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DESIGN OF LINEAR AND CIRCULAR POLARIZED ANTENNA FOR WLAN APPLICATION

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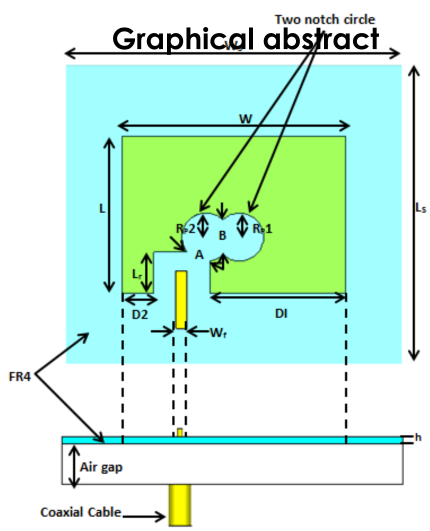
Graphical abstract



Abstract

In this paper, a linear and circular polarized antenna with operating frequency at 2.4 GHz for Wireless Local Area Network (WLAN) application is proposed. Firstly, a basic linear polarization antenna (Design A) was designed with rectangular slot at the rectangular patch and air gap between substrate and copper layer with distance of 10 mm. Next, in order to perform circular polarized, the antenna designed is added with optimized dual circular notch at the rectangular slot. This circular polarized antenna is designed with two different polarization types which are right-handed circular polarization (RHCP) with optimized dual circular notch at the patch (Design B) and left-handed circular polarization (LHCP) with optimized dual circular notch at the patch (Design C). The proposed antenna had been designed and simulated by using Computer Simulation Technology (CST) Microwave Studio Suite. The comparison result of simulation and measurement show that the proposed antenna can achieve axial ratio above 3 dB for linear polarized and below 3 dB for circular polarized with return loss less than -10 dB.

Keywords: Antennas, axial ratio, polarization, resonant frequency, return loss

1.0 INTRODUCTION

Microstrip antennas are among the most widely used types of antennas in the microwave frequency range, and they are often used in the millimeter-wave frequency range as well [1,2]. The design of microstrip patch antenna can be in many different shapes, such as rectangular, circular, triangular, elliptical and others. The rectangular patch antenna is the basic and the most commonly used microstrip antenna. The basic parameters of the rectangular microstrip antenna are the width and length of the patch. Microstrip patch antenna is widely applied in modern technology due to the advantages of low profile, low cost, ease of fabrication and light weight [3-6].

However, microstrip patch antenna is restricted with narrow bandwidth and low gain. In order to overcome this problem, there are a few modifications to done on the microstrip patch antenna, which included fed by L-strip [4,6], adding slot [7,8], stacked patch [9] and others. There are a few design techniques are proposed to obtained broadband operation with compact size, which included patch with thick air gap substrate, slotted ground plane, increase thickness of substrate and so on. In order to improve the bandwidth of the antennas, microstrip antenna with linear polarized can be designed by embedding suitable slots [4,10].

Polarization can be categorized into linear polarization (LP), circular polarization (CP) and elliptical polarization (EP). In order to improve the performance of wireless communication system, microstrip patch antenna with CP is preferable where it can combat the multipath effect when compared with LP antenna. This is due to CP antenna transmitted the signal in all plane while LP antenna transmitted the signal in one plane [3]. Generally, CP antenna can be designed by modify the basic geometry of antenna with different techniques, such as truncated corner [11,12], nearly square patch [3], double layer [8], altered the position or number of feed [3,12] and others.

For circular polarization, the electric field at that point traces a circle as a function of time and it only can be achieved when the magnitude of two components are same [3]. The two components have a time-phase difference of odd multiples of 90° [3]. Axial ratio can used to determine the quality of the circular polarization and linear polarization. The axial ratio for circular polarization is less than 3 dB for ratio accuracy; meanwhile linear polarization is more than 3 dB [11]. Circular polarized antenna can be achieved by using slot [8], truncated corner [3,5,13], nearly square patch [3], double layer [8], single feed [3], double feed [3] and others. In this paper, rectangular slot configuration is suggested for linear polarization antenna design and configuration of rectangular slot with dual circular notch is suggested for circular polarization antenna design.

2.0 ANTENNA DESIGN

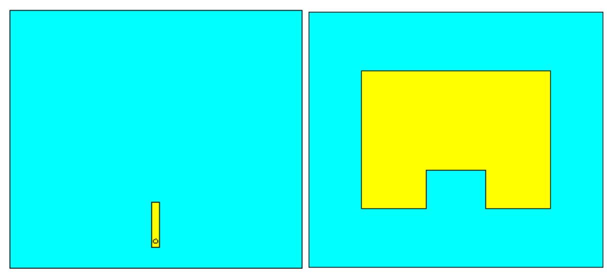
In this paper, the antenna is designed by using FR4 board with the thickness of the substrate, *h* is 1.6 mm. The dielectric constant, ε_r of the substrate is 4.4 and tangent loss, *tan δ* is 0.019. The thickness of copper, *t* is 0.035 mm. The antenna is excited with the coaxial probe feed to the strip line in order to represent as L-probe feed. The L-probe is printed at the upper substrate, while the microstrip patch antenna design is printed at the bottom substrate. The antenna design and its ground are separated by an air gap.

This work consist of three different stages for the antenna design which is Design *A*, Design *B* and Design *C*. Design *A* is a basic linear polarization antenna with optimized rectangular slot at the rectangular patch and a copper layer as the ground plane. Design *B* is right-handed circular polarization (RHCP) antenna and Design *C* is left-handed circular polarized (LHCP). In order to design circular polarized (CP) antenna by referring to the basic structure of linear polarized antenna, dual circular notch are embedded on the rectangular patch. The configuration of linear polarization, RHCP and LHCP antenna design is demonstrated in Figure 2, Figure 5 and Figure 6.

2.1 Design A – Linear Polarized Antenna

Design *A* is the common microstrip patch antenna that can operate in linear polarization with consists of three sections that are rectangular patch, FR-4 substrate and copper ground plane. Rectangular patch with rectangular slot has been decided to become the basic design of this proposed antenna. The strip feed line been used in the operation is to connect the source signal to the antenna. This design is expected to generate linear polarization with target resonant frequency of 2.4 GHz, axial ratio which meet above 3dB at resonant frequency and gain more than 7 dB.

Figure 1 is illustrated the front and back view of the linear polarization antenna while Figure 2 is illustrated the overall configuration of the linear polarization antenna. Parametric study is conducted on the thickness of air gap between substrate and ground plane, length of inverted patch and length of rectangular slot to study the behavior of linear polarized. The dimension of the ground plane is same as the dimension of the substrate. The dimensions of linear polarization antenna design are tabulated in Table 1.



(a) (b)

Figure 1 Linear polarization antenna design (a) front view and (b) back view

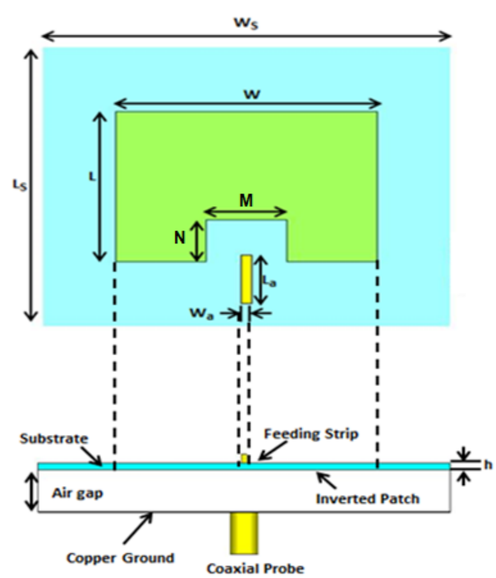
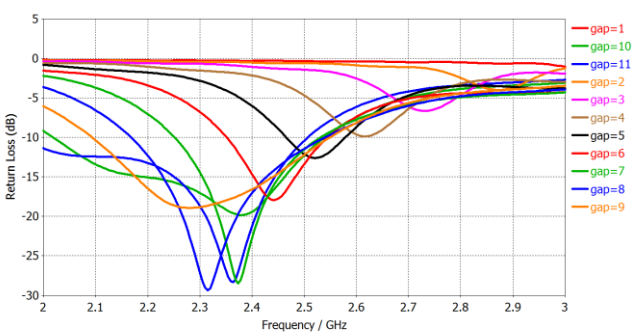


Figure 2 Configuration of linear polarization rectangular patch with rectangular slo

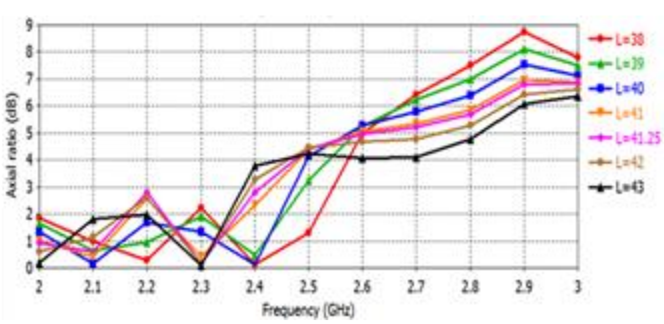
Table 1 Antenna design parameter for linear polarization

Description	Design Parameter	Value (mm)
Width of substrate	*Ws*	90
Width of inverted patch	*W*	58
Width of rectangular slot	*M*	18
Width of strip line	W_f	2.5
Length of substrate	*Ls*	80
Length of inverted patch	*L*	43
Length of rectangular slot	*N*	12
Length of strip line	L_a	14
Separation of strip line from rectangular slot	*A*	10
Thickness of air gap	*Gap*	10
Thickness of copper	*t*	0.035

Figure 3 shows the result performance for linear polarized antenna. Parametric study on the value of air gap is chosen from 1 mm to 10 mm to see any effects of the distance. From analysis, it can see at the distance of 10 mm the return loss shows the resonant frequency at 2.4 GHz. The next parametric study is on the length of inverted patch, *L* where the value chosen is from 38 mm to 43 mm. This parametric study is used to get the design requirement on axial ratio for linear polarization which needs to meet above 3 dB at resonant frequency. From analysis, it can be analyze that the decrease the value of length of inverted patch the value of axial ratio will decrease. Then, last parametric study for this design is length of rectangular slot, *Y* in order to get the better gain for this structure. From observation of value chosen in this parametric study, the higher the length will give the better gain.



(a)



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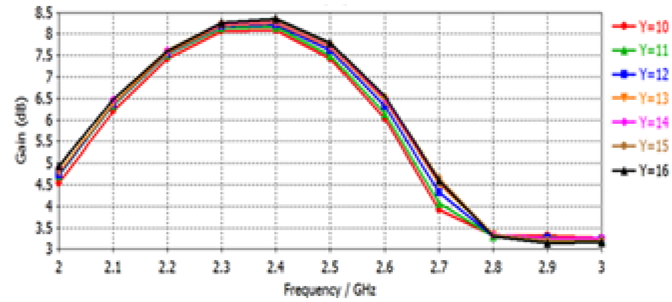
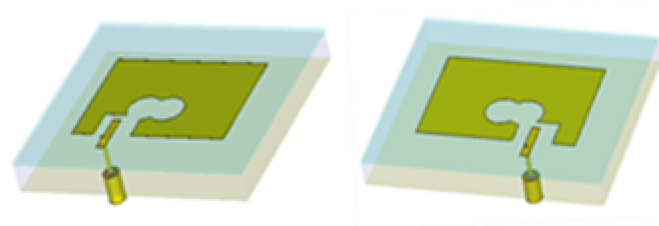


(c)

Figure 3 Antenna performances for linear polarized antenna with the variation thickness of air gap, *Gap*. (a) Return loss, length of inverted patch, *L* (b) Axial ratio and length of rectangular slot, *Y* (c) Gain

Figure 4 is illustrated the structure view of the RHCP and LHCP antenna, while Figure 5 and Figure 6 is illustrated the overall configuration of the circular polarization antenna. Parametric study is conducted on the length of feed and width of rectangular notch. The dimension of the ground plane is same as the dimension of the substrate. The dimensions of both CP antennas are tabulated in Table 2.



(a) (b)

Figure 4 Structure views of (a) right-handed circular polarized (RHCP) and (b) left-handed circular polarized (LHCP) patch antenna

2.2 Design B – RHCP Antenna

In order to design circular polarization (CP) antenna based on the basic structure of linear polarized antenna (Design A), the circular polarization antenna is constructed based on the specification requirement. The basic structure of the patch antenna is design by maintaining the previous specification and some modification has been constructed to generate circular polarization. Dual circular notch with the same radius are embedded on the rectangular patch which it is connecting with the rectangular notch. Figure 5 show the illustration of RHCP antenna design where the strip line dimension is same with the previous design (Design A) but shifted to the left side.

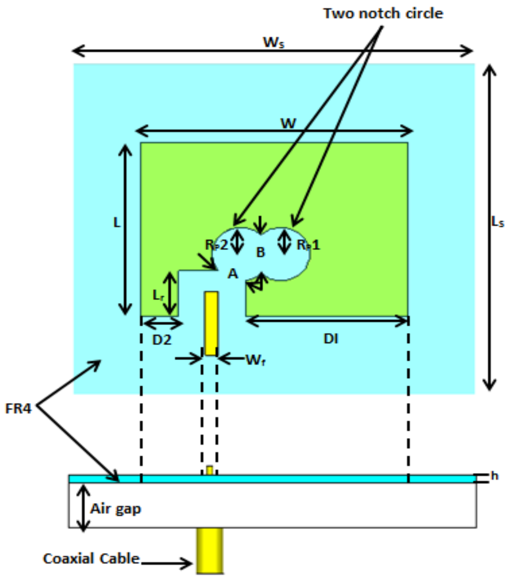


Figure 5 Configuration of L-probe right-handed circular polarized (RHCP) rectangular MSA with dual notch in vertical view

2.3 Design C – LHCP Antenna

The differences between RHCP and LHCP are the position of the rectangular notch and the coaxial feed, while the strip line dimension remain the same with the previous design but shifted to the right side. By moving the feeding position to the right will obtain left-handed circular polarized. Figure 6 show the illustration of the LHCP antenna design.

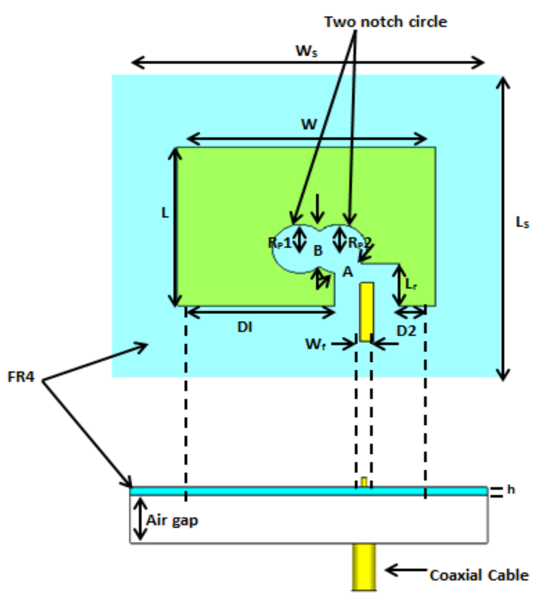
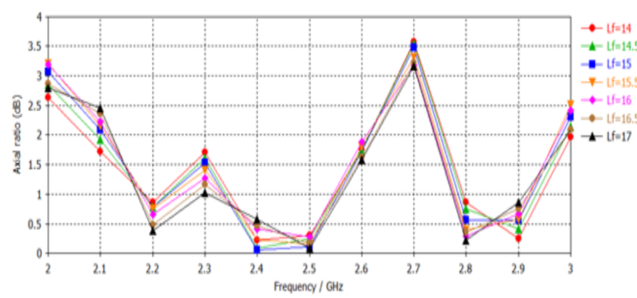


Figure 6 Configuration of L-probe Left-handed circular polarized (LHCP) rectangular MSA with dual notch in vertical view

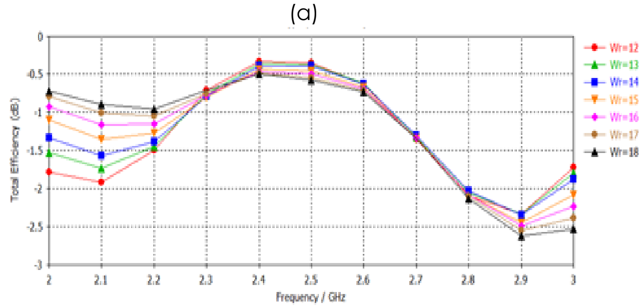
Table 2 Antenna design parameter for circular polarization

Design Parameter	Dimension (mm)	Description
g	10	Air gap
h	1.6	Thickness of substrate
A	14	Rectangular slot
B	2.2	Circular notch
L	42	Length of patch
L_f	15.5	Length of feed
L_r	11	Length of rectangular notch
L_s	80	Length substrate
R_p1	6.5	Radius of circular notch 1
R_p2	6.5	Radius of circular notch 2
W	60	Width of patch
W_f	3	Width of feed
W_r	15	Width of rectangular notch
W_s	90	Width of substrate
D1	36.5	Long side length
D2	8.5	Short side length

Figure 7 shows the result performance for circular polarized antenna. One of the parametric studies that include in this design process is length of feed, L_f which it can see the value have been chosen will give the effect to the axial ratio.



(a)



(b)

Figure 7 Antenna performance for circular polarized antenna with the variation length of feed, L_f (a) Axial ratio and width of rectangular notch, W_r (b) Total efficiency

As mention earlier, to make sure the polarization operate correctly in circular, this parametric study on length of feed is used to get the design requirement on axial ratio for circular polarization which needs to meet below 3 dB at resonant frequency. Parametric study on width of rectangular notch is to get the better total efficiency. Total efficiency must be more than -3 dB in order to get more than 50% antenna efficiency.

3.0 RESULTS AND DISCUSSION

This session will discuss the antenna parameters which included resonant frequency (*fr*), return loss (*RL*), bandwidth (*BW*), gain, directivity, total efficiency, axial ratio, surface current and radiation pattern of the linear polarization, RHCP and LHCP antenna. The effects on the antenna performance will be investigated for Design *A* - linear polarization and following by circular polarization which divided into two that is Design *B* - RHCP and Design *C* - LHCP. Simulation and measurement results for the proposed antenna are discussed.

3.1 Design A – Linear Polarized Antenna

Figure 8 show the side views of fabricated antenna for the Design A. Based on analysis in simulation, it is found that in Design A the length and width of rectangular slot need to be optimized in order to achieve the requirement response for linear polarization.

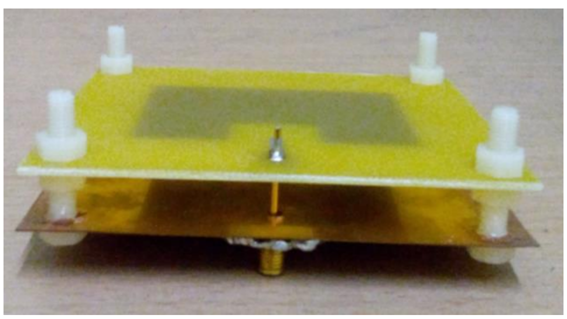


Figure 8 Antenna Design *A* side view

Figure 9 shows the simulated and measured return loss for Design A which is -19.849 dB at resonant frequency at 2.4 GHz and -25.685 dB at resonant frequency at 2.38 GHz respectively. The simulated and measured bandwidth is 443 MHz and 511 MHz respectively.

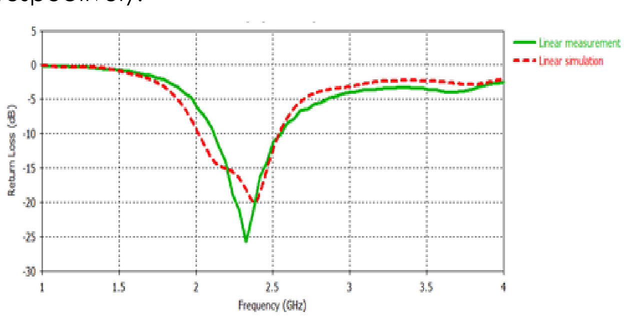


Figure 9 Return loss over frequencies of linear polarized antenna (Design *A*) – simulation vs. measurement

Polarization of the antenna can be determined based on the axial ratio. The axial ratio for antenna can be analyzed from the simulation result, where the axial ratio for linear polarized antenna is above 3 dB. Based on the simulation result, the axial ratio for Design *A* at 2.4 GHz is more than 3 dB. Design *A* axial ratio is 3.027395 dB which achieved specification for linear polarized as shown in Figure 10.

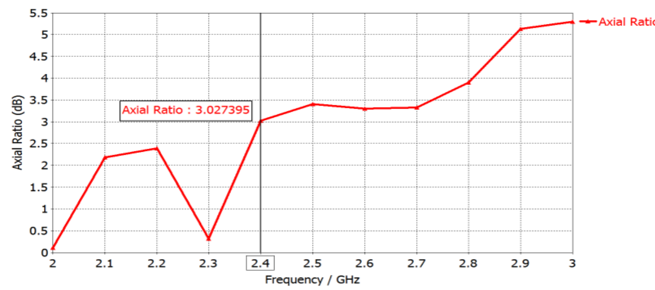
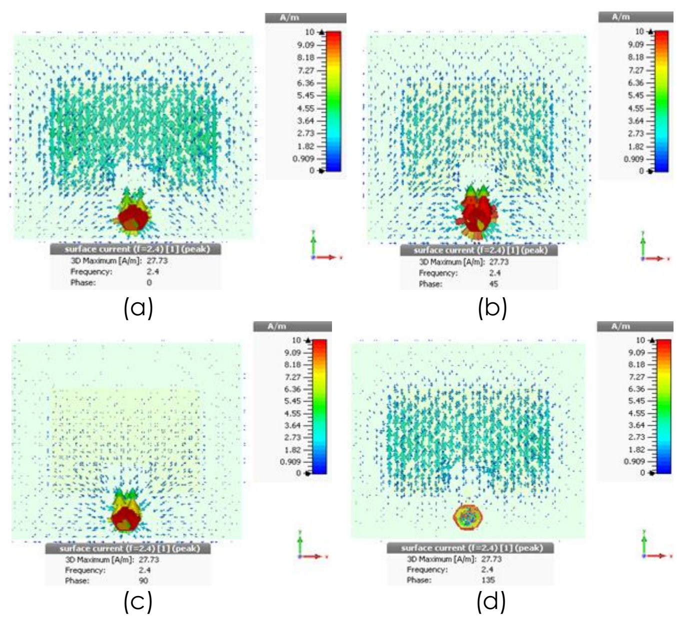
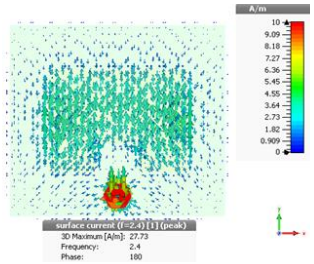


Figure 10 Axial ratio over frequencies of linear polarized antenna (Design *A*)

Besides, the types of polarization also can be determined based on the rotation of surface current which are analyzed from the CST software. When the arrows of surface current are changed alternately, this means that the antenna is performed as linear polarized. Figure 11 show the surface current at frequency 2.4 GHz for linear polarization with rectangular slot at 0 degree, 45 degree, 90 degree, 135 degree and 180 degree. The surface current for this design is strong at the feed of the antenna.

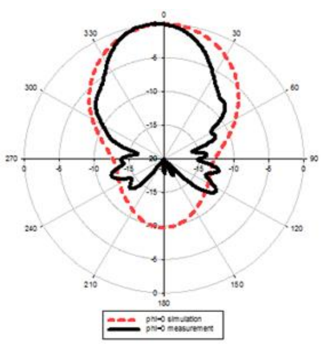




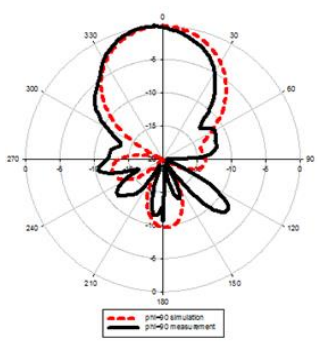
(e)

Figure 11 Surface current for linear polarized antenna (Design *A*) - (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°

The radiation pattern of antenna is determined in far field region. The radiation pattern between simulated and measured at a frequency 2.4 GHz when phi = 0°, phi = 90° and theta = 90° for linear polarization has been shown in Figure 12 below. Design *A* consists two side lobe and minor lobe for measured and major lobe for both measured and simulation at phi = 0°. For phi = 90°, simulated have one major lobe and back lobe while measured consists five minor lobe. Besides that, theta = 90° consist four back lobe and two major lobe. The radiation pattern for the linear polarized that is obtained from the measurement result is almost similar with the simulation result. Table 3 shows the result of gain, directivity and total efficiency of Design *A*.



(a)



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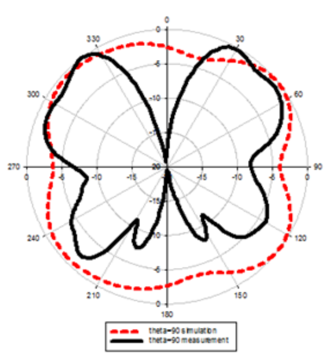


(c)

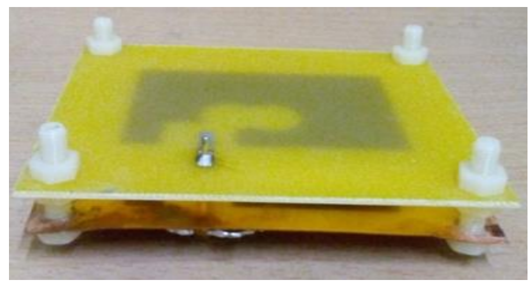
Figure 12 Radiation pattern of linear polarized antenna (Design *A*) at 2.4 GHz for (a) Phi = 0° (b) Phi = 90° and (c) Theta = 90°

Table 3 Result of gain, directivity and total efficiency for linear polarized antenna (Design *A*)

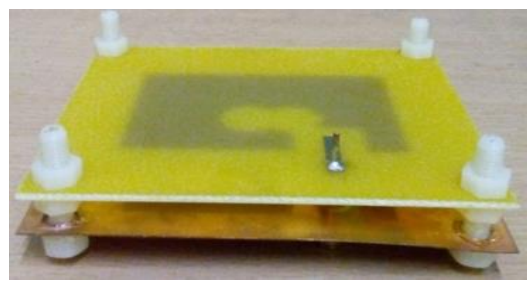
	Gain	Directivity	Total Efficiency
Simulation	7.9029 dB	8.333 dBi	-0.4306 dB
Measuremet	-15.931 dB	-	-

3.2 Design B and Design C – RHCP and LHCP Antenna

Figure 13 shows the fabricated circular polarized antenna design for RHCP (Design B) and LHCP (Design C) side view. Based on simulation, the radius of the notch circle and width of rectangular slot for Design B and Design C need to be optimized in order to achieve the requirement response for circular polarization.



(a)



(b)

Figure 13 Fabricated of circular polarized antenna (a) RHCP (Design *B*) and (b) LHCP (Design *C*) side view

Figure 14 shows the simulated and measured return loss for Design B is -17.228 dB at resonant frequency at 2.41 GHz and -13.21 dB at resonant frequency at 2.18 GHz respectively while for Design C are -14.86 dB at resonant frequency 2.43 GHz and -22.56 dB at resonant frequency at 2.18 GHz respectively. The simulated and measured bandwidth for both designs is more than 200 MHz.

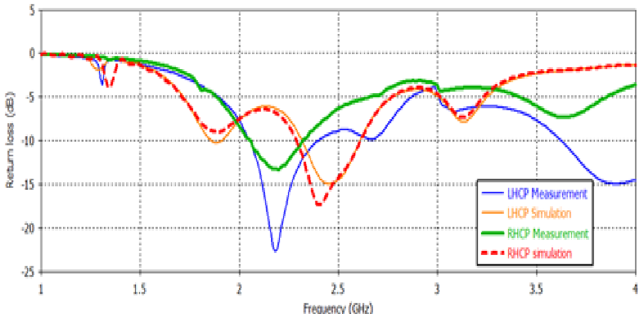


Figure 14 Return loss over frequencies of circular polarized antenna – RHCP (Design *B*) and LHCP (Design *C*) – simulation vs. measurement

Polarization of the antenna can be determined based on the axial ratio of the antenna which can be analyzed from the simulation result. The axial ratio for circular polarized antenna is below 3 dB. If the axial ratio of the antenna is below 3 dB, this indicated the antenna is performed in circular polarization. Based on the simulation result, the axial ratio for Design *B* and Design *C* are almost the same which is 0.2347 dB and 0.2345 dB respectively that achieved specification for circular polarized as shown in Figure 15.

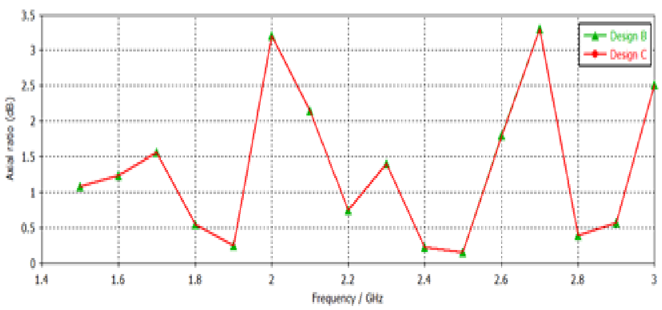


Figure 15 Simulation result for axial ratio over frequencies of circular polarized antenna Design *B* and Design *C*

Rotation of surface current which can be analyzed from the CST software also can determined either the antenna perform as RHCP or LHCP. The antenna is performed as right-handed circular polarized (RHCP) if the arrows of the surface current are rotated in clockwise. Then, if the arrows of the surface current are rotated in counter-clockwise, this indicated that the antenna is performed as left-handed circular polarized (LHCP). Figure 16 and Figure 17 shows the surface current at frequency 2.4 GHz for the RHCP and LHCP with rectangular slot connecting with dual circular notch antenna design at 0 degree, 45 degree, 90 degree, 135 degree and 180 degree.

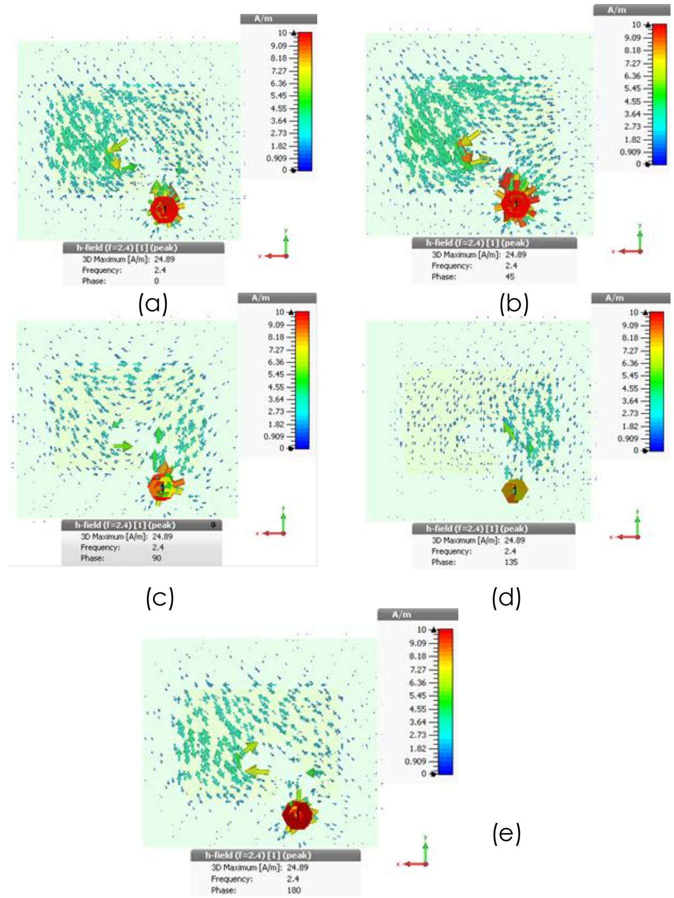
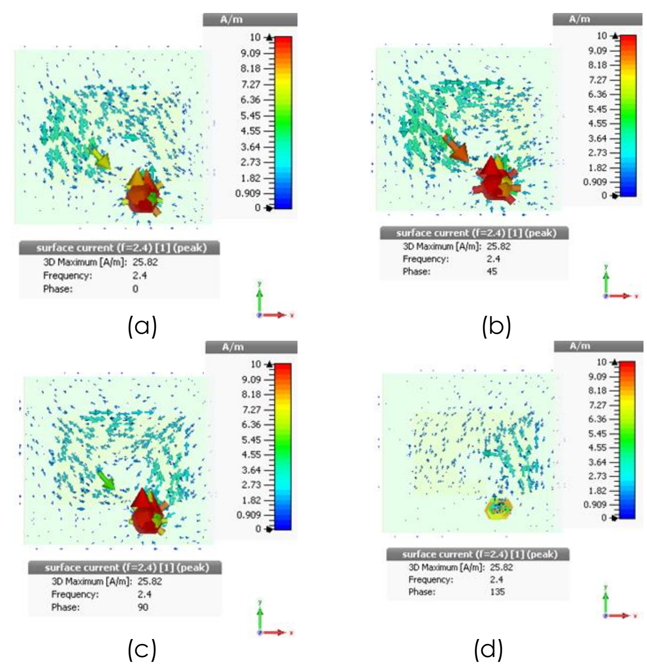
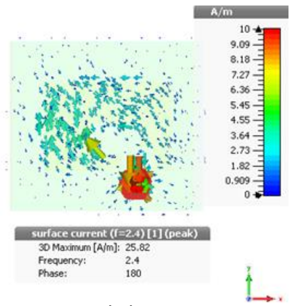


Figure 16 Surface current for RHCP antenna (Design *B*) - (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°

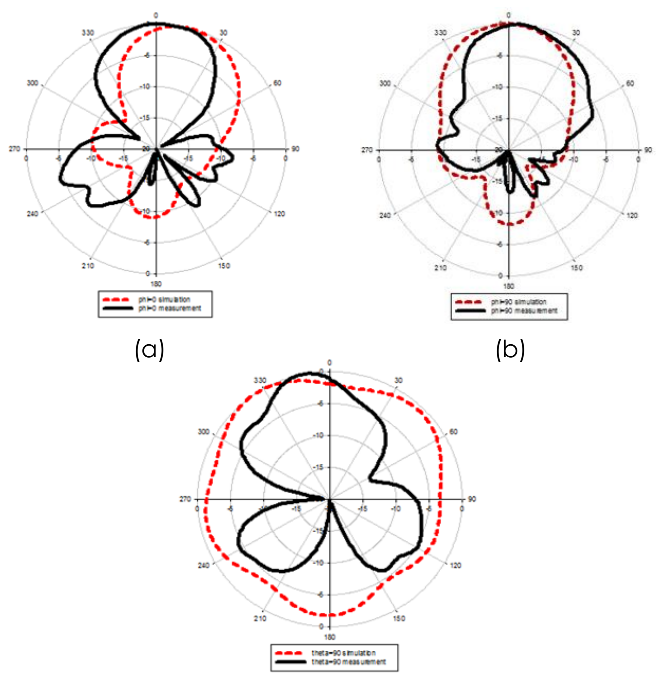




(e)

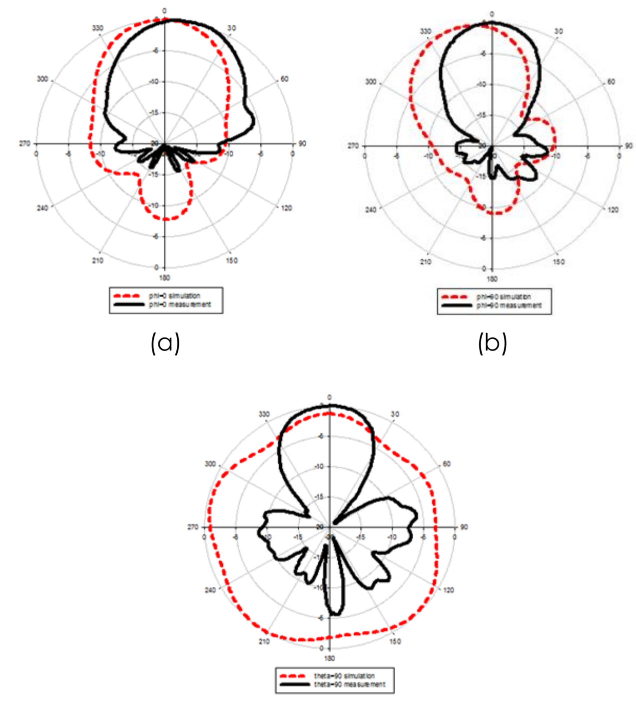
Figure 17 Surface current for LHCP antenna (Design *C*) - (a) 0° (b) 45° (c) 90° (d) 135° (e) 180°

The radiation pattern of antenna is determined in far field region. The radiation pattern between simulated and measured at a frequency 2.4 GHz when phi = 0°, phi = 90° and theta = 90° for RHCP and LHCP has been shown in Figure 18 and Figure 19 below. Based on Figure 18 and Figure 19, result of simulation at phi = 0 degree and phi = 90 degree are quite similar with the measured. While for the result of radiation pattern when theta = 90 degree, it shows that simulation resulted an omnidirectional radiation pattern for both design and its radiation pattern is differ from measured result. Table 4 shows the result of gain, directivity and total efficiency of Design *B* and Design *C*.



(a) (b) (c)

Figure 18 Radiation pattern of RHCP antenna (Design *B*) at 2.4 GHz for (a) Phi = 0° (b) Phi = 90° and (c) Theta = 90°



(a) (b) (c)

Figure 19 Radiation pattern of LHCP antenna (Design *C*) at 2.4 GHz for (a) Phi = 0° (b) Phi = 90° and (c) Theta = 90°

Table 4 Result of gain, directivity and total efficiency for RHCP antenna (Design *B*) and LHCP antenna (Design *C*)

Antenna	Parameter	Gain (dB)	Directivity (dBi)	Total efficiency (dB)
RHCP	simulation	7.8731	8.278	-0.4055
	measurement	9.1594	-	-
LHCP	simulation	7.856	8.261	-0.4056
	measurement	10.798	-	-

4.0 CONCLUSION

In this paper, single feed circular polarized antenna operating at frequency of 2.4 GHz for WLAN application is design based on the basic structure of linear polarized antenna (Design *A*) with rectangular patch embedded with rectangular slot. Optimum performance of linear polarized antenna is achieved when the inverted rectangular patch is separated by an air gap with thickness of 10 mm from the copper ground plane. From observation, axial ratio above 3 dB is achieved when the length of inverted patch, *L* is increased to 43 mm and better gain is achieved when the length of rectangular slot, *Y* increased to 16 mm. To achieve circular polarized based on basic structure of linear polarized design, dual circular notch with the same radius are connecting to the rectangular slot which then generate RHCP (Design *B*) and LHCP ((Design *C*). Parametric study on length of feed is used to get the design requirement on axial ratio for circular polarization which needs to meet below 3 dB at resonant frequency. Parametric study on width of rectangular notch is to get the better total efficiency which is must be more than -3 dB in order to get more than 50% antenna efficiency. The axial ratio for the RHCP and LHCP antenna that are analyzed from the simulation results are almost the same which is 0.2347 dB and 0.2345 dB respectively. The simulation and measurement results meet the requirement of both linear and circular polarized antenna for WLAN in the practical application for enhancement in performance.

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