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A Compact Antenna with Dual Polarization for Mobile and Wireless Communication

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ABSTRACT

In this paper, a dual-polarized antenna fed by CPW is presented. The proposed includes a conductor on the radiator and has defected ground, so it has been achieved as an omnidirectional antenna which makes it a low loss, and a simple antenna which is appropriate for a wireless communication system. By imposing the different circumstances of U-shape elements on the ground, the features of antennas have been improved. The scattering characteristic of the antenna are less than -20 dB with high impedance matching at 2.2GHz, 4.8GHz, and 6.6GHz. Also, the antenna covers 400 MHz bandwidth from 2 GHz to 2.4 GHz, 500 MHz bandwidth from 4.6 GHz to 5.1 GHz, and 1.3 GHz bandwidth from 5.7 GHz to 7 GHz, respectively. In addition, the maximum gain of the antenna is almost 10 dB. The simple and compact antenna with an overall size of 25x20mm^2 is designed on an FR-4 substrate with 0.8 mm thickness. On the one hand, the structure is fabricated and tested. The results of the antenna have shown that the measured results agree with the simulated results; The performance of the antenna with CPW-fed, consisting of compact size, circular polarization, and suitable gain at resonance frequencies, make it a suitable choice for the communication system and the portable device.

I. Introduction

Wireless communication systems are highly diverse with different applications [1]. Although electronic and telecommunication structures continue to downsize with the development of communication technologies and instruments, the previous capabilities need to be preserved in the new structures and methods proposed by scientists. Responsible for transmitting and receiving information, wireless communication systems are confronted with challenges such as noise, interference and etc. [2-3].

As one of the key elements of wireless communications, antennas have continued their development with technological advancements over time [4]. The physical size and configuration of an antenna are initially dependent on its operating frequency. Old antennas used to be very large and thus unsuitable for deployment in portable wireless circuits [5]. The next generations of antennas were able to solve most of the previous problems in this field. Microstrip antennas, slot antennas, and integrated-circuit antennas were invented to integrate with other portable circuits such as printed circuit boards (PCBs), or semiconductor chips. In addition to their other advantages, the use of integrated circuit technology in the fabrication of antennas has high precision in manufacturing, which cannot be achieved with traditional methods [6-7].

To transfer the highest power from the input to the radiating structure, an appropriate transmission and power line is required, for instance, a microstrip transmission line, parallel

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transmission line, and coaxial transmission line. In addition to these lines, delta matching helped perfect the integration of transmission lines with radiating structures. Ground and radiation structure are two important parts of radio systems. The full ground structure in the previous generation of antennas had a smaller bandwidth. However, a defected ground solved these problems and allowed antennas to cover multiple bands simultaneously [8]. The radiation structures have also experienced undergone significant changes and modifications in their shapes such as Circular, square, and star structures as well as the met material and integrated structures with multiple layers. Generally, the miniaturization of the configuration changes the electromagnetic characteristics, including the antenna gain and bandwidth [9].

An antennas with multi-purpose operation and multi-band coverage is now required more than often. Most communication systems prefer to use a single radiating element with multiple bands and purposes, leading to reduces size and weight. These antennas have numerous interesting applications. New antennas are multi-purpose and adaptable, so that with the smallest change in their dimentions, their operating frequency changes. Thanks to the switching mechanism, in adaptive antennas, the operating frequency, phase, and radiation pattern can be altered [10-11]. The gain and polarization of the antenna is known as min parameters of antenna. the higher the gain, the stronger the antenna, so the antenna will produce the radio frequency field strongly. The circular polarization antenna transmits waves that rotate continuously between horizontal and vertical planes to provide more flexibility. However, because the energy is split between the two planes, the readout range of a circularly polarized antenna is shorter compared to a linear polarized antenna with the similar gain[12-14]. A metamaterial fractal antenna with the size of 51.9×51.9 mm^2 has been designed on the FR-4 substrate in [4] fed by a CPW line on the top layer. It has narrow bandwidth at all bands and obtains the peak of gain 9.5 dBi [7]. Several antennas use slots and CPW feed lines to improve characters; for example, [8], introduces a wide circular polarized antenna with a peak gain of 3.5 dB at low frequency and almost 6 dB at high; moreover, in [10], it is designed for medical applications. For using DC voltage and circuit, these antennas become bulky or utilize multilayer substrate [13-14]. There are several 1-D and wearable structures for antenna polarization and gain enhancement [15]. Circular polarization is one of the main factors to consider in antenna design. [16-17].

Here, an antenna with a low profile and plain structure is provided at 2.2 GHz, 4.8 GHz, and 6.6 GHz, which is useful for mobile and wireless systems. The circularly polarized antenna consists of a simple defected ground structure with one U-shaped parasitic element and rectangle element on both sides of the feed line. This structure with a total size of 25×20mm^2 is simulated and printed on a low-cost efficient Fr-4 substrate with 0.8 mm thickness. The proposed antenna has been fabricated and tested. Using the U-shaped parasitic element has led to achieving circular polarization in the first and third band and liner polarization in the second band; in addition, using CPW feed line and defected ground structure has offered more than 50% size reduction of the structure compared to other similar ones. High gain antenna with dual polarization in the desired band provides the suitable structure for WLAN, Wi-Fi, and UMTS (Universal Mobile Telecommunication Service). The antenna has been optimized using a full-wave simulator (HFSS). It helps to analyze the structure to show the influence of each parameter efficiently. basic structure, according to desired antenna and normalized formulations have been obtained and extracted.

II. Antenna Geometry and Design Procedure

Size go hand in hand with electromagnetic features; therefore, nowadays, the structure should be physically developed. Antenna is the essential case of telecommunication systems that must be made smaller. Moreover, due to its integration into integrated structures, size reduction has negative effects on antenna characteristics. By introducing new methods of feeding as well as new antenna such as microstrip, to some extent, the situation gets improved [18-20].

Micro stripe antenna consists of ground conductor and the feed line connected to the patch, which is resonant at selective frequencies. Among the types of feed lines and antenna structures mentioned above, Coplanar waveguides (CPW) feed and rectangular-shaped patches are chosen for wireless communication systems due to their inherent wide bandwidth and better performance. CPWs and taper sector have also played a vital role in this research area. CPW feed line constructed on straightforward taper. The tapered segment attaches a 50Ω CPW signal line to the antenna. The taper is utilized to gain well impedance matching.

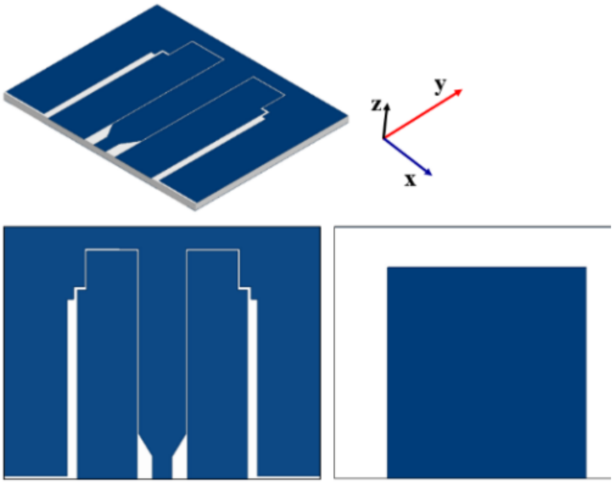
To reach maximum power from the feed to the patch, the antenna requires a transmission line and delta match which provides the best way for. The design of the antenna relies on the equations in [1-2]. The first and most important factor of the antenna is its bandwidth and resonance frequencies. Therefore, the S-Parameter curve helps to identify them. Additionally, antennas that work well must have matching frequencies. Firstly, the base antenna is designed according to Fig 1. S-parameters in Fig 3 show that the dual-band liner polarized antenna is achieved.

For further achievement and improving features, the process of designing and the diverse type of antenna is investigated in Fig 2. According to Fig 3, from 1 GHz to 8 GHz, the proposed antenna has covered several selective frequencies. The first one is at 2.2GHz and the other ones are at 4.8 and 6.6 GHz. In addition, it has 400 MHz, 500GMHz, and 1.3GHz bandwidth, respectively.

Based on Fig 3, it is shown that the antenna has reconfigurable features with varying U-shaped parasitic elements on the ground. Initially, the antenna has been a dual-band. After inserting that element, it has turned into a third band with suitable features for wireless communication systems. The parameters of the antenna are given in Table I.

TABLE I
PARAMETERS OF THE ANTENNA

Parameters		Parameters		Parameters	
W	25mm	g	15mm	g3	0.775mm
L	20mm	g1	0.125mm	w1	1.55mm
L1	16mm	g2	0.275mm	w2	3.75mm
w4	4.75mm	w5	4mm	w3	5mm



(Antenna)

Fig.1. The structure of base antenna

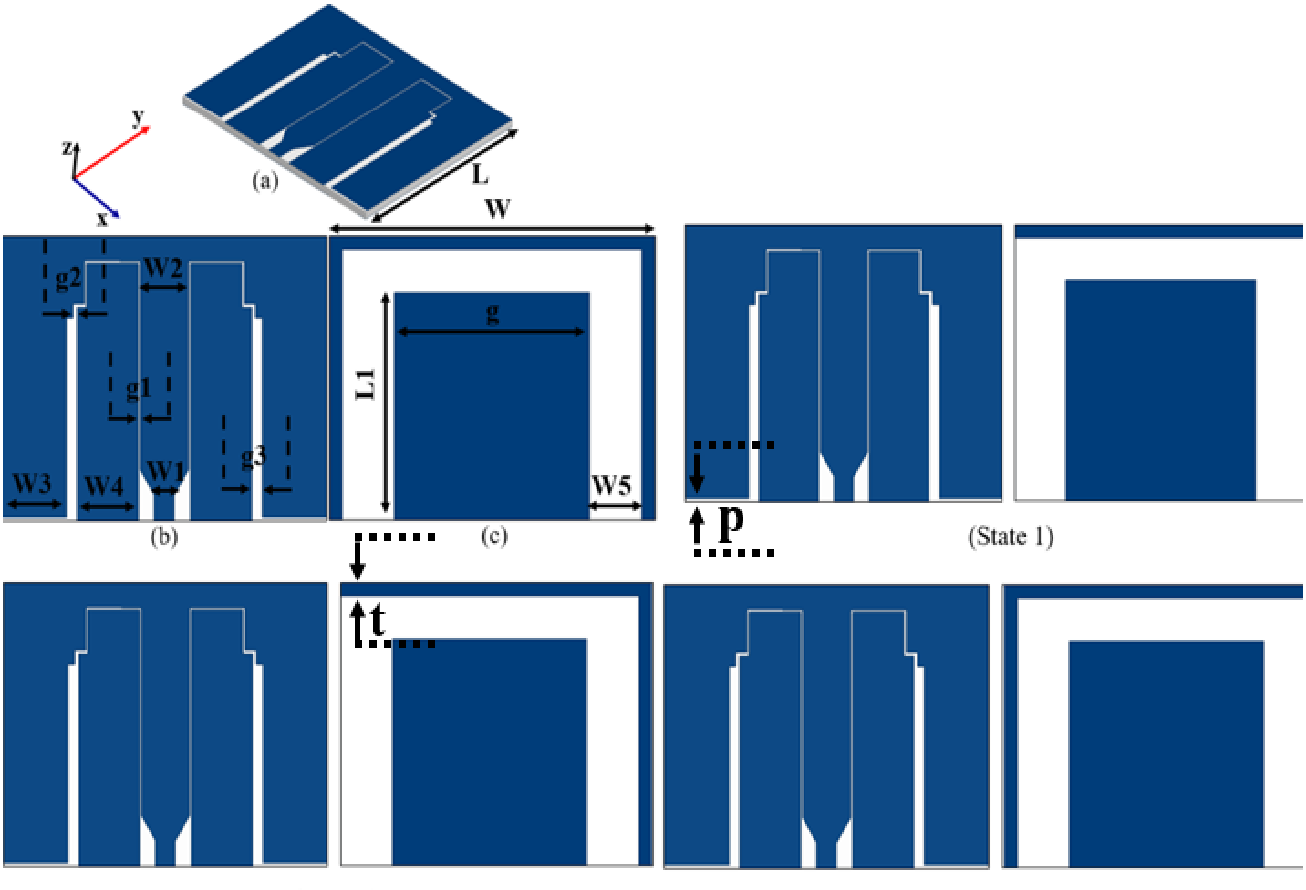


Fig.2. 3-D schematic and antenna evolutionary process.

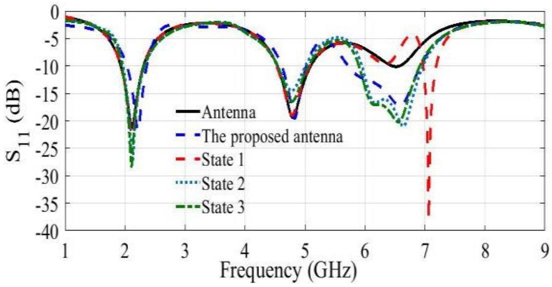


Fig.3**.** Simulated S-parameter of all state and the proposed antenna.

III. Surface Current Distribution

The surface current distribution is the best way to understand and depict the antenna patch radiation mechanism at the main frequencies shown in Figure 4-6 at the resonance frequencies of 2.2 GHz, 4.8GHz, and 6.6GHz, respectively. Apparently, the edge of the structure achieves the most current. From Fig. 3-5, it is clear that mainly current spread on the bottom part of the patch which makes resonance around 2.2 GHz. The resonance at around 4.8 GHz and 6.6 GHz is caused by the current distributed over the edge rectangular elements on both sides of the feed line as shown in Figure 4-6, respectively.

To investigate the polarization of the proposed antenna, the surface current distribution for 2.2 and 6.6 GHz frequencies in different phases of 0, 90, 180 and 270 degrees is shown in Figure 4-6. The rectangular elements on the both side of antenna produce circular polarization for antenna at f=2.2GHz. Similarly, the main part of the antenna in generating the 6.6 frequency is located around the edge and top of the patch. The current vector rotates counterclockwise, causing the left-handed circular polarization (LHCP) radiation to be in the θ = 0° direction.

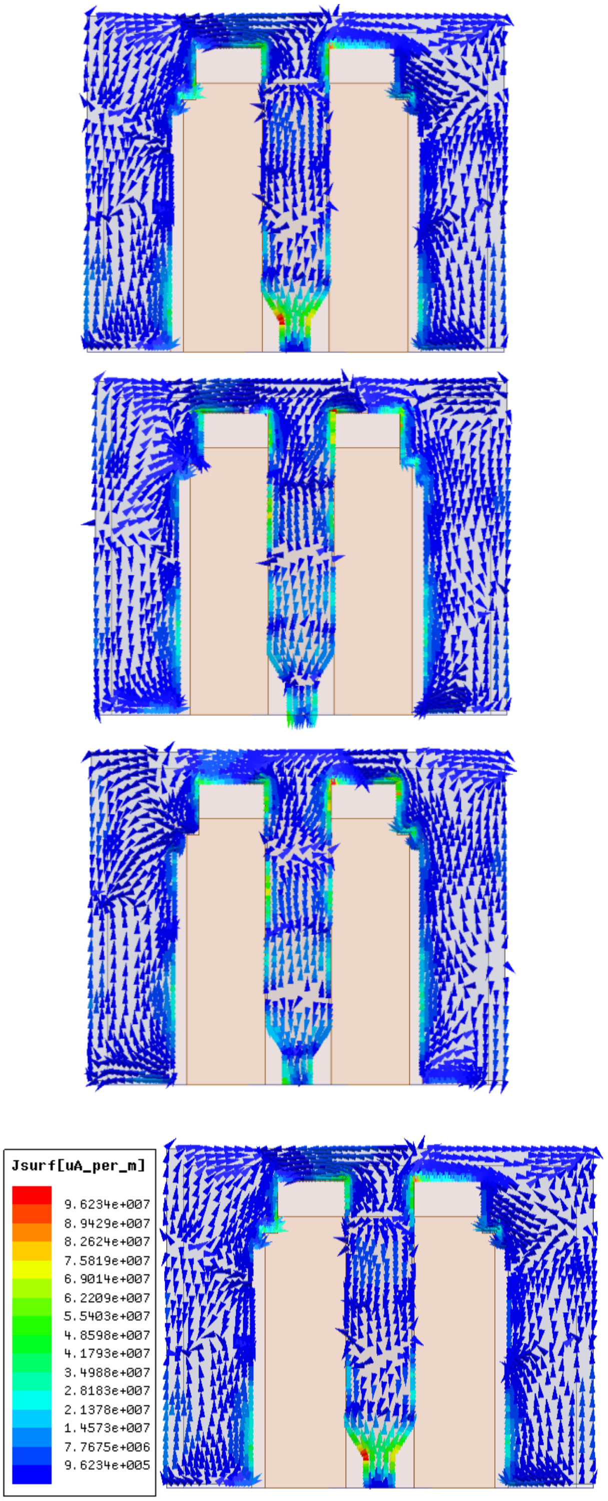


Fig.4. Simulated of surface current distributions at f=2.2GHz.

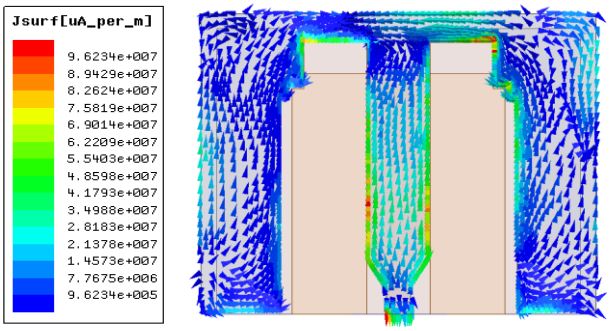


Fig. 5. Simulated of surface current distributions at 4.8 GHz.

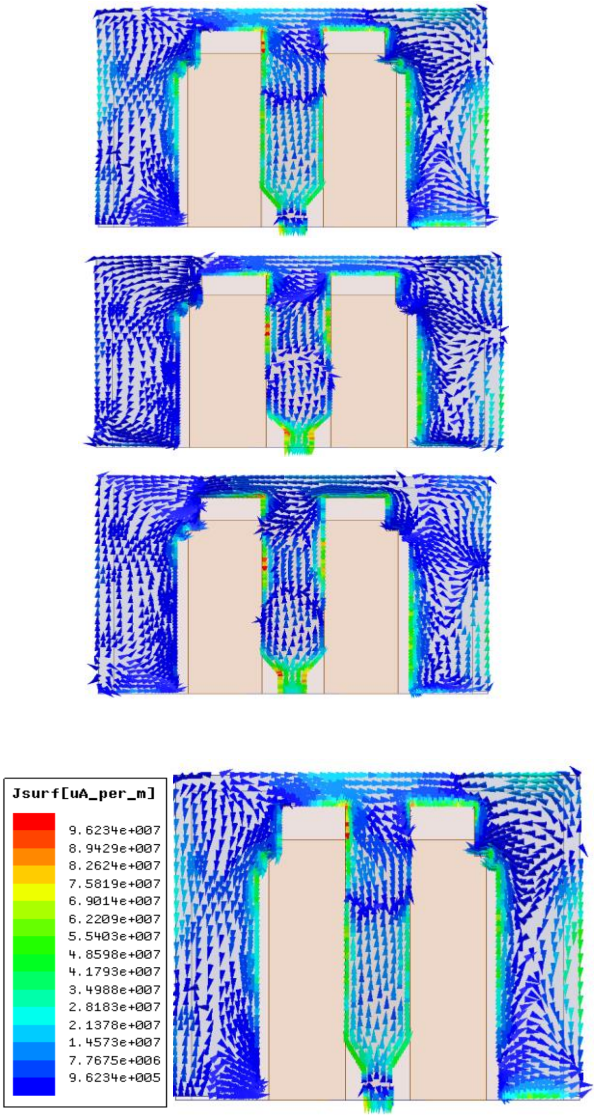
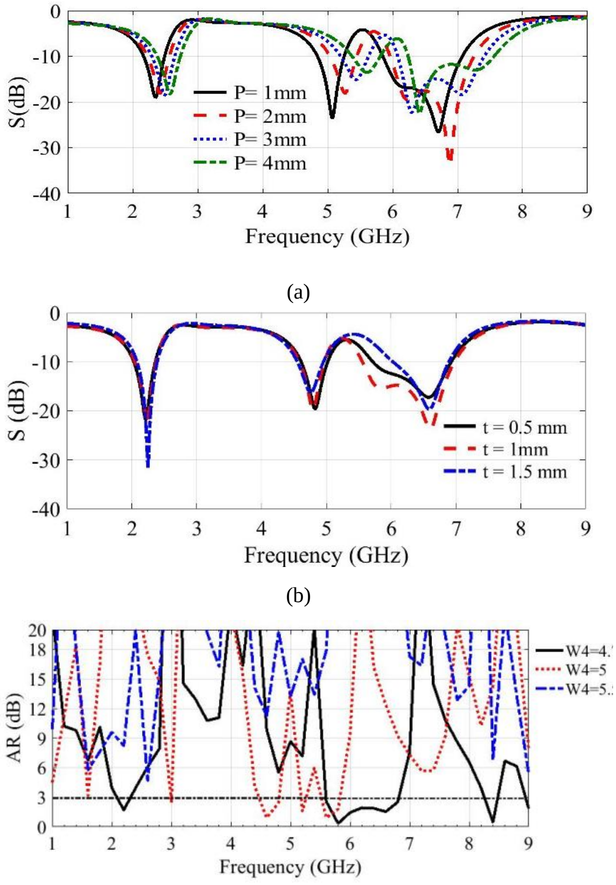


Fig. 6. Simulated of surface current distributions at 6.6 GHz.

IV. Parametric Study

In this section, in order to have a better comprehension of the results, parametric study on some important parameters in antenna design has been investigated. The main key is to obtain a good impedance matching and control it. Since the U-shaped element is the main part of the antenna, it can help control the antenna. Especially at the third resonance frequency, the change of P and it causes a minor variation in impedance matching and frequency shift. A parametric study has been investigated in HFSS software for important factors with several values. As depicted in Fig 7(a), for P=1 to 4 mm low impedance matching and bandwidth has been changed preciously. Moreover, the third band have been getting better compared to the past manner. Another parametric study is the width of the U-shaped parasitic element at the ground plane location, which shows that a small difference of 0.5 mm changes the resonance frequency and decreases the impedance matching as well as the third resonance frequency, according to Fig. 7(b). In order to clarify the performance of circular polarization of antenna, axial ratio can be helpful with presenting date. Therefore, axial ratio of antenna is obtained from 1GHz to 9GHz to illustrate behavior of antenna based on changing the amount of W4. In Fig 7(c), W4 values have been varied from 4.75mm to 5.5mm to show that stair-shape radiator is capable of creating circular polarization. The axial ratio is obtained 400 MHz and 1.3GHz bandwidth, from 2 GHz to 2.4 GHz and from 5.7 GHz to 7 GHz, respectively.



(a)

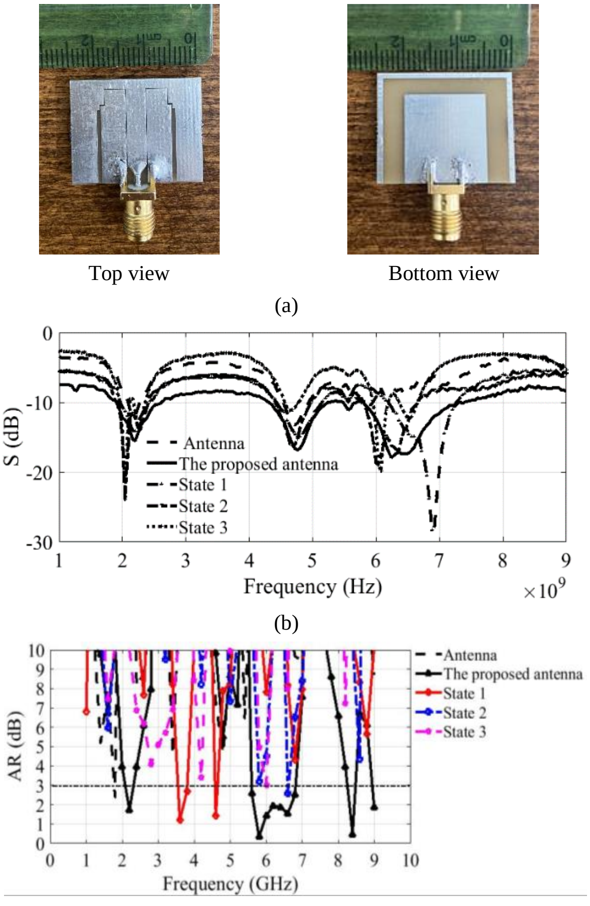
(b)

(c)

Fig. 7. (a) S-parameters for different values of P, (b) Simulated reflection coefficients for three values of t, and (c) Simulated axial ratio for three different values of W4.

V. Fabricated Antenna

pou E8363C illustrated as shown in Fig 8(a). Also, the measured and simulated results are presented in Fig 8(b). After making and testing the antenna, the test results are similar and in good agreement with the simulated results. As FR4 substrate provides suitable results in simulation process as well as an easy accessibility and lower cost in market, this material is selected to be used. Fortunately, the experimental results confirm the simulated ones to a high extent which ensures suitability of this material. In fact, a trade-off between cost, availability, and dielectric loss is performed which ends in selection of FR4 substrate. The proposed antenna works well in the desired bands of WLAN: The 802.11 working in five frequency ranges: 2.4 GHz, 4.9 GHz, 5 GHz, and 5.9 GHz bands. Each range is divided into a multitude of channels. Similarities can result from the quality of the substrate and the way the antenna is soldered, and the lack of the correct caliber of the measuring device.



(c)

Fig 8. (a) Fabricated structure top and bottom view, (b) Measured and simulated reflection coefficient, (c) simulated axial ratio for the proposed antenna and other state of antenna.

Although, the tested results explicitly testify that both results are almost the same, but fabrication and measurement setup tolerances cannot be ignored. In the proposed antenna, a bandwidth of 400 MHz from 2 GHz to 2.4 GHz, 500 MHz from 4.6 GHz to 5.1 GHz, and 1.3 GHz from 5.7 GHz to 7 GHz is obtained with good impedance matching. On the other hand, based on Fig 8(c), the simulation results of axial ratio show that circular polarization has been obtained at the desired frequencies. The antenna has circular polarization at 2.2 GHz and 6.6GHz with 200MHz and around 1GHz bandwidth, respectively.

VI. Radiation Pattern

Another key feature of an antenna is its radiation pattern as it indicates the direction and power of the transmitting wave. For communication systems, omnidirectional patterns are the best choice. Actually, in the omnidirectional manner, the antenna radiates around itself with approximately the same power, which is widely adopted by wireless communication and portable systems [21-23]. Based on Fig. 9, the simulated and tested results show that the radiation pattern of the proposed antenna is omnidirectional at 2.2 GHz, 4.8 GHz, and 6.6 GHz on XOZ plane and YOZ plane.

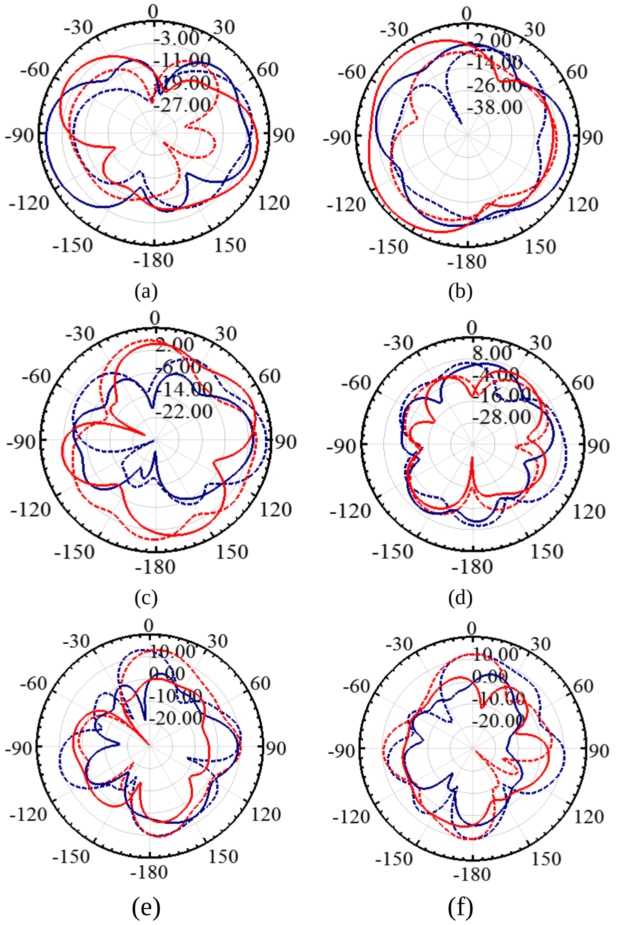


Fig.9. Measured and Simulated radiation patterns (a-b) at f=2.2GHz, (c-d) f=4.8GHz, and (e-f) f=6.6GHz. (Solid line is XOZ and dashed line is YOZ) (left-side and right-side results show LHCP and RHCP patterns, respectively), (red line belongs to measured results and blue one to simulated results).

VII. Comparison

Table II investigates the applicability and advantages of design in terms of size, gain, and polarization. Comparing the proposed antenna with the previous papers, simple and compact antenna fed by CPW and using a U-shaped element on the ground can cover better features, and higher gain at the same time.

TABLE II

COMPARISON OF THE PROPOSED ANTENNA AND SOME SIMILAR DESIGNS IN THE LITERATURE

Reference	Size (mm^3)	Gain (dB)	f (GHz)	Polarization
[2]	22×24×1.59	2.4 and 3.5	2.48 and 3.49	Liner
[3]	37.8×40.4×1.6	1.9 and 1.2	2.4 and 5.2	Circular
[4]	$0.42\lambda \times 0.8 \lambda$	6.84	5.8	Circular
[5]	30×20×0.8	2	2.9	Liner
[6]	28 × 26×1.6	2.9,4.13, and 5.8	2.4,4.4, and 7.4	Liner
[7]	35×23	2	2.1 and 4.5	Circular
[23]	$0.58\lambda \times 0.58 \lambda$	7.26	2.4	Circular
This work	25×20×0.8	3,6,and 10	2.2,4.8, and 6.6	Circular, liner

VIII. Conclusion

A third-band antenna with dual-polarized for wireless, Bluetooth application and mobile service has been simulated and tested. Bandwidth of 400 MHz at resonance frequency 2.2 GHz, 500 MHz at resonance frequency 4.8 GHz, and 1.3GHz at resonance frequency 6.6GHz is obtained, respectively. Also, the antenna has circular polarization at 2.2 GHz and 6.6GHz and linear polarization at 4.8GHz. The compact antenna with 25×20mm^2 sizes is fabricated and measured on an FR4 substrate with 0.8 mm thickness. A high gain of almost 7.5 dB and also circular polarization at two resonance frequencies have been earned by the simple structure. Suitable physical and electromagnetic properties are achieved in the mentioned frequency bands.

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