Compact Circularly Polarized Slotted Symmetric V slits Microstrip Patch Antenna for ISM Band Applications

Naw Khu Say Wah[1] and Hla Myo Tun[2]

[1,2] Department of Electronic Engineering, Yangon Technological University
Gyogone, Insein PO, 11011, Yangon, Myanmar
Email: nksw.ytu [AT] gmail.com

[2] Department of Electronic Engineering, King Lauk Phya Institute of Technology Myaungmya
Myaungmya, Myanmar
Email: hlamyotun.ytu [AT] gmail.com

ABSTRACT—*This paper presents a short microstrip patch antenna and analyzes its characteristics in simulation and measured ways. The proposed antenna is meant to be used from 2.4 to 2.5 GHz at the resonant frequency of 2.45 GHz Industrial, Science, and Medical (ISM) spectrum. Besides, insert a diagonal slot in the main patch, and two cutting edges with V-slit gives the antenna to propagate a circular polarization pattern. The paper aims to start learning a simple C.P. patch antenna supported the basic concept of microstrip antenna theory. A single-feed C.P., truncated corners, and slit and slot methods are employed to model the antenna apart from its parametric study. The substrate material of the developed antenna is FR-4, and it's a relative permittivity of 4.4. The antenna incorporates a compact overall size of 0.389λ_0 × 0.389λ_0 × 0.013λ_0, where λ_0 is that the corresponding free-space wavelength at 2.45 GHz. FEKO has been used for not only designing the antenna model but also analyzing its performances. Simulated and measured results have reported that the antenna can work in ISM bands (2.42-2.5 GHz) with VSWR< 2, low realized gain, and the limited 3-dB axial ratio at 2.45 GHz.*

Keywords— Circular polarization, Microstrip patch antenna, rectangular slot, V-slits, ISM bands

1. INTRODUCTION

ISM (Industrial, Scientific, and Medical) band is being designated to Industry, Science and Medical fields then different types of antennas, for example, a microstrip patch antenna, a helical antenna, a dielectric resonator antenna are used for various applications such as Wi-Fi, Bluetooth, and cordless phone and so on [1]. One of the largest ISM bands applications is wireless networking (Wi-Fi), including IEEE 802.11, laptops, tablet computers, computer printers, cellphones, etc. Some short-range communication devices such as radio control channels for UAVs (drones), RFID systems for merchandise, wireless surveillance systems, and wild animal tracking systems operate in the ISM frequency bands [2].

Microstrip patch antenna technology has gained a lot of attention from researchers and industrials in the field of high-frequency equipment because of their numerous advantages such as light-weight, low maintenance, ease of fabrication, and ease of integration in miniaturized circuits. Moreover, the microstrip patch antenna has been used for wideband, narrowband, and multiband purposes. These kinds of antennas are mostly used in the applications of wireless communication, radar, some satellite communication, spacecraft [3], wearable devices [4], and medical applications [5], and so on. Antenna polarization, one of the most vital factors in wave propagation between transmitting and receiving antennas, is divided into three types: linear, elliptical, and circular polarizations [6]. In a portable wireless communication system, the demand for circularly polarized microstrip antennas is greater than linearly polarized ones due to its traits of decreasing the power loss in the misalignment of transmitting and receiving [7-11]. To be an accurate alignment between transmitting and receiving, each antenna station should be a linear polarized antenna for propagating in the same polarization. Some popular circularly polarized microstrip patch antenna for portable/handheld devices are RFID reader antenna, WLAN, GPS, rectenna for energy harvesting, mobile phone antenna, and so on. Usually, a single-feed microstrip patch antenna generates linearly polarized radiation without introducing some perturbation, such as making a slit or slot to the antenna patch to excite two orthogonal modes for C.P. radiation. [12-13]. The single-feed microstrip patch antennas are usually more compact as compared to the dual-feed antennas. However, the circularly polarized patch antenna's compact size can be obtained with limited gain, narrow 3-dB A.R. bandwidth, and impedance bandwidth [14].

In the literature, authors have intensely concentrated on various techniques of generating C.P. radiation of the single-feed configuration. In [15], three types of single-feed circularly polarized microstrip patch antennas (diagonal-fed nearly square, truncated-corners square, and square with a diagonal slot) have been studied analytically by employing impedance Green's functions for segments with magnetic wall boundary as well as experimentally. The authors described that the square patch antenna with a diagonal slot has the largest axial ratio bandwidth among the three antennas reported. In contrast, the minimum VSWR is obtained with a diagonal-fed nearly square patch antenna. In [16], the authors have presented that the trimmed slits and its length adjustment supported the microstrip patch antenna with a reduced patch size to perform C.P. radiation at a fixed operating frequency, also provided a wide C.P. bandwidth and reduced failures due to fabrication. In [17], the compact circular polarization (C.P.) operation has been achieved by cutting a cross-slot of unequal arm lengths in a circular microstrip patch or by insetting four narrow slits of different lengths at the edges of a square microstrip patch. Due to the cross slots perturbation or the narrow slits, the antenna's fundamental resonant mode occurs at a lower frequency and is split into two near-degenerate orthogonal modes with equal amplitudes and a 90o phase difference; this results in compact C.P. operation. In [18], a novel design of single-feed equilateral-triangular microstrip antenna for circular polarization (C.P.) has been presented that the single-fed triangular patch can be C.P. antenna by embedding a narrow slot or a cross-slot of unequal slot lengths in the main patch. Furthermore, circular polarization is theoretically possible from a microstrip antenna excited by a single feed if two spatially orthogonal modes are excited in phase quadrature [19].

This paper focuses on a single-fed microstrip patch antenna combined with a diagonal slot, truncated corners, and V-slits to design a compact C.P. patch antenna with good impedance matching at ISM bands. Still, other limitations such as low gain, narrow bandwidths are taking into account in this model. The main idea of loading V-slits each truncated corner to the main patch is to monitor the 3dB axial ratio at 2.45 GHz. This paper's remainder is organized as follows: In Section II, the configuration of the proposed antenna, the operating mechanism, and the simulated results are presented. In Section III, the measured and simulated results are discussed. After all, the conclusions are drawn in Section IV.

2. ANTENA CONFIGURATION AND ANALYSIS

2.1 Design of Proposed Antenna

The proposed antenna configuration is depicted in Figure 1. The antenna has been designed on a 1.6 mm thick-single layer FR4 substrate having a relative permittivity of 4.4 with a loss tangent of 0.025. The total size of the antenna is 47.63 mm× 47.63 mm× 1.6 mm. Basically, the trimmed-corner technique is mostly used for generating circular polarization in a single-fed patch antenna. In our design configuration, we have used a combination of two corners-truncated and symmetric V-shaped slits on a radiating patch to create the minimum 3 dB axial ratio response at the desired resonant frequency. Moreover, a symmetric V-slit at each truncated corner also extends the current distribution on the main patch to be miniaturized the patch antenna's physical dimension. There are different reasons for loading slots on the patch antenna. If slots are placed on the patch, that decreases the antenna gain due to metallic size reduction. A slot could also be added to adjust the antenna's input impedance if the antenna's input impedance is far from the characteristic impedance of the cable and the reflection loss is too small. The microstrip line feed effects and a diagonal slot on the main patch provide better impedance matching with 50 ohms coaxial probe feed for the antenna configuration. This feeding method is very widely used because it is effortless to design and analyze and easy to manufacture. The overall dimensions of the developed antenna are as described in Table 1.

Table 1. Dimensions of the proposed compact C.P. antenna

W_g(mm)	L_g(mm)	W_p(mm)	L_p(mm)	C_w(mm)	W_f (mm)
47.63	47.63	2	27	7.07	2.88
V_w(mm)	**V_d(mm)**	**s_l(mm)**	**s_w(mm)**	**L_f(mm)**	
3.7	6.5	15.56	1.41	10.32	

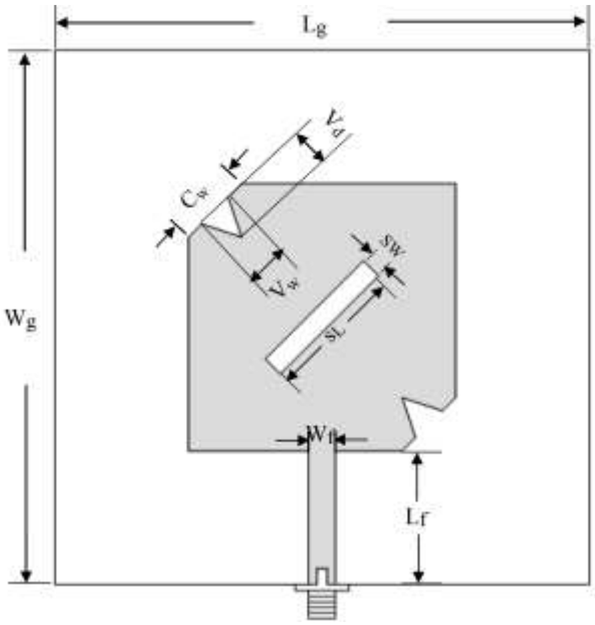

Figure.1. The Geometry of the proposed compact C.P. antenna model

2.2 Operation Principle

Initially, a compact microstrip patch antenna without slot and slit, using a square patch of 27× 27 mm^2 to operate at the resonant frequency 2.45 GHz in ISM bands, has investigated. Fixing the corner-truncated ratio, 5/5 is 1, the length of the cutting-edge Cw is 7.07 mm. The trimmed area ratio at two corners of the patch to the total antenna size, 2A/S, is 0.034 (3.4% in size reduction). As shown in Figure 3, the frequency in resonant range shifts to the right of the higher frequency range in performance analysis. According to the trimmed corner's effect at two edges of the patch, it gives wider bandwidth, and the resultant impedance bandwidth of 10 dB return loss is in the frequency range from 2.5 to 2.7 GHz (8.2 % B.W.). According to the C.P. antenna's fundamental principle, the antenna can generate circular polarization by trimming the patch's edges. From the simulation result, we noticed that this compact microstrip patch has an axial ratio of 2.86 dB at 2.55 GHz with the wider impedance bandwidth from 2.5 to 2.7 GHz. Obviously, the antenna design needs some parameter optimization to obtain a good impedance matching at the desired frequency of 2.45 GHz and better A.R. result in its performance. Besides, our major consideration is size miniaturization and introducing the V-slits and a diagonal sot in the design configuration to achieve a compact C.P. antenna at the desired frequency.

Next, the single-feed corner-truncated C.P. microstrip patch antenna has been modified by loading a slot diagonally at the patch's center. Its characteristics have been discussed in simulation approaches. The depiction of compact antenna models with and without slot is shown in Figure 2. The dimension of the rectangular slot sw× sL is 1.41×15.56 mm^2. Adding a slot into the main patch makes more decrease the antenna size in the ratio of As/S' is 0.182 (18 % reduction in size). The patch's properties' significant variation with the slot is that the frequency is moving to the left, the lower frequency span, and its return loss is better at 2.4 GHz and 2.65 GHz, which is a merit of the configuration. It could be realized from Figure 3 that at 2.42 GHz, the return loss is about -13 dB, and at 2.65 GHz, the return loss is about -16.4 dB, respectively. However, in surface current excitation, a small number of electric currents canceled each other around the slot's edge. It affects the axial ratio to go higher than 3 dB, and consequently, the antenna loses its circular polarization radiation.

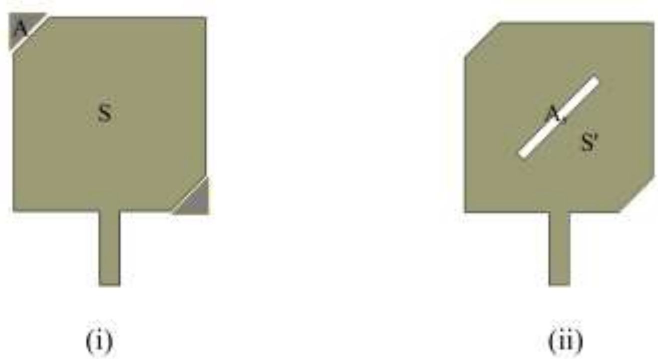

Figure.2. The single-fed corners-truncated patch model (i) without slot (ii) with slot

For the last configuration, adding a new idea of molding symmetric V-slit at each of the corners-truncated edges of the slotted patch and each V-slit is formed by extracting a small triangular patch from the main patch. It is noticed that the V-slit's vertex and width can able to control the axial ratio and reflection coefficient of the antenna. The resultant antenna model is shown in Figure 1, and its model in the simulation window can see in Figure 5. Figures 3 and 4 demonstrate the comparisons of simulated $|S_{11}|$ and the axial ratio between the antenna's three different geometry.

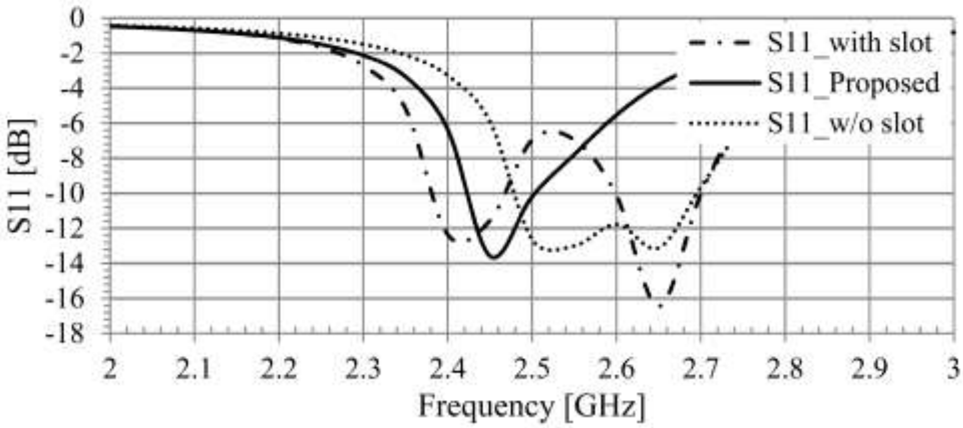

Figure.3. A comparison of $|S_{11}|$ between three different layouts of antenna

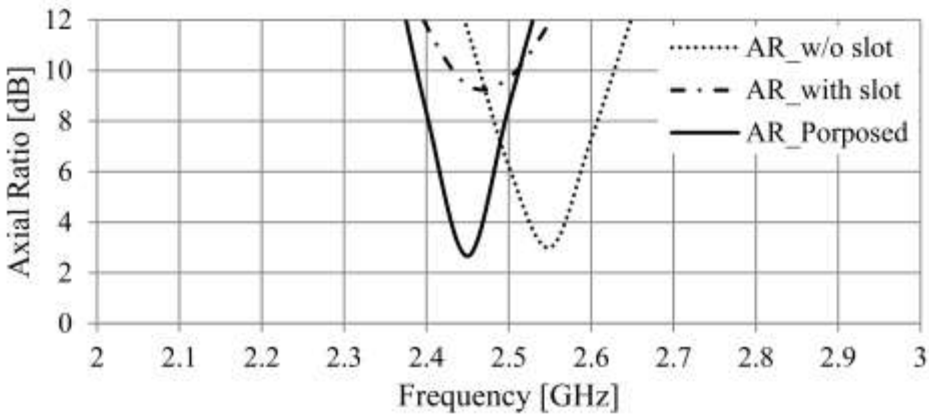

Figure.4. A comparison axial ratio between three different layouts of antenna

3. SIMULATED AND MEASURED RESULTS

The antenna prototype has experimented and then measured results were compared with simulation results. Figure 6 illustrates the comparison of the simulated and measured $|S_{11}|$. Good agreement is found between simulated and measured results of the reflection coefficient, except for a small frequency shift, probably due to the fabrication tolerances. From the simulated results, we found that the proposed antenna gives the reflection coefficient $|S_{11}|$ between the frequency range from 2.42 GHz to 2.5 GHz, and its response is sharpened at 2.45 GHz of 14 dB. In the meantime, the measured impedance bandwidths or $|S_{11}|$ less than 10 dB is from 2.43 GHz to 2.54 GHz (5%), thus satisfying the ISM bands applications from 2.4 to 2.5 GHz.

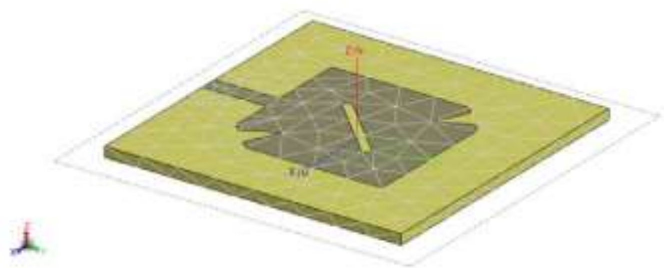

Figure.5. The proposed antenna in FEKO electromagnetic simulator

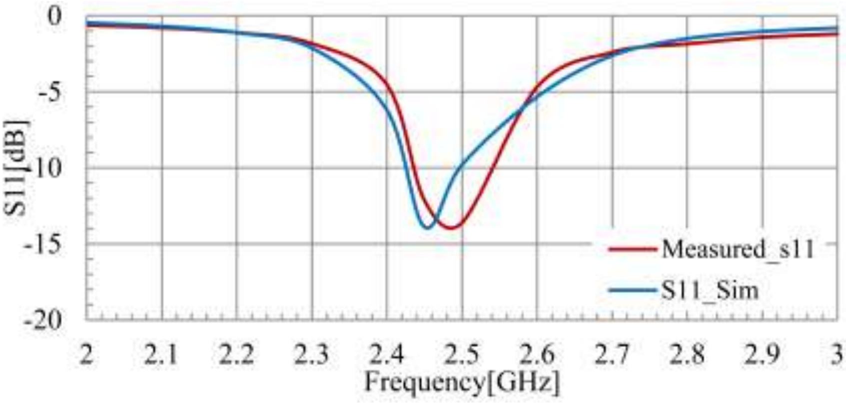

Figure.6. Measured and simulated $|S_{11}|$ versus frequency

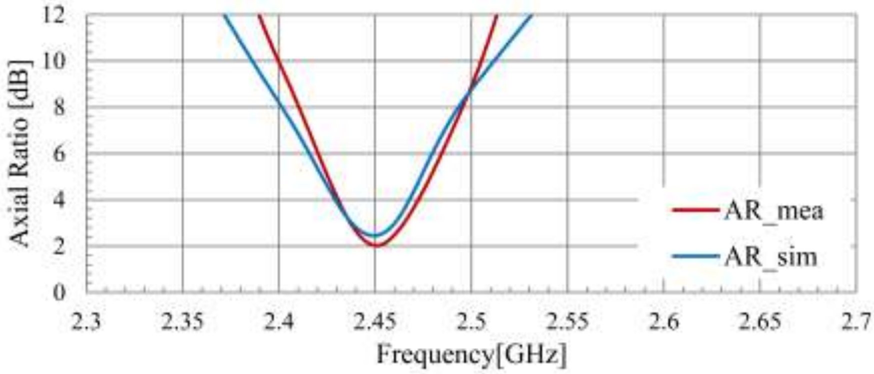

Figure.7. Measured and simulated axial ratio versus frequency

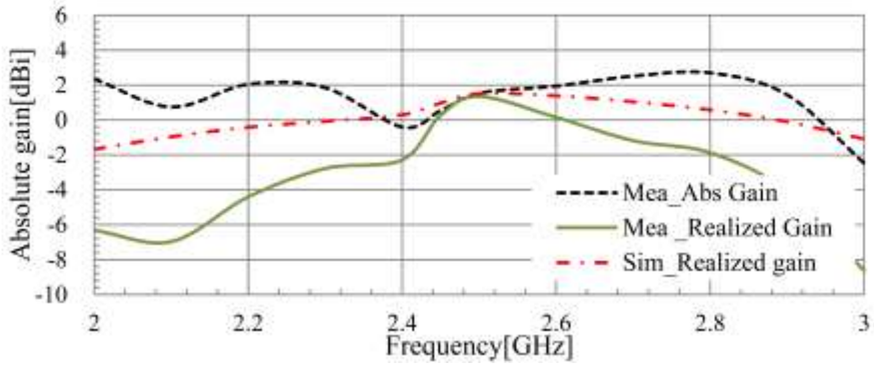

Figure.8. Measured and simulated gain versus frequency

Figure.9. (a) Fabricated antenna prototype (b) Measurement of the antenna in the anechoic chamber

The distribution of current and the radiation pattern of the antenna are discussed by simulation. Fig 10 shows the simulation results of the current distribution of the antenna surface.

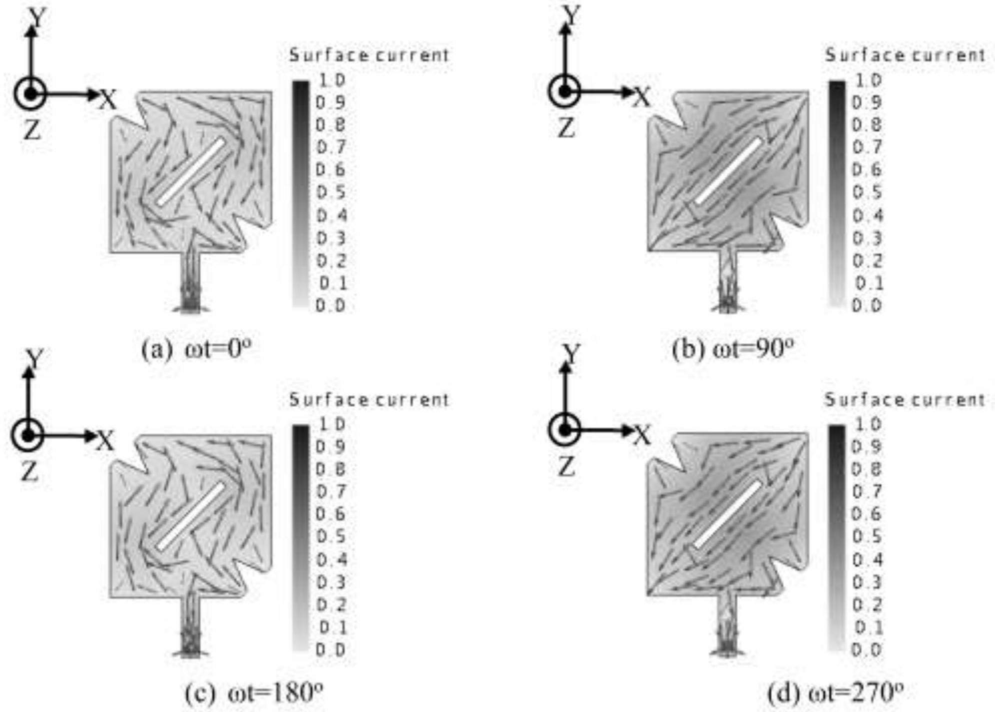

Figure.10. Surface current distributions at 2.45 GHz with different time phases (a) 0° (b) 90° (c) 180° (d) 270°

In Figure 10 (a) and (c), the current flowing from one radiating edge to another radiating edge takes a longer patch from around the diagonal slot due to the patch's slot-loading. Due to this longer current path, there is a shift in the antenna's resonant frequency that leads to antenna miniaturization. Besides, it is observed that the non-uniformly excitation of surface electric currents close to the slot causes field cancelation: this can affect the 3-dB axial ratio quality and give higher cross-polarization in radiation. From Figure 10 (b) and (d), the radiating patch has a straight flow of current from one radiating edge to another radiating edge. To comprehend the antenna C.P. operation's sense, the current distributions at 2.45 GHz on the radiating patch of the proposed antenna in XY-plane for different phase angles are studied. These four subplots depict the surface current vectors at different time phases (ωt) from 0°, 90°, 180°, and 270° with an interval of 90°. It is expected from the current distribution that asymmetry in the antenna structure can rotate the current that leads to C.P. radiation.

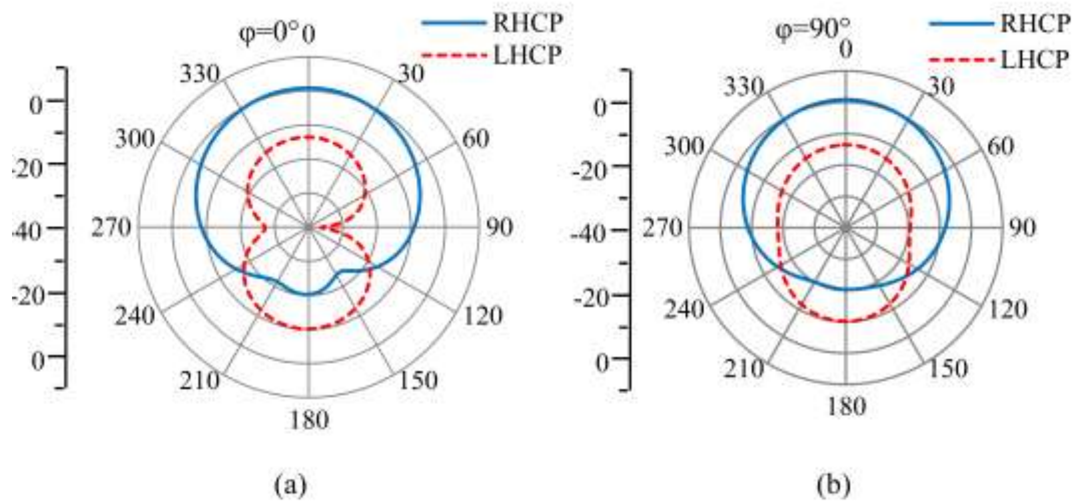

Figure.11. Simulated radiation patterns of the proposed compact C.P. antenna at 2.45 GHz: (a) XZ-plane and (b) YZ-plane

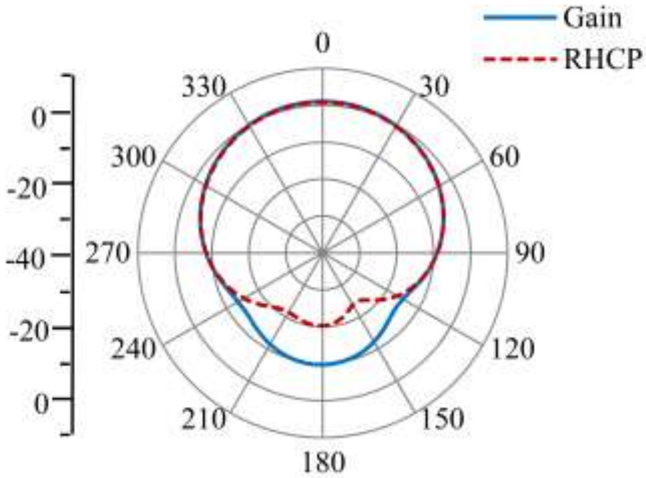

Figure.12. Simulated Gain patterns of the antenna at 2.45 GHz

Moreover, the patch's current excitations are anticlockwise, which means the antenna works in RHCP mode. The simulated radiation patterns in both X.Z.- and YZ-plane are illustrated in Figure 11. It is observed that the proposed antenna generates a good RHCP radiation in broadside direction with signs of radiation dissipation lower than -10 dB. The level of cross-polarization, LHCP radiation could be further improved with slight modification in the perturbation geometry loaded on the radiating patch. There has no beam asymmetry or tilt in the radiation patterns due to symmetry in feed structure. The proposed single-fed antenna gives simulated peak gain and RHCP gain of 0.97 dB and 0.87 dB; moreover; it generates right-hand circular polarization in its radiation characteristics, as shown in Figure 12.

4. CONCLUSION

A 2.45 GHz compact circularly polarized single-fed directional microstrip patch antenna for ISM frequency band applications is proposed and fabricated. The proposed antenna consists of a trimmed-edge square patch loaded with a diagonal slot and V-slits in its design layout. Inserting a diagonal slot and a pair of V-slits at each trimmed edge were utilized to improve the antenna's axial ratio and impedance matching. The size of the antenna is 47.63 mm×47.63 mm×1.6 mm. The simulation results showed that the compact C.P. antenna satisfied the port reflection coefficient $|S_{11}|$ <-10 dB in the 2.42~2.5 GHz, realized gain of 0.87 dB, and the minimum 3-dB axial ratio of 2.45 dB at the resonant frequency of 2.45 GHz. In antenna measurement, the measured $|S_{11}|$ bandwidth, 3-dB axial ratio bandwidth and realized gain were 2.43-2.54 GHz (5%), 2.438-2.465 GHz (1.1%), and 0.3 dB. We have found that the proposed compact C.P. directional antenna meets the qualification of planar and compact ability in its design. It can also be said that the simulated and measured results are in good agreement despite the shift in the resonant peak value, which may be due to the effect of the soldering of the SMA and connecting cable losses during measurement. Possibly, the losses of conductor associated with the microstrip feed line that experienced the antenna gain drops of 0.57 dB from the simulated result. By properly tuning the dimensions of slot and slits with simulation software, the proposed design with relatively high gain, a wider 3-dB axial ratio bandwidth, would be obtained.

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