Broadband Right-Handed Circular Polarized (RHCP) Antenna with Loop Metasurfaces

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***Abstract*—In this paper, an analysis of different designs of metasurface (MS) structure of the circular polarized antenna was proposed to analyse its effects towards the antenna performance. Firstly, the antenna was designed based on an inverted suspended rectangular slot at the rectangular patch and air gap between the substrate and copper layer with a distance of 10 mm. Then, as a way to create the circular polarization, the designed antenna is added with an optimized dual circular notch at the rectangular slot. This circular polarized antenna design is a right-handed circular polarization (RHCP) with optimized rectangular slot and dual circular notch at the patch. Then, the RHCP antenna is combined with the MS design which is integrated at the copper ground layer of the antenna. The L-probe technique is used in this antenna design and the signal into the antenna structure is fed by the 50Ω probe feed SMA connector. Computer Simulation Technology (CST) Microwave Studio Suite software is used as the simulation tool for the designed proposed antenna. The result of performance in terms of return loss, bandwidth, gain, directivity, axial ratio and total efficiency for the proposed antenna at the design frequency are analysed. Comparison results of simulation show that the proposed RHCP antenna with and without MS can achieve an axial ratio below 3 dB with return loss less than -10 dB at the targeted frequency. The target application for this antenna design is the Wireless Local Area Network (WLAN) which operates at 2.4 GHz frequency.**

***Index Terms*—Antenna; Metasurface; Axial Ratio; Right-Handed Circular Polarized.**

I. INTRODUCTION

The microstrip patch antennas are one of the most well-known kinds of antennas in the microwave frequency range as well as in the millimetre-wave frequency range [1]. Microstrip patch antenna could be in a lot of various shapes such as circular, rectangular, elliptical and triangular. The basic and most commonly used microstrip antenna is the rectangular patch antenna due to its advantages which are ease of fabrication, low profile and cost and also lightweight [2].

The polarization of an antenna may be categorized into linear polarization (LP), elliptical polarization (EP) and circular polarization (CP). In a circular polarized antenna, the plane of polarization rotates in a circle making one complete revolution during one period of the wave. A circular polarized wave radiates energy in both the horizontal and vertical planes and all planes in between. In order to determine circular polarization, the axial ratio must below than 3 dB [3]. The circular polarized antenna can be achieved by using truncated corner [2], slot [4] and double layer [4]. For this work, the configuration of the rectangular slot with a dual circular notch was suggested for the right-handed circular polarization antenna design.

Metasurface (MS) is a two-dimensional metamaterial design which has been getting attention from researchers for the past several years. With the advantages of low cost and succinct planar structure, metasurface offers a great number of potential applications in electromagnetics, one of which is the design of planar antennas with better performances [5-7]. Some well-known application examples are the improve performance of patch antennas [8]. In [8], the metasurface was proposed for the linear and circular polarized antennas where simultaneous enhancement performances such as the gain, antenna efficiency and bandwidth for both the linear and circular polarized antenna were obtained after adding the metasurface atop the source patch.

In this work, an analysis of a wideband right-handed circular polarized antenna backed by different metasurface design was presented. The wideband RHCP radiation was gained by the separation of the air gap between the substrate and copper ground plane. The proposed antenna was designed with the help of the CST Microwave Studio. The analysis of different designs of RHCP metasurface antenna such as the axial-ratio bandwidth (ARBW), realized gain, directivity, total efficiency and return-loss bandwidth (RLBW) are discussed.

II. ANTENNA DESIGN

On this study, the antenna was designed using an FR4 board with dielectric constant, εr of the substrate was 4.4, tangent loss, tan δ 0.019, substrate thickness h, 1.6 mm and copper thickness, t was 0.035 mm. In order to represent as L-probe feed, the antenna was feed with the coaxial probe to the strip line. The L-probe was designed on the upper substrate, while the rectangular microstrip patch antenna was designed on the bottom substrate. The antenna design and its ground were separated by an air gap and metasurface design.

This work consists of two stages of the antenna design; first is to design and optimize the RHCP antenna first and next to add the different designs of metasurface (MS) (Designs A, B, C, and D). Design A is a circle loop, Design B square loop, Design C horizontal rectangular loop and Design D vertical rectangular loop. The configuration of the RHCP and RHCP with MS antenna design is demonstrated in Figures 1, 2 and 3.

A. Right-Handed Circular Polarized (RHCP) Antenna

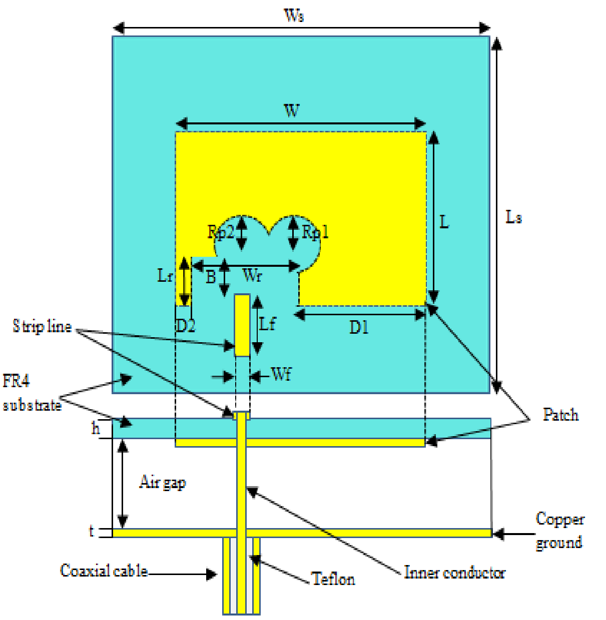

Figure 1: Configuration of L-probe right-handed circular polarized (RHCP) rectangular MSA with dual notch in vertical view

B. Right-Handed Circular Polarized (RHCP) Antenna with Metasurface (MS) Design

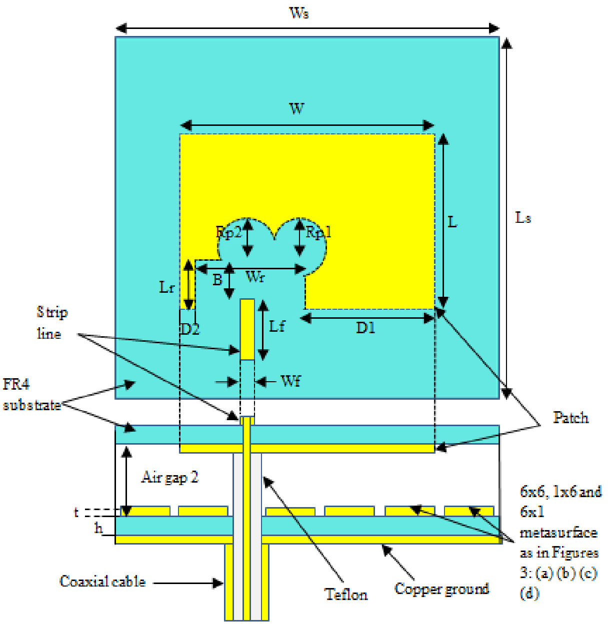

Figure 2: Configuration of L-probe right-handed circular polarized (RHCP) rectangular MSA with dual notch and metasurface in vertical view

C. Metasurface Design

The length and width of the substrate are indicated as *Ls* and *Ws*, whereas *L* and *W* are used for the inverted rectangular patch. The specification of the metasurface substrate, feedline and inverted rectangular patch of each antenna is similar to the RHCP antenna design. The size of different shapes for the designs of MS was decided according to the parametric study. The ideal specifications for both antennas with and without MS are tabulated in Table 1.

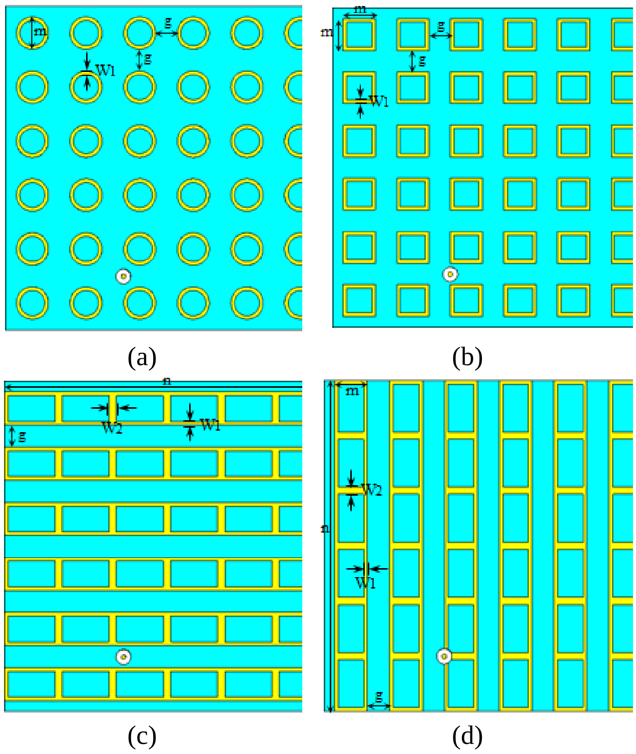

Figure 3: Type of loop metasurface design (a) 6x6 circle loop (Design A) (b) 6x6 square loop (Design B) (c) 1x6 combine horizontal rectangular loop (Design C) (d) 6x1 combine vertical rectangular loop (Design D)

Table 1
Antenna Design Parameter

Design Parameter	Dimension (mm)	Description
Air gap	10	Air gap
Air gap 2	8.4	Air gap
h	1.6	Thickness of substrate
t	0.035	Thickness of copper
B	8.5	Feed from slot
L	40	Length of patch
L_f	15.5	Length of feed
L_r	11	Length of rectangular notch
L_s	90	Length substrate
R_p1	6.5	Radius of circular notch 1
R_p2	6.5	Radius of circular notch 2
W	56	Width of patch
W_f	3	Width of feed
W_r	25	Width of rectangular slot
W_s	90	Width of substrate
D1	27.5	Long side length
D2	3.5	Short side length
m	9	Width of metasurface
n	90	Length of metasurface
g	6	Gap between metasurface
W1	1	Width of loop
W2	2	Width of combine loop

III. RESULT

This section discusses the antenna parameters which include the axial ratio (AR), directivity, realized gain, return loss (RL), resonant frequency (fr), total efficiency and bandwidth of the antenna. The effects of Designs A, B, C, and D, and Basic design on the RHCP antenna performance were investigated. The comparison of the simulation result of the different shapes of the MS design are illustrated in Figures 4, 5, 6, 7, and 8.

A. Axial ratio (AR)

In Figure 4, the polarization for the antenna may be identified according to the axial ratio analysed by the CST software. The axial ratio of CP must below 3dB. The comparison of the axial ratio for RHCP antenna with and without MS is illustrated in Figure 4. For the Basic design, the axial ratio 3dB bandwidth for RHCP was 1711MHz. Meanwhile, for Designs A, B, C, and D, the axial ratio 3dB bandwidth was 2186MHz, 2170MHz, 2160MHz, and 2076MHz, respectively, wider than the bandwidth of the RHCP design without MS. At 2.4GHz, the axial ratio for Basic design was 0.27dB; Design A 0.23dB; Design B 0.40dB; Design C 1.08dB and Design D 0.16dB. It was indicated that although the RHCP Basic design was integrated with MS, all of the designs were still operated and presented in circular polarization at 2.4GHz. Design D gave the best axial ratio which was close to 0dB.

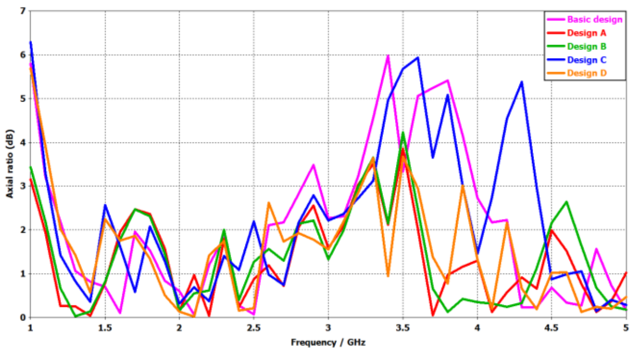

Figure 4: Comparison of simulated axial ratio for RHCP antenna without and with different MS design – simulation

B. Directivity (Dir.), Realized Gain (gain), Total Efficiency (effc.)

Figure 5 illustrates the simulation view for the graph of directivity over frequency. Based on the simulation results, the directivity for all of the antenna designs at 2.4GHz with and without MS was almost similar. The directivity of the Basic design and Designs A, B, C, and D was 8.51dBi, 8.15dBi, 8.02dBi, 8.29dBi, and 8.24dBi, respectively. The directivity of the RHCP antenna design with MS slightly decreased but overall was still above 8dB.

Based on Figure 6, the gain of the Basic antenna design achieved 8.25dB at 2.4GHz. However, the gain for the RHCP antenna design with MS decreased whereas the directivity of Design A was 7.56dB, Design B 7.38dB, Design C 7.44dB and Design D 7.74dB. As illustrated in Figure 7, the total efficiency for the Basic RHCP antenna was achieved above -0.5dB at 2.3GHz and 2.4GHz.

The total efficiency at 2.4GHz of the Basic RHCP antenna was -0.27dB, while Design A was -0.59dB, Design B -0.65dB, Design C -0.85dB and Design D -0.50dB. Although decreasing, overall, the total efficiency of the antenna with MS can be said to still have a good agreement. The total efficiency must be more than -3dB in order to get more than 50% antenna efficiency.

C. Return Loss (RL), Resonant Frequency (fr) and Bandwidth (BW)

According to the simulation result as demonstrated in Figure 7, the return loss of all of the designs achieved below than -10dB at the frequency of 2.4GHz with bandwidth (BW) greater than 350MHz. The resonant frequency of the

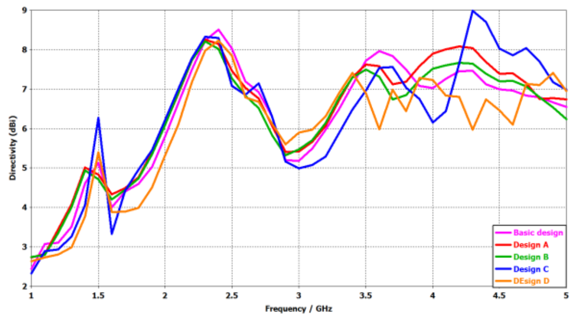

Figure 5: Comparison of simulated directivity for RHCP antenna without and with different MS design – simulation

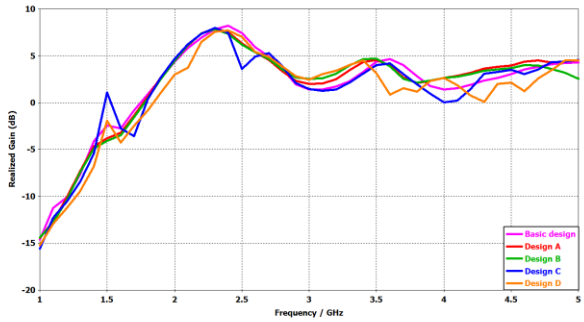

Figure 6: Comparison of simulated realized gain for RHCP antenna without and with different MS design – simulation

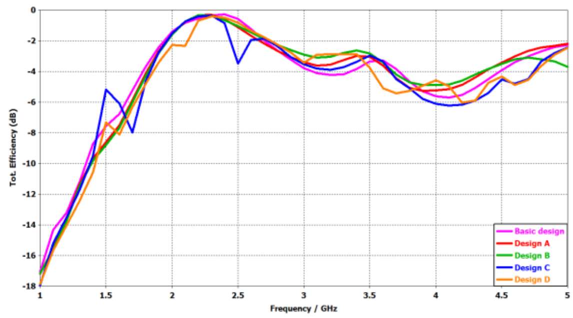

Figure 7: Comparison of simulated total efficiency for RHCP antenna without and with different MS design – simulation

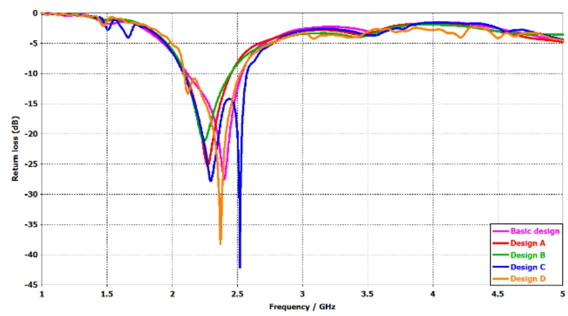

Figure 8: Comparison of simulated return loss for RHCP antenna without and with different MS design – simulation

simulation result for the Basic design dropped at 2.4GHz with the simulated return loss -27.54dB. The return loss at 2.4GHz for Designs A, B, C, and D was -12.83dB, -11.79dB, -15.16dB and -22.63dB, respectively. With the integration of MS at the Basic design, the simulation result demonstrates that the resonant frequency was shifted which was either dropped or increased. The resonant frequency for Designs A, B, C, and D was at 2.27GHz with -25.23dB, 2.24GHz with -21.19dB, 2.52GHz with -42.14dB and 2.37GHz with -38.24dB.

The bandwidth of the Basic design was 422MHz which covered the frequency from 2.1157GHz until 2.5377GHz. The bandwidths of Designs A and B were less than the Basic design which was 357MHz and 353MHz. However, Designs C and D showed a wider bandwidth result compared to the Basic design and Designs A and C which was 491MHz and 430MHz, respectively. Since all of the bandwidths for this antenna were more than 200MHz, the antenna covered broadband operation and met the broadband application.

The comparisons of the axial ratio, directivity, gain, return loss, resonant frequency and total efficiency for the RHCP antenna with and without metasurface at the frequency of 2.4GHz are tabulated in Table 2.

Table 2
Comparison of Basic Design and Different MS Design

Antenna design	Simulation (2.4GHz)					
	AR (dB)	*Dir. (dBi)*	*Gain (dB)*	*RL (dB)*	f_r *(GHz)*	*Effc. (dB)*
Basic Design	0.27	8.51	8.25	-27.54	2.4	-0.27
Design A	0.23	8.15	7.56	-12.83	2.27	-0.59
Design B	0.40	8.02	7.38	-11.79	2.24	-0.65
Design C	1.08	8.29	7.44	-15.16	2.52	-0.85
Design D	0.16	8.24	7.74	-22.63	2.37	-0.50

IV. CONCLUSION

In this paper, the basic design of the RHCP antenna operating at the frequency of 2.4 GHz for WLAN application was designed based on the rectangular patch embedded with a rectangular slot and connecting dual circular notch with the same radius to the rectangular slot in order to generate CP antenna. Parametric study on various shapes of MS was used in order to analyze the performance of the RHCP antenna after integrating it with MS at the ground layer. From the observation on the simulation result, the axial ratio still remained below 3dB and at the frequency of 2.4GHz, the return loss remained below -10dB and total efficiency remained above -3dB although with the integration of MS. The bandwidths for the RHCP antenna with and without MS were more than 350MHz and met the requirement of the broadband antenna operation. The results of the gain, directivity and total efficiency were reduced compared to the result of the Basic design due to the shifting of the resonant frequency. The separation of the air gap between the substrate and copper ground plane for the RHCP design increase the bandwidth and gain of the antennas. However, integrating MS between both of the substrate and copper ground affected the air gap and resulted in the frequency shift and decrease in the antenna performance at 2.4GHz. Overall, although there was no significant enhancement in the performance of the RHCP Basic design compared to RHCP with the different integration of MS design at 2.4GHz frequency, Design D gave the best axial ratio which was 0.16dB and 3dB axial ratio bandwidth with the integration of MS design more than 2000MHz, wider than RHCP without the MS design.

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REFERENCES

[1] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, Microstrip Antenna Design Handbook, Artech House, 2000.

[2] D. Prajakta, B. Chandan and S. Tazeen, “Design of modified E-shape microstrip patch antenna for circular polarization,” International Journal of Emerging Technology and Advanced Engineering, vol. 3, Issue 10, pp. 247-250, Oct 2013.

[3] M. Yahya and Z. Awang, “Cross Polarization Ratio Analysis of Circular Polarized Patch Antenna,” 2010 International Conference on Electromagnetics in Advanced Applications (ICEAA), pp. 442-445, Sep 2010.

[4] M. Z. A. Abd. Aziz, N. A. D. A. Mufit, M. K. Suaidi, A. Salleh, M. H. Misran and M. K. A. Rahim, “Study on Microstrip X-linear polarized and X-circular polarized antenna,” 6th European Conference on Antennas and Propagation (EuCAP), 2012, pp. 907-911.

[5] H. L. Zhu, S. W. Cheung, K. L. Chung, and T. I. Yuk, “Linear-to circular polarization conversion using metasurface,” IEEE Trans. Antennas Propag., vol. 61, no. 9, pp. 4615–4623, Sep. 2013.

[6] C. L. Holloway et al., “A discussion on the interpretation and characterization of metafilms /metasurfaces: The two-dimensional equivalent of metamaterials,” Metamaterials, vol. 3, no. 2, pp. 100–112, Oct. 2009.

[7] A. Ludwig, C. D. Sarris, and G. V. Eleftheriades, “Metascreen-based superdirective antenna in the optical frequency regime,” Phys. Rev. Lett., vol. 109, pp. 223–901, 2012.

[8] K. L. Chung and S. Chaimool, “Diamagnetic metasurfaces for performance enhancement of microstrip patch antennas,” in Proc. European Conf. on Ant. and Prop. (EUCAP), 2011, pp. 56-60.