Miniaturization of Broadband Right-Handed Circular Polarized (RHCP) Antenna Using 8 x 8 Square Loop Metasurfaces (MS)

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***Abstract*—In this paper, an analysis of metasurfaces (MS) structure to a right-handed circular polarized (RHCP) antenna with L-probe technique is proposed in order to miniaturize the antenna size and investigate the MS effects towards antenna performance. Firstly, the RHCP antenna was designed based on inverted suspended rectangular patch with rectangular slot and two dual notches with an air gap between substrate and copper plate layer at distance of 10 mm. Next, the MS is placed on a top layer of RHCP antenna with an air gap separation of 3 mm The design and simulation process is done by using Computer Simulation Technology (CST) Microwave Studio Suite software. Target application for this antenna design is for Wireless Local Area Network (WLAN) which operating frequency at 2.4 GHz. Antenna performances in term of return loss, resonant frequency, bandwidth, gain, directivity, axial ratio and radiation pattern at 2.4 GHz frequency are analyzed. The comparison result of simulation and measurement show that the proposed RHCP antenna without MS (Design A) and with MS (Design B) obtained bandwidth more than 200 MHz and forming miniaturize of RHCP antenna with substrate size reduction up to 39.5 %, yet achieving a similar antenna performance**

***Index Terms*—Antenna; Broadband; Circular Polarized; Metasurfaces; Miniaturization.**

I. INTRODUCTION

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 [1, 2]. Other than that, some well-known application examples are the improve performance of patch antennas gain and bandwidth [3,4]. Thus, this can be the solution for the microstrip patch antenna disadvantages which are normally related to restricting with narrow bandwidth and poor gain.

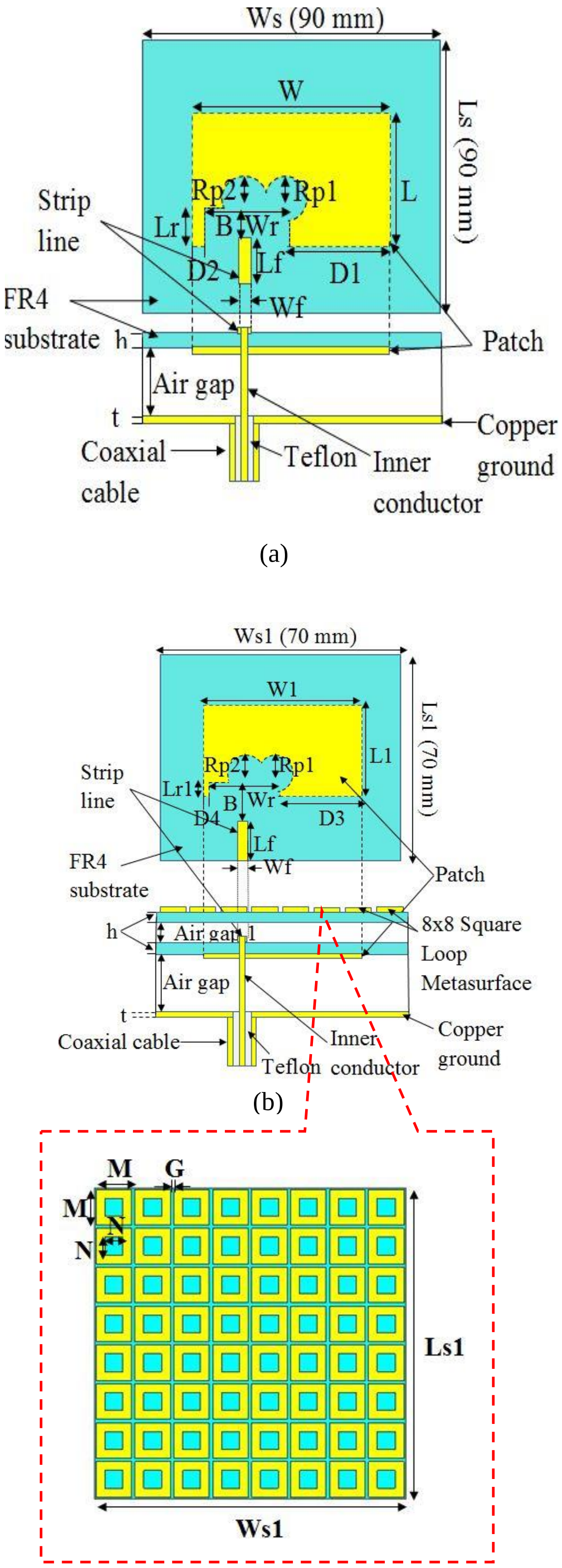
Microstrip patch antenna size is in general contrarily proportional to the frequency of operation. In recent year, with the increasing demand for a compact wireless device, small and simple antenna structures have been a great topic of interest [5-10]. As in [10], it is proposed to use MS to miniaturize patch antenna where the patch antenna size resulted in a size reduction of 67% and yet maintaining similar antenna performance.

In this work, an analysis of a wideband right-handed circular polarized (RHCP) antenna backed by 8 x 8 square loop metasurfaces design was presented for antenna miniaturization and bandwidth enhancement. The proposed antenna without MS (Design A) and with MS (Design B) was designed to be similar for a result comparison at 2.4 GHz frequency. The antenna is designed with the help of the CST Microwave Studio. The result of simulation and measurement for return loss (RL), resonant frequency (f_r), axial-ratio bandwidth (ARBW), realized a gain, directivity, bandwidth (BW), total efficiency and radiation pattern is then demonstrated and discussed. With the use of MS, substrate size can be reduced by 39.5 % yet achieving 10-dB return loss bandwidth and 3dB axial ratio bandwidth improvement.

II. ANTENNA DESIGN

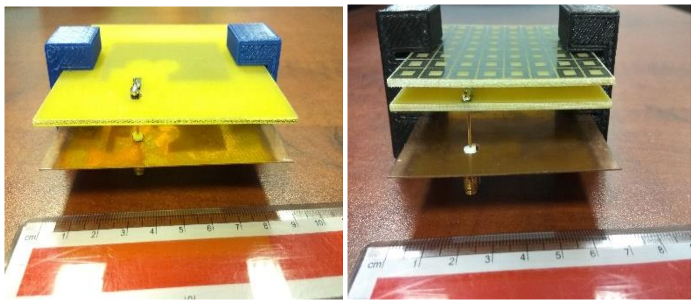
The antenna design and dimension for broadband right-handed circular polarized (RHCP) with and without 8 x 8 square loop metasurface (MS) is illustrated and tabulated as in Figure 1 and Table 1. The substrate dimension for the design without MS (Design A) is 90 x 90 mm as shown in Figure 1 (a), while with MS (Design B) is 70 x 70 mm as shown in Figure 1 (b). The antenna was designed by using an FR4 substrate and copper plate layer with a separation of 10 mm air gap distance between each other. L-probe technique is used in this design where the antenna is excited with the coaxial probe feed to the strip line.

The MS antenna (Design B) is adding at the top of the antenna with separation of 3 mm air gap from the RHCP antenna substrate as in Figure 1 (b). The MS is designed on the front of a single-sided substrate. This MS consists of 8 x 8 homogeneous pattern of square loop MS where each of the MS is separated by 0.75 mm gap between each other centre as demonstrated in Figure 1 (c). Each of the unit cells are printed periodically along the x-axis and y-axis with having an outer width of *M* and inner width of *N*. The width (W_s) and length (L_s) of substrate, copper ground plane and proposed MS substrate are all equal which is 90 x 90 mm for Design A and 70 x 70 mm for Design B. Fabricated prototype design is shown as in Figure 2. Optimization on the dimension of the design has been made to get the best performance result for both antenna designs. Both antennas are designed to operate at the frequency of 2.4 GHz. The optimize dimension for Design A and Design B antenna are tabulated as in Table 1.



(a) (b) (c)

Figure 1: Configuration of RHCP antenna Design A and Design B
(a) Design A vertical view (b) Design B vertical view (c) MS front view



(a) (b)

Figure 2: Fabricated prototype of RHCP antenna (a) Design A (b) Design B

Table 1
Dimension of Broadband RHCP Antenna Design A and Design B

Design Parameter	Dimension (mm)	Description
Air gap, Air gap 1	10, 3	Air gap
h	1.6	Thickness of substrate
t	0.035	Thickness of copper
B	8.5	Feed from rectangular slot
L, $L1$	40, 35	Length of patch
L_f	15.5	Length of feed
L_r, L_{r1}	11, 7	Length of rectangular notch
L_s,W_s	90	Length and width of Design A substrate
L_{s1},W_{s1}	70	Length and width of Design B substrate
Rp_1, Rp_2	6.5	Radius of circle notch 1 & 2
W, W_1	56, 52	Width of patch
W_f	3	Width of feed
W_r	25	Width of rectangular slot
D_1,D_3	27.5, 25.5	Long side length W & W2
D_2,D_4	3.5, 1.5	Short side length W & W2
M	8	Width of single unit MS
N	4	Length of single unit MS
G	0.75	Gap between metasurfaces

III. RESULT

In this section, the result of return loss, resonant frequency, bandwidth, realized gain, axial ratio, directivity and radiation pattern are shown as in Figure 2 and Figure 3. While Table II shows the performance comparison of Design A and Design B simulation and measurement for all of the RHCP antenna parameter.

A. *Return loss (RL), Resonant Frequency (f_r) and Bandwidth (BW)*

Return loss (S11) of simulation and measurement result for Design A and Design B is shown as in Figure 3. Simulation of Design A shows that the resonant frequency (f_r) is at 2.39 GHz with -30.82 dB return loss (RL) having a bandwidth (BW) of 428 MHz (18.49%) which is from 2.11-2.54 GHz. The measured resonant frequency is at 2.4 GHz with -28.46 dB RL where the impedance bandwidth decreases to 230 MHz respectively.

It can be seen that, with the use of metasurface, the resonant frequency of simulated Design B is shifted to 2.48 GHz with -30.54 dB RL and the BW is improved from 428 MHz (Design A) to 740 MHz (1.89-2.63 GHz) which is 32.74%. The measurement result of the resonant frequency for Design B is shifted to a lower frequency at 2.36 GHz with -28.60 dB RL where the bandwidth is slightly decreased to 588 MHz respectively. Simulation and measurement return loss of Design A and Design B at 2.4 GHz covering less than -10 dB yet achieving more than 90 % antenna efficiency.

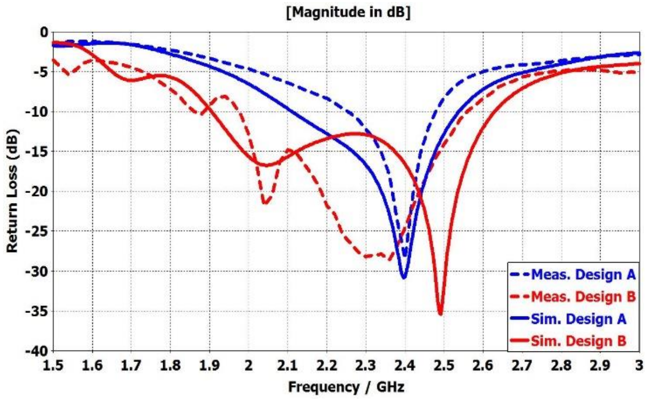


Figure 3: Comparison of simulated and measured return loss of the RHCP antenna Design A and Design B

B. Axial Ratio (AR)

The simulation axial ratio versus frequency for Design A and Design B antenna is shown in Figure 4. The axial ratio at 2.4 GHz for Design A and Design B is 0.39 dB and 0.24 dB respectively. The 3-dB axial ratio bandwidth (ARBW) is achieved covered from the frequency range of 1.12-2.82 GHz (Design A) and 1.33-3.08 GHz (Design B). The ARBW is improved from 1700 MHz (Design A) to 1750 MHz (Design B) with the addition of metasurface.

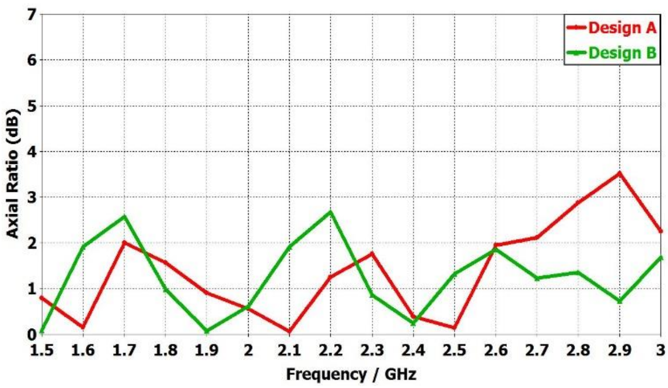


Figure 4: Simulated axial ratio for an inverted suspended circular patch with square slot antenna design

C. Radiation Pattern

The radiation pattern of the antenna is measured in far field region at 2.4 GHz frequency for phi = 0°, phi = 90° and theta = 90°. Comparison of the simulated and measured radiation pattern for Design A and Design B at 2.4 GHz frequency is demonstrated as in Figure 5 and Figure 6. From observation on both figures, the shape of the radiation pattern from the measurement is quite smaller compared to the simulation. Based on Figure 5 and Figure 6, the main lobe direction of phi = 0° are at 4° and 9° respectively. While, for phi = 90° the direction of both designs is the same which at 1°. At theta = 90°, the main lobe direction of Design A is at 123°, while Design B at 0° respectively.

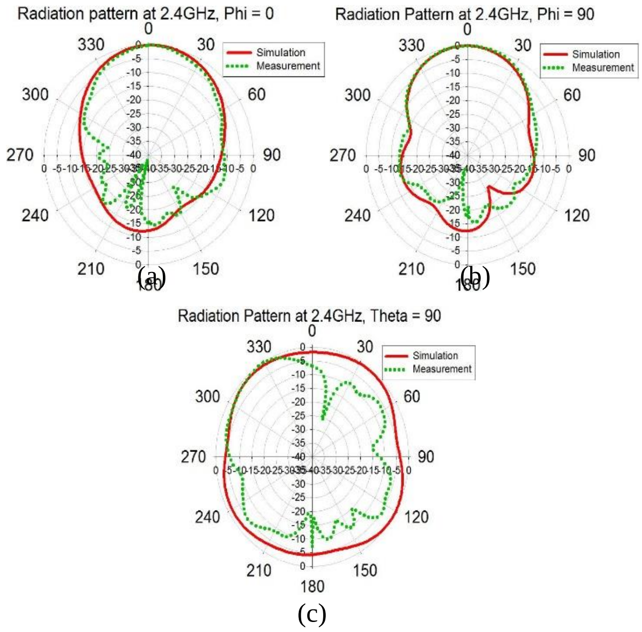


Figure 5: Comparison of simulated and measured radiation pattern of Design A antenna at 2.4 GHz frequency (a) phi = 0° (b) phi = 90° (c) theta = 90°

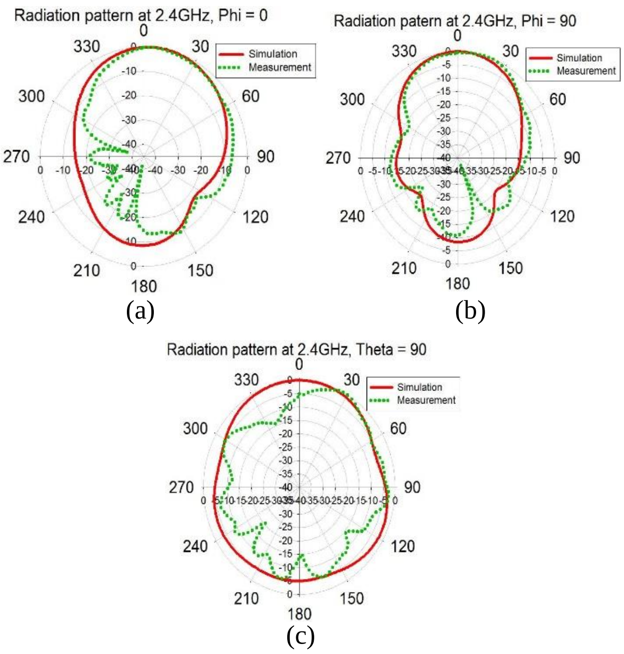


Figure 6: Comparison of simulated and measured radiation pattern for Design B antenna at 2.4 GHz frequency (a) phi = 0° (b) phi = 90° (c) theta = 90°

The simulation and measurement result for Design A and Design B at 2.4 GHz are tabulated in Table 2. Based on Table 2, the comparison result of return loss (RL), realized a gain, an axial ratio (AR), total efficiency, directivity and bandwidth are demonstrated. According to Table 2, the simulation result of gain for Design A and Design B are 8.27 dB and 8.14 dB. However, based on a calculation of the data taken from measurement, the result of gain reduced to 5.07 dB (Design A) and 4.12 dB (Design B) respectively.

Table 2
Comparison Performance Result of simulation and measurement for RL, Realized Gain, AR, Total Efficiency, Directivity and Bandwidth of Design A and Design B RHCP Antenna

Antenna parameter	Design A (90 x 90 mm)		Design B (70 x 70 mm)	
	Sim.	Meas.	Sim.	Meas.
Return loss	-30.72	-28.46	-16.57	-24.50
Realized gain	8.27	5.07	8.14	4.12
Axial ratio	0.39	-	0.24	-
Total efficiency	-0.26	-	-0.26	-
Directivity	8.53	-	8.40	-
Bandwidth	428	230	740	588

IV. CONCLUSION

In this paper, using MS to miniaturize the size of RHCP antenna from 0.72 λ_o x 0.72 λ_o (90 x 90 mm) to 0.56 λ_o x 0.56 λ_o (70 x 70 mm) and widen the bandwidth of the antenna has been proposed in this study. The MS which consisting of 8 x 8 square loop ring is put atop the RHCP antenna with 3 mm air gap. Simulated and measured results have shown with the integration of MS, the RHCP antenna substrate size can be reduced which is up to 39.5 % of size reduction and widen the antenna bandwidth up to 740 MHz (32.74%), yet maintaining quite similar performances in terms of realized gain, axial ratio, total efficiency and directivity at the same operating frequency (2.4 GHz).

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