Polarization Reconfigurable Cross-Slots Circular Patch Antenna

M. N. Osman, M. K. A. Rahim, M. F. M. Yussof, M. R. Hamid, H. A. Majid

Communication Engineering Department, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

nasrun_osman@yahoo.com, mkamal@fke.utm.my, fairus@fke.utm.my, rijal@fke.utm.my, huda_set@yahoo.com

Abstract—In this paper, an antenna with polarization reconfigurability is presented. The antenna consists of a two cross-slots diagonally positioned in the centre of a circular patch antenna. Two pair of switches are placed in the slots and by controlling the length of the slots, three different polarizations can be reconfigured. The proposed antenna is capable to reconfigure between linear polarization (LP), right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP). The linear polarization is achieved when the lengths of both slots are equal and the circular polarization type is obtained due to the inequality of the slot length. Details of the design and simulation results are discussed. This reconfigurable antenna with polarization diversity can be used for wireless local area network (WLAN) application.

Index terms—polarization reconfigurable, patch antenna, cross-slot

I. INTRODUCTION

Reconfigurable antennas plays an important role towards smart, cognitive and modern wireless communication systems. Recently, polarization diversity antenna has received a significant attention due to its ability to reduce the multipath fading, realizing frequency reuse and immunity to interference signals. Apart from that, this type of reconfigurability are capable to improve the gains offered by multiple-input multiple-output (MIMO) systems hence provide better channel reliability and capacity [1,2]. To design an antenna with polarization reconfigurability, the antenna structure, material properties, or feed configurations have to be modified to alter the current flows of the antenna.

Several antennas with polarization reconfigurations have been proposed in the literature. The polarization diversity was successfully achieved through the modification to the feeding network [3,4]. In [5], a compact polarization reconfigurable antenna is proposed by switching transition between coplanar waveguide mode and slot line mode to achieve both orthogonal linear polarizations.

Single-fed patch antenna with polarization reconfigurable is designed by using perturbation method such as introduction of loop slots in the ground plane [6,7]. For reconfigurability, the slots are connected through p-i-n diodes, which act as a switch. Another solution proposed is based on the establishment of the slots on the patch itself [8-10]. By using this method, the slot dimension is manipulated to obtain the desired polarization mode.

This paper proposed an antenna with polarization reconfigurability based on the use of circular patch with two crossing diagonally slots. Two pair of switches are used to control the slot length. Consequently, depending on the switch configuration the antenna can excited with RHCP, LHCP and LP polarization mode. The simulated results are presented and key parameters for the proposed antenna are investigated. In this study, copper strips are used as switches for proof of concept.

II. ANTENNA STRUCTURE AND APPROACH

In this section, the structure of the proposed antenna is described. Figure 1 shows the geometry of the proposed antenna. A circular patch, having a radius r, is designed on the top layer of the substrate and finite ground plane on the bottom layer. A dielectric used in the design is Taconic RF35 with thickness, h of 1.52 mm, permittivity of 3.54 and tangent loss of 0.0018. The antenna is excited with a coaxial feed with a distance of d from the center of circular patch and incorporating at 45° to the two arms of the cross slots. Two slots, having a width of $w1$, is located diagonally cross on the same layer of circular patch. Four copper strips, which act as diode, are located at specific position to control the length of the slot in order to achieve polarization reconfigurability. The presence of the copper strips means the state of diode is ON while represent OFF with the absence of copper strips.

Due to the existence of slots, the equivalent excited patch surface current path along the direction perpendicular to the narrow slot is lengthened while on the parallel to the slot orientation is only have slightly affected. Hence, by further selecting the proper slot length difference and suitable position for feeding, the two near-degenerate orthogonal resonant modes can have equal amplitudes and 90 degree out of phase, and CP operation can thus be obtained. Alternatively, when the length of the both slot arms are equal, there is no phase difference between modes and therefore the antenna will excite LP operation.
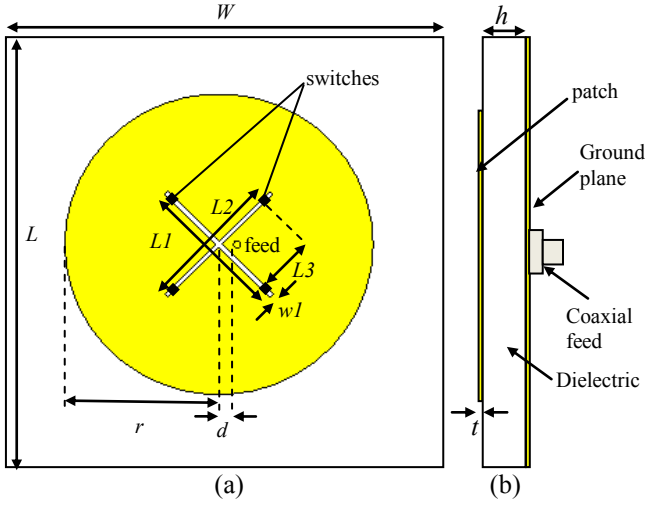
Figure 1: Geometry of the proposed antenna (a) front view and (b) side view

(a)

(b)

Figure 2: Effect of the slot length, L1 (mm) to the ;(a) S11 (dB) and ;(b) AR (dB)
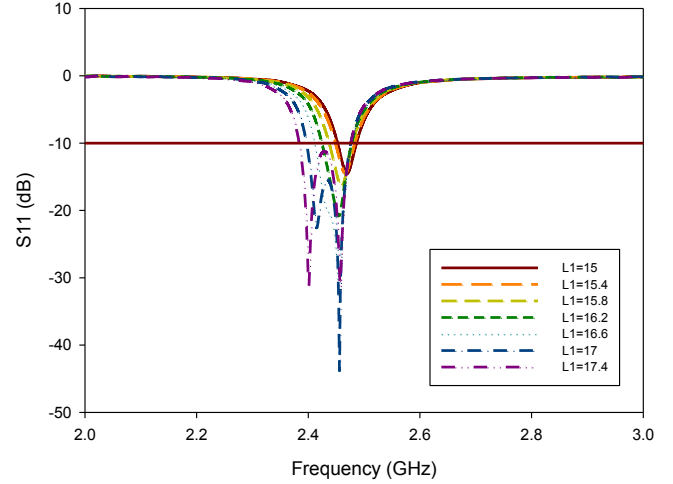
III. STUDIES OF KEY PARAMETERS

The effect of slot length towards the result of return loss and axial ratio are investigated. In this analysis, one of the slot length, *L1* is varied from 15 mm to 17.4 mm while the other slot length, *L2* is remained at 15 mm. The effects are shown in Figure 2. It shows that by lengthening the slot, the return loss is improved and produces wider bandwidth as shown in Figure 2(a). At certain length, two resonant frequencies are obtained due to the two unequal slot lengths.

Meanwhile, in Figure 2(b), it is found that the slot length greatly influence the CP characteristics. When the lengths of both slots are equal, which means the length different is zero, the axial ratio is at constant value and the antenna is excited with horizontal LP. However, as the length difference is varied from zero to 2.4 mm, the polarization is changed from LP to elliptic polarization. The axial ratio decreases as *L1* increases. At the specific slot length, starting from 16.2 mm, the axial ratio value is dropped to below than 3 dB, which proved that the CP is excited. The range of slot length between 16.2 mm to 17mm is where the antenna is excited with two-orthogonal equal magnitude modes with 90 degree out of phase. The polarization is switched again to the elliptic polarization (AR > 3 dB) when the slot length *L2* is greater than 17 mm.
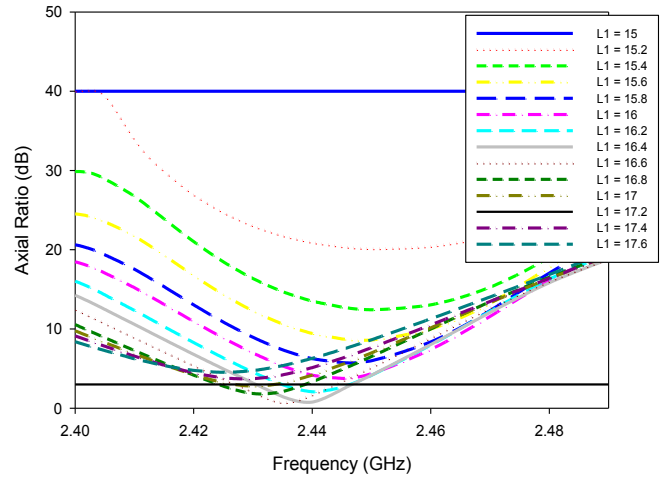
The parameter *r,* influencing the operating frequency and the distance *d* is optimized to obtain a good impedance matching. The optimized values for the parameters are given in Table I. The dimension of the copper switches used in the design is 0.5 mm x 0.5 mm.

TABLE I
DIMENSIONS OF THE PROPOSED ANTENNA

Parameters	*L*	*W*	*L1*	*L2*	*L3*
Value (mm)	55	55	16.4	16.4	15
Parameters	*r*	*D*	*w1*	*h*	*t*
Value (mm)	17	2	0.5	1.52	0.035

IV. SIMULATION RESULTS AND DISCUSSION

Two pair of switches is used to control the length of the slots. Pair 1, consist of switch 1 (S1) and switch 2 (S2) are for *L1* meanwhile pair 2 which is a combination of switch 3 (S3) and switch 4 (S4) are for *L2*. By changing the state of the switch, either ON or OFF, consequently the polarization of the antenna can be changed. When slot length *L1* is less than *L2*, RHCP mode is achieved while in contrast it, LHCP mode is excited when *L1* is greater than *L2*. When both slot lengths are equal, horizontal LP is excited. There are four configurations involved; S1&S2 is ON and S3&S4 is OFF; S1&S2 is OFF and S3&S4 is ON; all switches are ON, and; all switches are OFF.
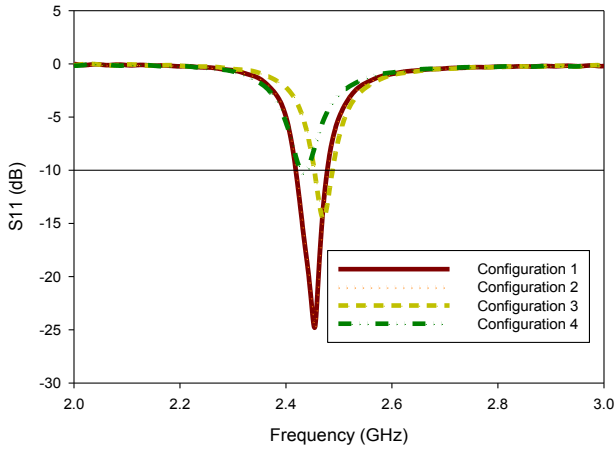
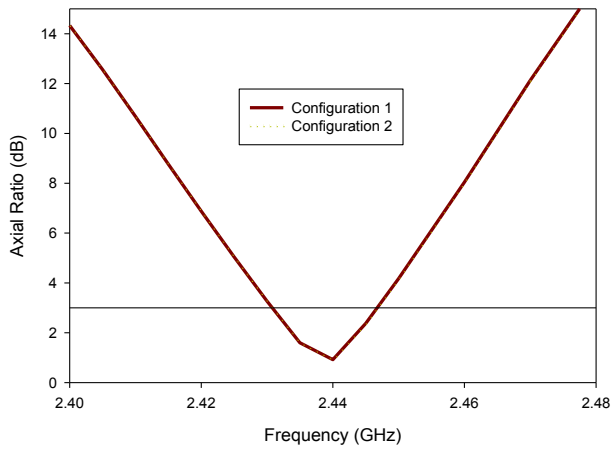Figure 3: Simulated return loss, S11 (dB) for all switch configurations

Figure 4: Simulated axial ratio (dB) for CP

Figure 5: Electric field distribution on the patch for configuration 1 at 2.44 GHz (a) 0°; (b) 90°; (c) 180° ; (d) 270°

Figure 6: Simulated radiation patterns for E-plane and H-plane for all switch configurations at resonant frequency
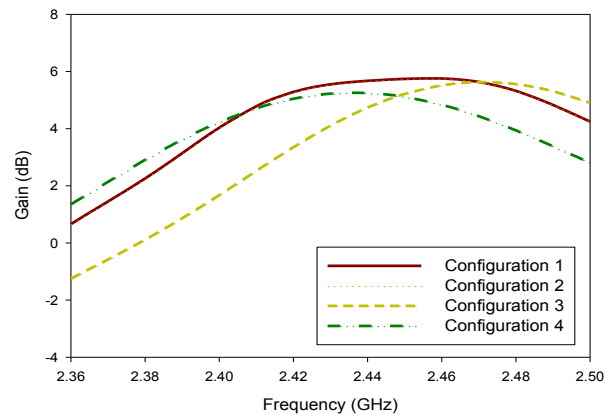
Figure 7: Simulated gain over frequency for all switch configurations

The simulated S-parameters for all configurations are shown in Figure 3. The simulated 10-dB return loss impedance bandwidth, are from 2.418 to 2.478 GHz, 2.454 to 2.488 GHz, and 2.427 to 2.440 GHz for both type of CP (configuration 1 and configuration 2), configuration 3 and configuration 4, respectively. The percentage of bandwidth for CP is 2.4% (60 MHz) with respect to the center frequency of 2.454 GHz. The bandwidth of the proposed antenna is narrow due to the characteristics of the patch antenna itself.

For antenna configuration 3 and configuration 4, it excites with LP. However, the resonant frequency is different as the length of the slots give an effect to the resonating frequency. Lengthened the slot length will decreased the center frequency. Hence, the presence of the copper strips will radiate at higher frequency compare to when all switches are at OFF state.

Figure 4 presents the axial ratio against frequency graph for the CP modes. The axial ratio value for LP is constant for any frequency. The antenna excites with CP mode between frequency range of 2.431 GHz to 2.447 GHz, which is about
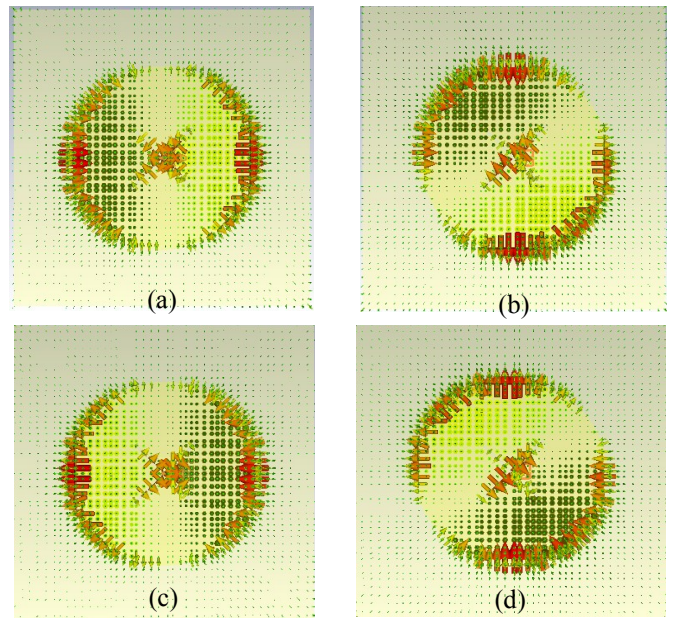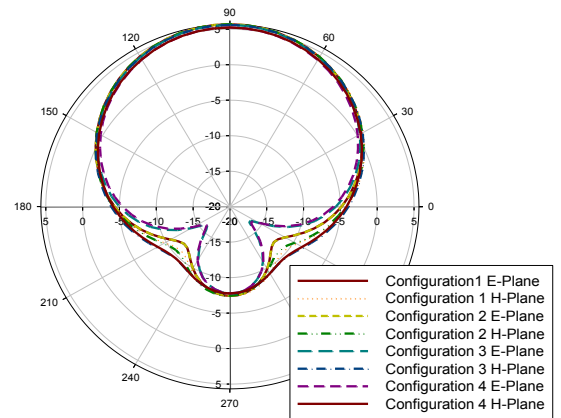
TABLE II
SIMULATION RESULTS OF THE PROPOSED ANTENNA

Configuration	Switch state				Polar Type	F_r (GHz)	S11 (dB)	Bandwidth (GHz)		AR Bandwidth (GHz)		Gain (dB)
	S1	S2	S3	S4				f_L	f_H	f_L	f_H	
Configuration 1	ON	ON	OFF	OFF	RHCP	2.454	-24.812	2.418	2.478	2.431	2.447	5.7
Configuration 2	OFF	OFF	ON	ON	LHCP	2.454	-24.812	2.418	2.478	2.431	2.447	5.7
Configuration 3	ON	ON	ON	ON	LP	2.471	-14.554	2.454	2.488	NA		5.6
Configuration 4	OFF	OFF	OFF	OFF	LP	2.434	-10.360	2.427	2.440	NA		5.2

16 MHz of 3-dB bandwidth. The percentage of bandwidth for CP is 0.7% with respect to the center frequency 2.471 GHz when $L1$ = 16.4 mm.

The return loss and axial ratio for both RHCP and LHCP give similar results. The different is on how the electric field flow on the patch antenna, either on clockwise or anticlockwise rotation. Figure 5 shows the electric field distribution on the radiating patch at different phase for RHCP which illustrates the rotation of an electric field with right-hand circular path.

The simulated radiation pattern for E-plane and H-plane are plotted in Figure 6. The gain obtained at the resonant frequency for CP is 5.7 dB whilst 5.6 dB and 5.2 dB for antenna configuration 3 and configuration 4 respectively. The variation value of gain over frequency is shown in Figure 7. Good broadside radiation patterns with 3-dB beamwidths with more than 90° are observed for all configurations. The summary for the simulated results are tabulated in Table II.

V. CONCLUSIONS AND FUTURE WORK

A cross-slots microstrip patch antenna with polarization reconfigurability has been presented in this paper. From the simulation results, it shows that the polarization reconfigurability can be obtained by controlling the length of the slots. To achieve this, four switches are used to enable the antenna to radiate between LP, RHCP and LHCP. The simulated bandwidth extends from 2.418 to 2.478 GHz for CP. Bandwidth for LP is 34 MHz and 13 MHz for antenna configuration 3 and configuration 4 respectively. An axial ratio bandwidth of 16 MHz is achieved for CP mode. Throughout the simulation process, copper strip is used to represent switch. In future, the proposed antenna will be fabricated and PIN diodes will be used as switches to replace the copper strips. This proposed antenna can support various applications in WLAN systems.

REFERENCES

[1] D. Piazza et al., "Design and evaluation of a reconfigurable antenna array for MIMO systems", *IEEE Transactions on Antenna and Propagation*, vol. 56, pp. 869-879, March 2008.

[2] D. Piazza, P. Mookiah, M. D'Amico, and K.R. Dandekar, "Pattern and polarization reconfigurable circular patch for MIMO systems", *European Conference on Antenna and Propagation*, pp. 1047-1051, March 2009.

[3] W. Cao et al., "A reconfigurable microstrip antenna with radiation pattern selectivity and polarization diversity", *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 453-456, 2012.

[4] S.-Y. Lin, Y.-C. Lin, C.-Y. Li, and Y.-M. Lee, "Patch antenna with reconfigurable polarization", *Asia Pacific Microwave Conference Proceedings*, pp. 634-637, 2011.

[5] Y. Li, Z. Zhang, W. Chen, and Z. Feng, "Polarization reconfigurable slot antenna with a novel compact CPW-to-slotline transition for WLAN application", *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 252-255, 2010.

[6] R.-H. Chen and J.-S. Row,"Single-fed microstrip patch antenna with switchable polarization", *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 4, pp. 922-926, April 2008.

[7] Yang, B. Shao, F. Yang, A. Elsherbeni and B. Gong, "A Polarization Reconfigurable Patch Antenna with Loop Slots on the Ground Plane," IEEE *Antennas and Wireless Propagation Letters*, vol. 11, pp. 69-72, Jan 2012.

[8] C.-C. Wang, L.-T. Chen, and J.-S. Row, "Reconfigurable slot antennas with circular polarization", *Progress In Electromagnetics Research Letters*, vol. 34, pp. 101-110, 2012.

[9] E. A. Soliman, W. D. Raedt, and G. A. E. Vandenbosch, "Reconfigurable slot antenna for polarization diversity", *Journal of Electromagnetic Waves and Application*, vol. 23, pp. 905-916, 2009.

[10] B. Kim, B. Pan, S. Nikolaou, Y.-S. Kim, J. Papapolymerou and M.M. Tentzeris, "A novel single-feed circular microstrip antenna with reconfigurable polarization capability", *IEEE Trasactions on Antennas and Propagation*, vol. 56, No. 3, pp. 630-638, March 2008.