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Circular Complementary Split Ring Resonator Rotation for Linear Array Millimeter Wave Microstrip Patch Antenna

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Abstract: This paper proposes multiple linear array millimeter wave MPAs that could operate at various frequencies depending on the angular rotation of the CSRR structure. The main contribution of this work is the range of frequencies of the linear array MPA found when the position of the CSRR structure is changed angularly. This is achieved by positioning the CSRR structure on the ground plane of the MPA and rotate it to an incremental of 22.5°. Computer Simulation Technology software is used to simulate the antenna designs. The performance of the antenna is evaluated against the single element millimeter wave MPA with similar angular rotation to the CSRR structure. The reflection coefficient graph shows at 0° rotation, the antenna has dual band performance at 26 GHz and 28 GHz. At 22.5° and 45° CSRR structure rotation, the antenna shows triple band performance with different operational frequencies and different polarization depending on the frequencies. Finally, at 67.5° CSRR structure rotation, the antenna now is operational only at 20 GHz frequency with horizontal polarization performance. Plus, the results between the single element MPA with circular CSSRR and the linear array MPA with circular CSRR shows similar behavior in which the rotation of the CSRR did not affect the antenna differently even with an increase of the number of elements. The millimeter wave MPA with CSRR angular rotation can be utilized in various applications as it covers multiple frequencies depending on the angle of rotation of the CSRR structure.

Keywords: CSRR, CST simulation, linear array MPA, millimeter wave frequency.

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1. INTRODUCTION

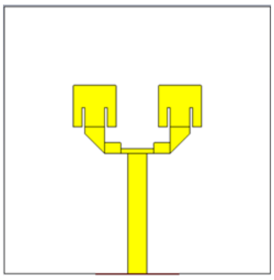
Millimeter wave applications is expected to increase dramatically in the following years due to the launch of 5G in early 2020. In Malaysia, Malaysian Communications and Multimedia Commission (MCMC) has identified the frequencies 26/28 GHz as the pioneer millimeter wave spectrum bands for the rollout of 5G. Millimeter wave antennas generally has a compact feature due to high frequency. However, this is in line with the requirements of the modern wireless communication system which are low profile, lightweight, high gain, ease of installation, and a compact size to ensure reliability and mobility characteristics. By utilizing microstrip patch antenna (MPA), most of the characteristics will be met as it is lightweight, miniature size, and offers ease of integration. Plus, MPAs are also one of the popular choices of antenna in wireless communication application due to the advantages it offers [1].

On that note, MPAs generally radiates a singular frequency band. There are multiple techniques that can be utilized to widen the bandwidth of the frequency or increase the number of radiating frequencies of the MPA [2-5]. In this paper, a circular complementary split ring resonator (CSRR) is introduced to a linear array MPA. CSRR structure is commonly used to increase the number of operating frequency band of an antenna. The utilization of SRR and CSRR in wireless communication offers the possibility of different or desirable frequency ranges and application. This technique is also important as there are increasing number or classes of regulated frequencies and standard frequency range that could benefit from the SRR or CSRR structure [6-8]. In this paper, simulation results of the angular rotation of circular CSRR structure on linear array MPA are analyzed and presented.

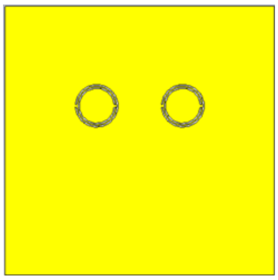
2. RESEARCH METHOD

A single element MPA with circular CSRR was designed and simulated using the same technique [2] to compare with the addition of element to the antenna structure. The simulation process of the antenna is done using Computer Simulation Technology (CST) software. The substrate used for the antenna design is Rogers RT5880 with permittivity, $\varepsilon r = 2.2$, dissipation factor, tan $\delta = 0.0009$, and thickness, $h = 0.508$ mm. Plus, copper with thickness, $t = 0.035$ mm is chosen as the radiating element.

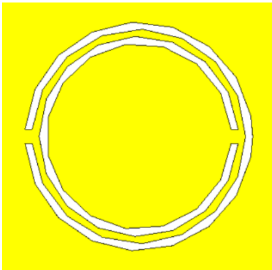
A 50 Ω input impedance transmission line is placed to feed the antenna. The power plane and ground plane of the 1×2 linear array MPA with circular CSRR is as shown in Fig. 1(a) and 1(b) respectively, and the focused view of the CSRR structure is shown in Fig. 1(c) below. The circular CSRR structure is placed right behind the square patch of the slotted MPA. The parameter of the antenna is tabulated in Table 1 below.



(a)



(b)



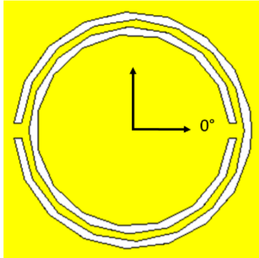
(c)

Figure 1. The (a) power plane, (b) the ground plane of the 1×2 linear array MPA with circular CSRR, and (c) a section of the CSRR structure for clearer view.

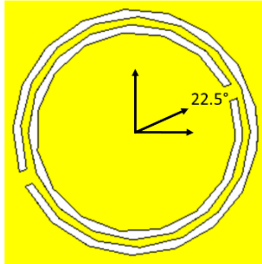
Table 1. The parameters of the antenna design

Antenna design	Parameter	Value (mm)
Microstrip Patch Antenna	Patch width	3.2
	Patch length	3.1
	Slot width	0.2
	Slot length	1.4
Complementary Split Ring Resonator	Outer circle radius	1.6
	Inner circle radius	1.4
	Circle thickness	0.1
	Short length	0.2

Then, the circular CSRR structures on the ground plane of the antenna is the rotated from 0° to an increment of 22.5° up until 67.5°. The antennas are referred to by the angle of the rotation of their CSRR structure. Fig. 2(a) shows the CSRR at its default position, Fig. 2(b) shows the CSRR rotated at 22.5°, Fig.2 (c) shows the CSRR rotated at 45°, and finally Fig. 2(d) shows the CSRR structure rotated at 67.5°.



(a)



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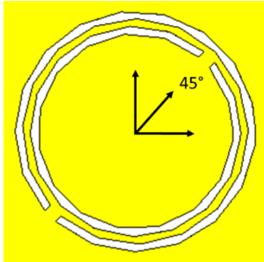
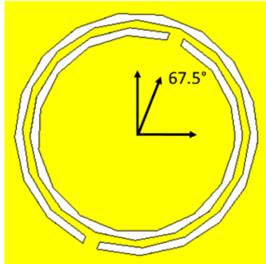


(c)



(d)

Figure 2. The section of the rotated CSRR structures at (a) 0°, (b) 22.5°, (c) 45°, and at (d) 67.5°.

3. RESULTS AND ANALYSIS

Fig. 3 shows the graph of reflection coefficient of the 1×2 linear array MPA with circular CSRR structure rotated at various degrees. From the graph, the red line represents the simulated reflection coefficient of the 1×2 linear array MPA with circular CSRR structure with shorted ends that lies on the x-axis also referred to as the 0°. It is noted that the antenna could operate at frequencies 26 GHz and 28 GHz with total efficiency of 89% and 91% respectively. Next, the green line shows the simulated S11 for 1×2 linear array MPA with circular CSRR structure rotated at 22.5°. The graph shows the antenna now radiates at frequencies 22.5 GHz, 26 GHz, and 28 GHz with total antenna efficiency of 88%, 86%, and 90% respectively. When the CSRR structure is rotated at 45°, it is matched at frequencies 17.25, 21.45, and 28 GHz with total antenna efficiency of around 88% on all frequencies. Finally, when the CSRR structure is rotated to 67.5°, the antenna now matched only on one frequency, 20 GHz with antenna efficiency of 91%. Fig. 4 shows the total efficiency graph of all four variation of 1×2 linear array MPA with circular CSRRs.

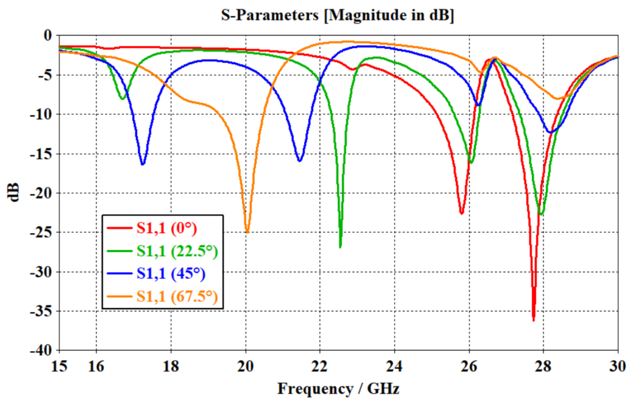


Figure 3. The reflection coefficient, S11, of the 1×2 linear array MPA with circular CSRR rotated at various angles

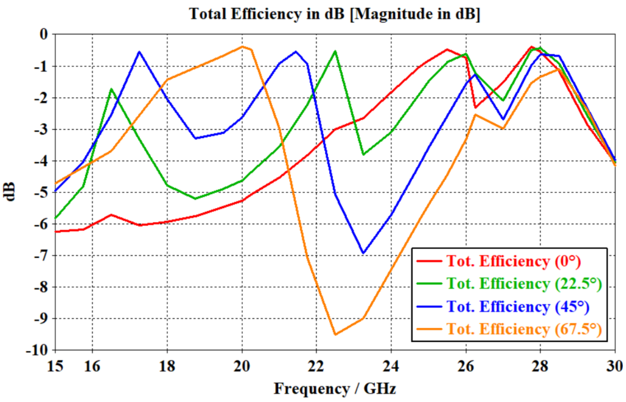
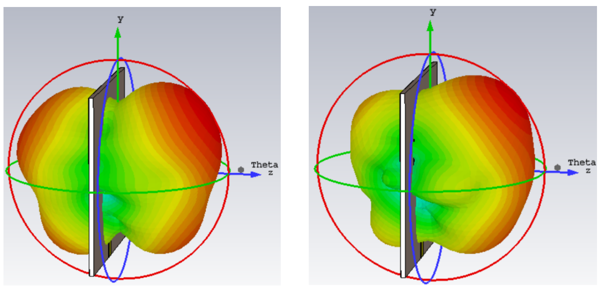


Figure 3. The total efficiency of the 1×2 linear array MPA with circular CSRR rotated at various angles

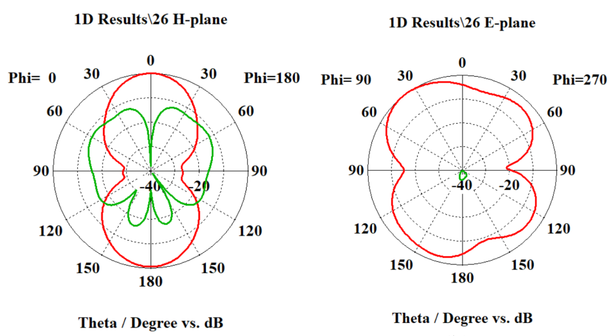
Next, Fig. 5(a) and 5(b) shows the 3D radiation pattern of the 1×2 linear array MPA with circular CSRR at 0°. It is noted that at 26 GHz, the antenna exhibits severe back radiation compared to radiation at 28 GHz. This is common characteristics found in defected ground structures for microstrip patch antenna designs.



(a) (b)

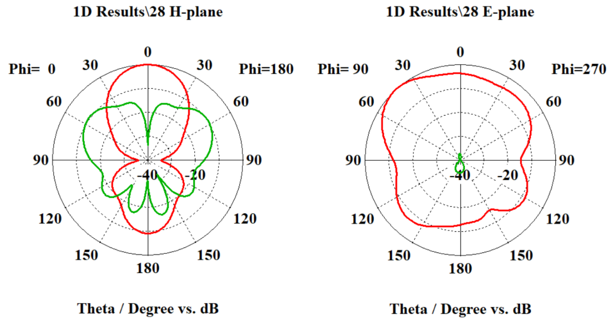
Figure 5. The 3D view of radiation pattern of the 1×2 linear array MPA with circular CSRR rotated at 0° at (a) 26 GHz and at (b) 28 GHz.

Fig. 6(a) and Fig. 6(b) shows the polar plot of the MPA with CSRR at 26 GHz with gain of 7 dB. The polar plot of the antenna shows the expected pattern from a patch antenna with vertical polarization characteristics. The red line shows co-polarization plot, and the green line shows the cross-polarization plot for the frequency. Fig. 7(a) and Fig. 7(b) shows the polar plot of the MPA with CSRR at initial position at frequency 28 GHz with gain of 9.26 dB.



(a) (b)

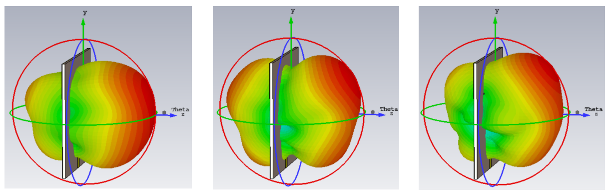
Figure 6. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 0° at frequency 26 GHz at (a) H-plane and at (b) E-plane



(a) (b)

Figure 7. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 0° at frequency 28 GHz at (a) H-plane and at (b) E-plane

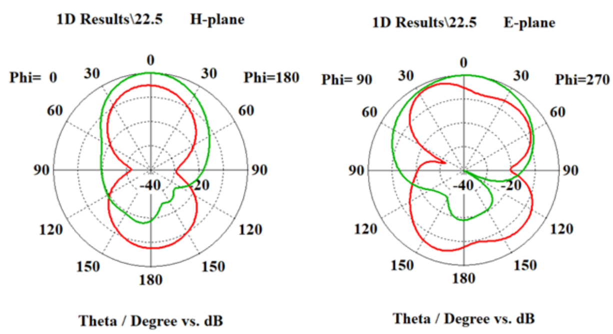
The radiation pattern for 1×2 linear array MPA with circular CSRR rotated at 22.5° in 3D is as shown in Fig. 8(a) with frequency 22.5 GHz, 8(b) at frequency 26 GHz, and finally 6(c) at frequency 28 GHz. Like antenna at rotation of 0°, the back radiation is strikingly severe at 26 GHz compared to other frequency.



(a) (b) (c)

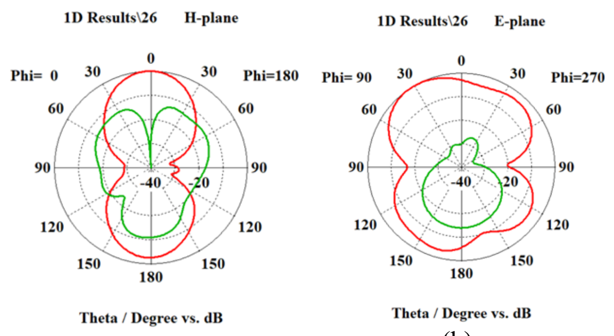
Figure 8. The 3D view of radiation pattern of the 1×2 linear array MPA with circular CSRR rotated at 22.5° at (a) 22.5 GHz, at (b) 26 GHz, and at (c) 28 GHz.

The radiation pattern of the antenna with CSRR structure rotated to 22.5° is quite interesting. Fig. 9(a) and Fig. 9(b) show the polar plot of the antenna at frequency 22.5 GHz with gain of 8.17 dB. The red line shows the co-polarization plot, and the green line shows the cross-polarization plot. This means at 22.5 GHz the antenna is horizontally polarized. Fig. 10(a) and Fig. 10(b) shows the polar plot of the antenna at 26 GHz with gain of 7.64 dB and Fig. 11(a) and Fig. 11(b) shows the polar plot of the antenna at 28 GHz with gain of 9.26 dB. For frequencies 26 GHz and 28 GHz, the antenna is vertically polarized.



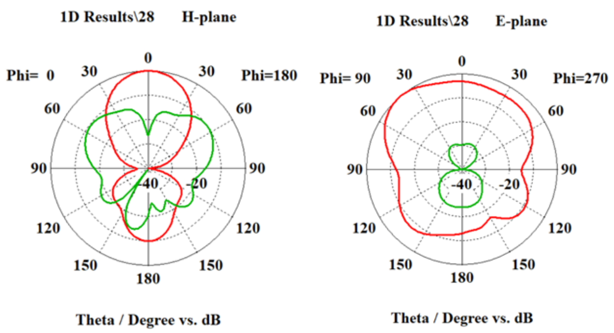
(a) (b)

Figure 9. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 22.5° at frequency 22.5 GHz at (a) H-plane and at (b) E-plane



(a) (b)

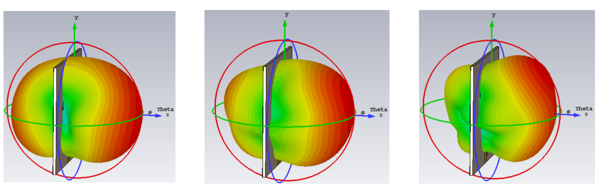
Figure 10. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 22.5° at frequency 26 GHz at (a) H-plane and at (b) E-plane



(a) (b)

Figure 11. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 22.5° at frequency 28 GHz at (a) H-plane and at (b) E-plane

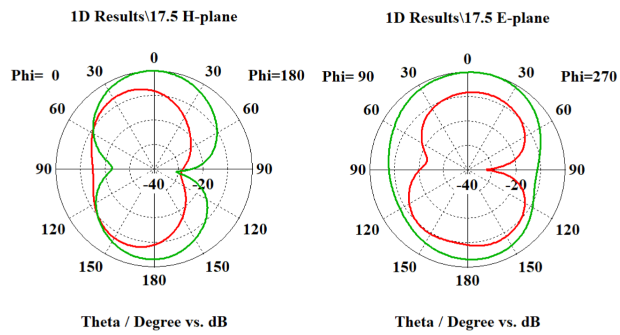
For the 1×2 linear array MPA with circular CSRR structure rotated at 45°, the 3D radiation pattern in shown in Fig. 12 below. Fig. 6(a) shows the radiation pattern of the antenna at 17.5 GHz, Fig. 12(b) shows the radiation pattern of the antenna at 21.45 GHz, and finally Fig. 12(c) shows the radiation pattern of the antenna at 28 GHz.



(a) (b) (c)

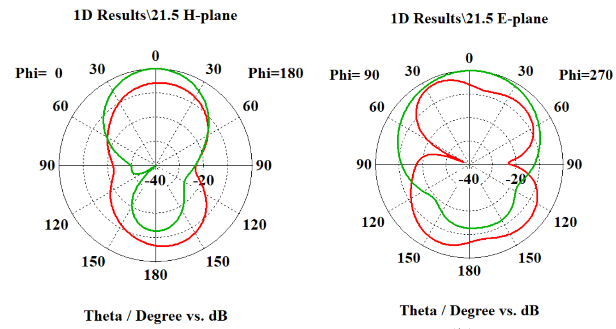
Figure 12. The 3D view of radiation pattern of the 1×2 linear array MPA with circular CSRR rotated at 45° at (a) 17.25 GHz, at (b) 21.45 GHz, and at (c) 28 GHz.

Interesting characteristics of the antenna are also present in the 1x2 linear array MPA with CSRR structure rotated at 45°. Fig. 13(a) and Fig. 13(b) shows the polar plot of the antenna at 17.5 GHz with gain of 6.46 dB. Fig. 14(a) and Fig. 14(b) shows the polar plot of the antenna at frequency 21.5 GHz with gain of 6.88 dB. The red line represents the co-polarization plot, and the green line is fo the cross-polarization plot. For both these frequencies, the antenna is horizontally polarized. On the other hand, Fig. 15(a) and Fig. 15(b) shows the polar plot of the antenna at 28.5 GHz frequency with gain of 8.95 dB. The antenna is vertically polarized at this frequency.



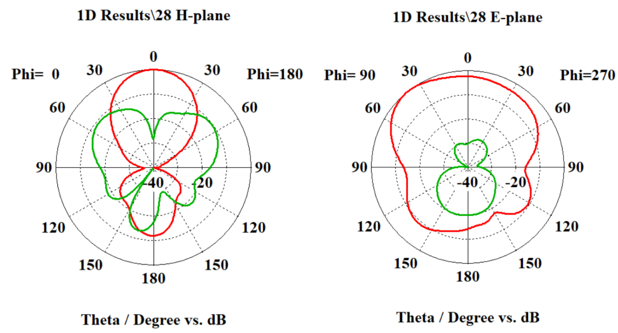
(a) (b)

Figure 13. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 45° at frequency 17.5 GHz at (a) H-plane and at (b) E-plane.



(a) (b)

Figure 14. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 45° at frequency 21.5 GHz at (a) H-plane and at (b) E-plane.



(a) (b)

Figure 15. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 45° at frequency 28.5 GHz at (a) H-plane and at (b) E-plane.

Finally, for the 1×2 linear array MPA with CSRR structure with angle rotation at 67.5°, Fig. 16 shows the 3D radiation pattern at the frequency 20 GHz.

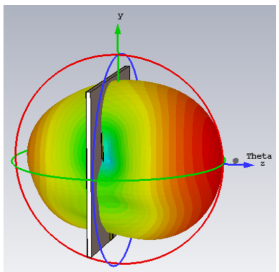
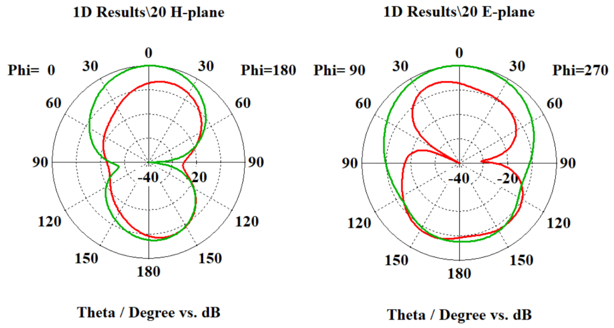


Figure 16. The 3D view of radiation pattern of the 1×2 linear array MPA with circular CSRR rotated at 67.5° at 20 GHz

Fig. 17(a) and Fig. 17(b) below shows the polar plot of the antenna at frequency 20 GHz with gain of 7.52 dB The red line shows the co-polarization plot, and the green line shows the cross-polarization plot for the antenna. Form the graph, the antenna is horizontally polarized.



(a) (b)

Figure 17. The polar plot of the 1×2 linear array MPA with circular CSRR rotated at 67.5° at frequency 20 GHz at (a) H-plane and at (b) E-plane.

Finally, Table 2 below summarizes the simulated results obtained from the antennas at different angle of rotation, their operating frequencies, the total efficiency, and the gain of the antenna at selected frequencies.

Table 2. The summary of simulated results obtained from the 1×2 linear array MPA with circular CSRR at various angle rotation

Antenna design	Angle of rotation	Frequency (GHz)	Total Efficiency (%)	Gain (dB)
1×2 linear array MPA with circular CSRR	0°	26	84	7.01
		28	88	9.26
	22.5°	22.5	88	8.17
		26	86	7.64
		28	90	9.26
	45°	17.25	88	6.46
		21.45	88	7.33
		28	86	8.95
	67.5°	20	91	7.52

4. CONCLUSION

The aim of this study was to investigate the effect of a couple of CSRR structure on the overall performance of the 1×2 linear array MPA. The benchmark antenna or the antenna with 0° angle rotation yield a dual-band performance with vertical polarization. Then, the antenna rotated at 22.5° and 45° yields three operational frequency bands with different polarization depending on the frequencies. Finally, the antenna rotated at 67.5° yield a single low frequency band with horizontal polarization characteristic. The results obtained from the simulation of the angle rotation on 1×2 linear array MPA with circular CSRR is similar with the simulation result obtained from rotating the CSRR structure on the single element MPA with circular CSRR with slight difference on the operational frequency and the polarization. However, it can be concluded that the number of CSRR structure on the antenna, if it is aligned with the slotted square patch antenna, would have negligible effect on the performance of the antenna.

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