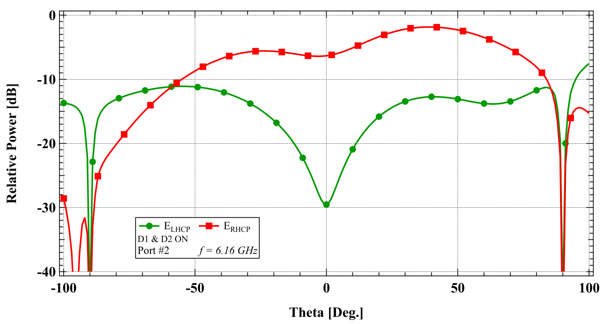

Fig. 9: Relative power for RHCP mode.

shows that the cross polarization level for both circumstances is greater than 25 dB, ensuring correct circular polarization radiation.

When either one of the diodes and one of the ports is active, the antenna appropriately propagates in a circular fashion. Because just one diode and a port are used, the electrical length of the antenna is diagonally asymmetric, resulting in a quarter wavelength phase difference between two equal amplitude electric field vectors and hence, CP is achieved.

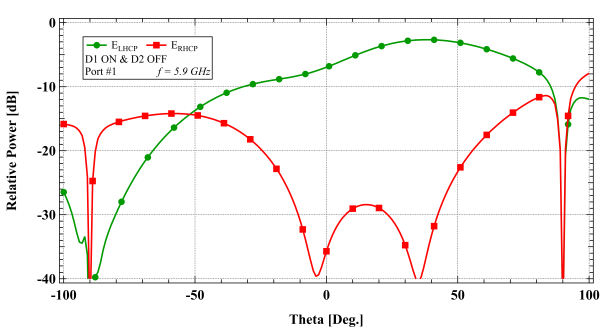

Fig. 10: Relative power for LHCP mode, when D1 ON and input feed to port #1.

Fig. 10 and Fig. 11 illustrate the cross polarization level for both left-hand and right-hand circular polarization for several diode and input port conditions.The figure indicates that the cross polarization level is larger than 25 dB in both cases, ensuring accurate circular polarization propagation.

The axial ratio curve for the proposed antenna for various

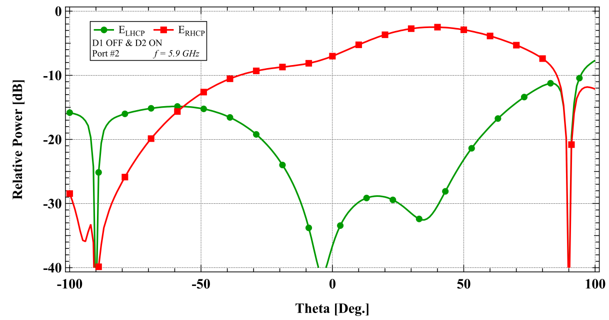

Fig. 11: Relative power for RHCP mode, when D2 ON and input feed to port #2.

diode and input port circumstances is shown in Fig. 12. The picture depicts the axial ratio for all of the scenarios listed above that potentially cause CP, and it is obvious from the graphic that the axial ratio for all of the cases mentioned is less than 3 dB that is they can properly generate circular polarization and can switch between polarization states.

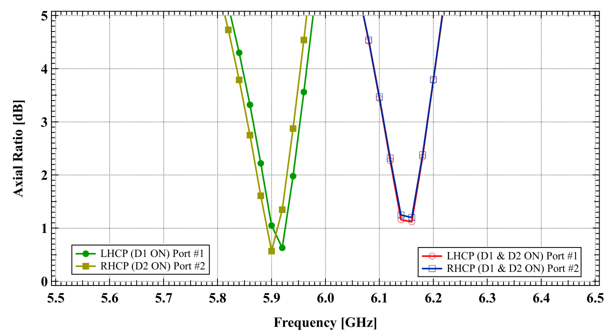

Fig. 12: Axial Ratio for several diode and input conditions.

C. Stub Length Variation

Figure 13 clearly shows that the stub length has an influence on circular polarization. The antenna can propagate circular polarization at 5.9 GHz frequency, which is a frequency band used in WLAN applications, with a stub length of 11.76 mm. The resonance frequency in circular polarization fluctuates as

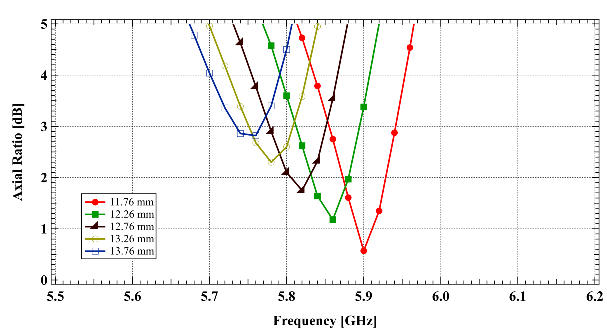

Fig. 13: Axial Ratio for RHCP for several stub length when port #2 fed and D2 is ON.

the stub length rises, as does the value of the axial ratio.

Because the axial ratio is extremely near to 3 dB for a stub length of 13.76 mm, the antenna may lose its CP radiation at a certain length of the stub. The antenna has an 3 dB axial ratio bandwidth of $> 1.6\%$

IV. Conclusion

This study proposes a cockroach-shaped microstrip patch antenna with polarization reconfigurability. The antenna has the ability to transition between four polarization states. The findings demonstrate that the antenna has an axial ratio bandwidth of 1.69% and can generate $\pm 45^0$ linear polarization, as well as RHCP and LHCP. The antenna's impedance bandwidth is 23%, demonstrating satisfactory impedance matching. In all polarization states, the antenna has a gain of more than 5 dBi.

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