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5.8 GHz Circularly Polarized Rectangular Microstrip Antenna Arrays simulation for Point-to-Point Application

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ABSTRACT

In this paper, the design and simulation of rectangular microstrip antenna arrays for improving antenna gain is performed for point-to-point application. The circular polarization is proposed to restrict the limitation of linear polarization which is less reliable in base station antenna. The circular polarization antenna is made to allow the receiver constantly to receive the power at any wave angle and make the transmission between two antennas are more constant. The proposed design is composed of four elements microstrip antenna with an array configuration operating at 5.8 GHz. Each element is constructed from four truncated arrays radiating elements and an inclined slot on each patch which capable to achieve circular polarized capability. The design of the 2x1 and 2x2 of rectangular microstrip array antenna was implemented from the design of single rectangular patch antenna as the basic building element. The designed 2x1 and 2x2 array were fed by microstrip transmission line which applied a technique of quarter wave impedance matching. The antenna design was etched on Rogers RT 5880 substrate with 2.1 and 1.53 mm of dielectric constant and thickness respectively. All the designed structure were simulated in CST software. The main results of the designed antennas were compared in terms of gain, axial ratio and return loss. Based on the return loss simulation results, the designed antennas resonated exactly at the desired resonant frequency of 5.8 GHz which indicates good antenna designs. Compared to the single patch antenna having an antenna gain of 8.26 dB, the 2x1 and 2x2 arrays achieved a gain of 10.24 dB and 13.29 dB respectively. The results show that the designed rectangular microstrip antenna arrays have an improved gain performance over the single patch antenna.

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1. Introduction

The antenna is one of the vital parts in wireless communications that acts as transmitting and receiving data communications. For the high demands in communication industries, the microstrip patch antenna are suitable used because it can indicate a good signal with a compact structure and easy to construct. The antennas which are used in these applications should be low profile, light weight, low volume, and large bandwidth [1,2]. Microstrip antenna is most preferred since it meets these requirements. The antenna that mounted on the rigid surface should be low-profile, simple, and inexpensive to manufacture [2]. Although microstrip antenna has a lot of advantages, it also has some disadvantages such as low gain, narrow bandwidth with low efficiency which can be overcome by constructing many patch antennas in array configuration [2,3].

Polarization is important to limit the wireless communication due to resulting wave having an angular variation. Circular polarization is invented to constantly receive a power at any angle [4]. High gain antenna is one of directional antenna that focused on narrow beam width, and it permits more precise on the targeting of the radio signal and usually is placed at the open area so that the radio waves to be transmitted will not interrupt.

Circular polarization can be obtained if the axial ratio of the antenna is below than 3 dB at 0 phase shift [4]. This can be accomplished for instance by adjusting the physical dimensions of the microstrip patch or various feed arrangements. To design circular polarization antenna, the patch must undergo some modification such as making perturbation on the patch oppositely truncated or located an inclined slot with diagonal feeding [5]. Commonly, both edges of geometry parallel to its major axis are truncated. It is realized that the impedance bandwidth and axial ratio bandwidth of modified antenna are improved on proposed truncations in the edge [6].

In this paper, the design of single patch element, 2x1 and 2x2 arrays of microstrip antennas with microstrip line as feeding method is presented. Quarter-wave transformer is used to match the feeding line to the radiating patch of antennas. The arrays were used to illustrate the improved gain performance of antenna arrays when compared with a single antenna. The centre frequency is determined to operate at 5.8 GHz which is suitable for point-to-point communications.

2. Design Methodology

2.1 Design of Single Rectangular Microstrip Patch Antenna

The geometry of the proposed antenna having a resonance frequency at 5.8 GHz is shown in Figure 1 with various dimensions. The antenna is mounted on a Rogers RT 5880 (lossy) substrate having thickness 1.5 mm with relative permittivity of 2.2. The patch and the ground plane are made up of radiating element like a copper having a thickness of 0.053mm with a dimension 70 X 70 mm. The antenna is fed by microstrip transmission line with a width of 4.8 mm. The corners of the rectangular patch are truncated to reduce the size of the proposed antenna as well as to obtain CP rotation [7,8]. For the substrate, Rogers RT 5880 (lossy) is used in this project with have a thickness of 0.51 mm and has a permittivity 2.2. The Rogers material give a result in high gain compared to FR-4. Multilayer antenna is made to increase the thickness of substrate which can make the antenna performance better. The layer of substrate is added by three layer which make the thickness of the substrate used in this project is 1.53 mm. The thick substrate is good to use in wide application because in can improve the gain, bandwidth, and the radiation pattern of the antenna [9]. Figure 2 (a) and Fig 1 (b) show the side view and back view of antenna design that consists of 3 layers of substrate with patch at the top layer of substrate and a full ground plane respectively.

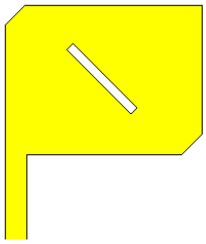

Fig. 1. Proposed Antenna Design

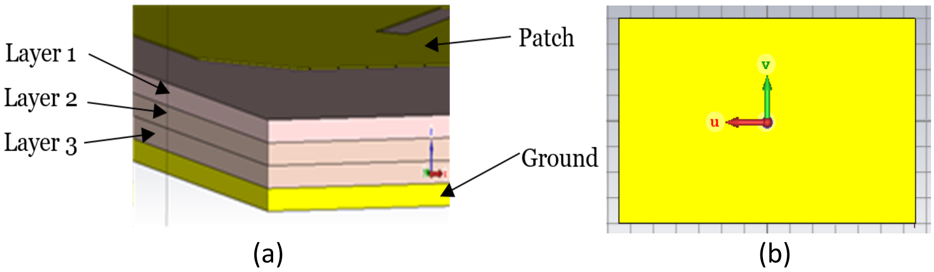

Fig. 2. Antenna Structure (a) Side View (b) Back View

Equation of width and length of rectangular patch antenna [10]:

$$L = \frac{C}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{1}$$

$$W = \frac{C}{1+\varepsilon r}\sqrt{\frac{2}{1+\varepsilon r}} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left(1+\frac{12h}{w}\right)^{-\frac{1}{2}} \tag{3}$$

$$\Delta L = \frac{0.412h(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.8)\left(\frac{w}{h}+0.8\right)} \tag{4}$$

Equation to find the size of truncation [11]:

$$Qo = \frac{C\sqrt{\varepsilon r}}{4fh} \tag{5}$$

$$\frac{\Delta S}{S} = \frac{1}{2\,Qo} \tag{6}$$

$$a = L\sqrt{\frac{\Delta S}{S}} \tag{7}$$

Table 1
Optimized Specification of Single Antenna Design

Parameter	Value
Operating Frequency	5.8 GHz
Dielectric Substrate	2.2
Thickness of substrate	1.53 mm
Thickness of copper	0.053 mm
Size of Substrate	70 mm x 70 mm
Size of Patch	38.8 mm x 28.2 mm
Width of truncation	6.24 mm
Size of Slot	2 mm x 20 mm
Size of Feedline	4.8 mm x 19.10mm

2.2 Rectangular Microstrip Patch Array Antenna

The gain and bandwidth of the single element rectangular microstrip patch antenna cannot satisfy the requirements of point-to-point communication system. Besides, single element microstrip patch antenna usually not suitable for application which need the higher gain and large bandwidth. Single patch antenna that has a low gain antenna can be improved their performance by adding more patches of antenna in an array configuration [12,13]. In this research, the design of 2 and 4 patch elements is configured as one dimensional in 2x1 and 2x2 array which contribute to increasing of antenna gain. The patch antenna is fed by using transmission line which separated into two and four division lines based on the number of radiating elements. The quarter wave impedance matching technique is used to match the radiating patch to distribute the power to the surrounding area. The 50 Ω transmission line are utilized to be matching between 70 Ω and 100 Ω.

2.2.1 Design of quarter-wave impedance matching

Before designing the arrays, the quarter wave impedance matching technique is utilized to match the radiating patch to allocate the power to the surrounding area as well as to diminish reflection loss. The 50 Ω transmission line is made to be matching between 70 Ω and 100 Ω. Figure 4 show the quarter wave impedance matching used to match the radiating elements for 2x1 and 2x2 arrays.

The formula for the quarter-wave transformer is known as:

$$Z_1 = \sqrt{ZoRin} \tag{1}$$

Where,
Z_1: Transformer characteristic impedance
Z_0: Input transmission line characteristic impedance
R_{in}: Edge resistance at resonance.

The calculation of impedance is made from formulation of microstrip feedline. The sizes for 50 Ω feedline, 70 Ω quarter-wave transformer and 100 Ω impedance line are developed by applying the same equation which are presented in (1-4). A single patch antenna was combined using corporate feed network to produce an array antenna. Corporate feed network is used for power division between antenna elements and to deliver power splits of 2n (i.e., η = 2, 4, 8, 16, 32, etc.). Each of the four elements receives equal amplitude in phase signal. By altering the width of the line and maintaining the equal length to each patch elements can control the amount of power delivered between them. The width of the transmission line is calculated based on the line impedance equation. The corporate feed network is used to match 100Ω patch to the 50Ω input by using quarter-wavelength transformers. To match the transmission line and quarter-wave, λ/4 transformer is used. The transformer impedance, ZT and the length of transformer, L are derived by equation 9, 10 and 11. The transformer impedance, ZT is given by David *et al*., [14].

$$Z_T = \sqrt{Zc\ ZL} \tag{9}$$

$$d = \frac{\lambda}{2} = \frac{c}{2fo} \quad ; \lambda = 2\left(\frac{C}{2fo}\right) \tag{10}$$

$$L = \frac{\lambda}{4} \tag{11}$$

The antenna array is made up of a quarter-wave feed network laterally with two and four identical elements of rectangular patch antenna designed and simulated using CST. The quarter-wave transformer impedance matching technique is applied to distribute the power towards the surrounding area of the patch as shown in Figure 3.

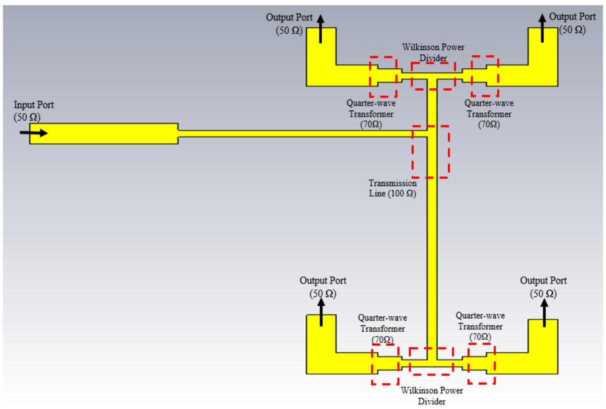

Fig. 3. Optimized Corporate Feed Network

The feed network can be optimized by using appropriate 90° bending at the quarter-wavelength transformer of 70.71 Ω. Meanwhile, the input port of 50Ω is placed at the center of the corporate feed network. The sizes for 50 Ω feedline, 70.71 Ω quarter-wave transformer and 100 Ω impedance line are attained by put on the same equation which is presented in (9-11) the dimension of the feedline after optimization is tabulated in Table 2 below. The dimensions of corporate feed network are illustrated in Figure 4.

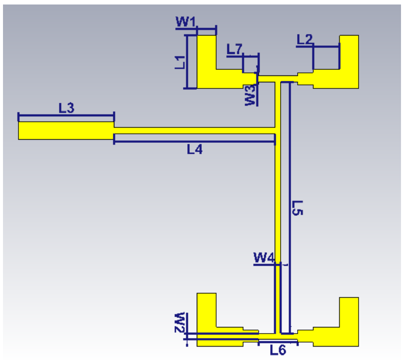

Fig. 4. Dimension of Corporate Feed Network

Table 2
Design Dimension of Feedline

Parameter	Dimension (mm)
W1	4.80 (50 Ω)
W2	1.50 (100 Ω)
W3	3.00 (70 Ω)
W4	1.50
L1	13.25
L2	6.70
L3	24.00 (Input Port 50 Ω)
L4	40.25
L5	62.99
L6	9.80
L7	3.85

2.2.2 Design of a 2x1 rectangular microstrip antenna array

The design of a 2x1 (2 elements) rectangular microstrip antenna array arrangement is presented in this sub-section. The design specifications for the 2x1 arrays are same as single element antenna which have the resonant frequency of 5.8 GHz and using the same substrate materials. It also has similar geometrical parameter to the single element. The two patch is connected by microstrip transmission line, and the quarter wave impedance matching technique is applied to reduce reflection loss [15] as presented in Figure 5. All the specification for 2x1 array design is tabulated in Table 3.

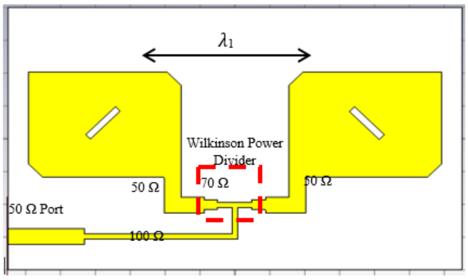

Fig. 5. 2x1 Array Antenna Design

Table 3
Optimized Dimension of 2x1 Array Antenna

Parameter	Value
Operating Frequency	5.8 GHz
Dielectric Substrate	2.2
Thickness of substrate	1.53mm
Size of substrate	130mm x 80 mm
Size of Patch	38.8 mm x 28.2 mm
With of Truncation	5.85 mm
Size of Slot	2mm x 12 mm
λ_1	30.90 mm

2.2.3 Design of a 2x2 rectangular microstrip antenna array

The design of 2x2 array antenna in Figure 6 also has quite like the design of 2 patches antenna, but the difference is by adding two patch antenna that constructed in 2x2 array. There are four patches antenna connected in array configuration which excited by 50 Ω source feedline. The microstrip feedline is used in this design because of easy to construct and match the impedance by using quarter wave impedance matching technique [16]. The significance adding more patches in an array is to increase the gain of antenna so that will be suitable used in base station application. The dimension and specification of 2x2 array design are same as 2x1 array but have some modification in size since added two more patches. The specifications are shown in Table 4.

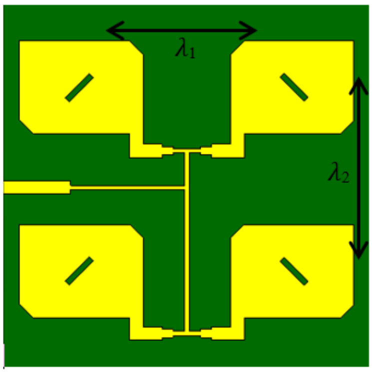

Fig. 6. 2x2 Array Antenna Design

Table 4
Optimized Dimension of 2x2 Array Antenna

Parameter	Value
Operating Frequency	5.8 GHz
Dielectric Substrate	2.2
Thickness of substrate	1.53mm
Size of substrate	130mm x 130 mm
Size of Patch	38.8 mm x 28.2 mm
With of Truncation	5.85 mm
Size of Slot	2mm x 12 mm
λ_1	30.90 mm
λ_2	36.77 mm

3. Result and Discussion

The simulation results by using CST Studio Suite are done to see the performance between these antenna designs. Figure 7 shows the simulation result between single antenna and array antenna. It shows that the three design has achieved their resonated frequency at 5.8 GHz. The antenna also performing well since all the return loss is drop below than -10 dB. However, 2x2 array present that has a good performance compared to others where the return loss drops deeper than the others design which is -28.76 dB.

The frequency is drop at 5.8 GHz with a return loss of -24.4 dB which considered as a good antenna. The axial ratio of this antenna also has a CP rotation which shows the result of axial ratio below than 3 dB. However, the gain 8 dB of the single antenna should be improved to get a higher gain to suitable used in this application.

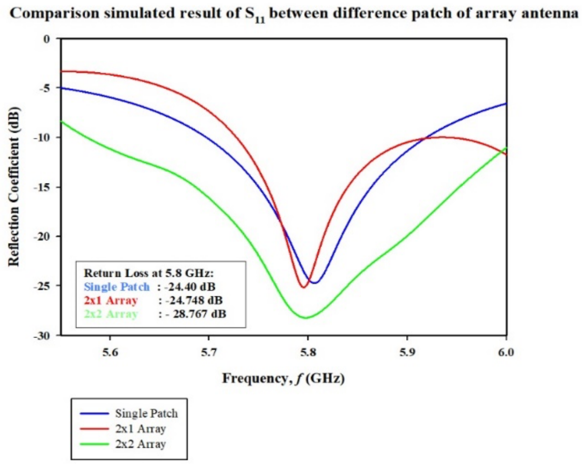

Fig. 7. Simulation Result

An array antenna also proved that increasing the antenna gain when added more patch antenna in array configurations. As presented in Figure 8, the antenna gain increase as in increasing the number of patches. The gain of antenna improved from 8.45 dB, 10.77 dB for single patch and 2x1 array to 13.27 dB for 2x2 array. Thus, the array is justifying a good method for improved the antenna gain.

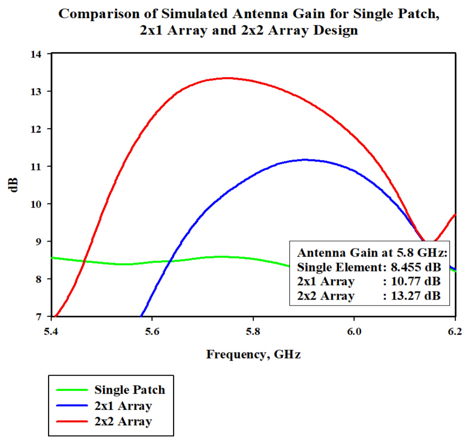

Fig. 8. Antenna Gain

Figure 9 shows the antenna radiation pattern for Single Element, 2x2 and 2x1 arrays antenna at the frequency of 5.8 GHz. All showing a unidirectional radiation pattern since the design comprises of a main lobe and some minor lobes. Mostly, the antenna has small side lobe and back lobes radiation pattern which considered as unidirectional antenna.

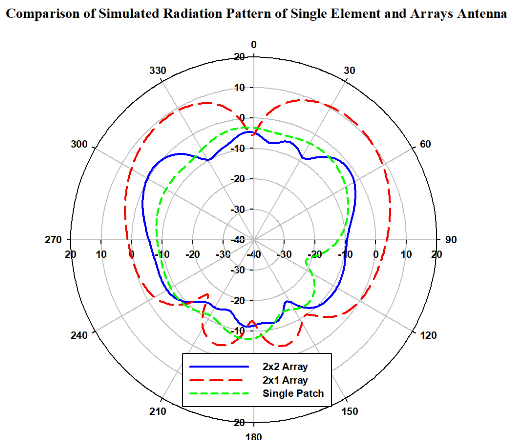

Fig. 9. 2D Radiation Pattern

Besides the antenna gain and radiation pattern simulation, axial ratio was simulated to make sure the antenna has CP rotation. All the design has justified a circularly polarized antenna since the axial ratio achieved below than 3 dB at the desired frequency of 5.8 GHz. As illustrated in Figure 10, the comparison results of axial ratio for 3 designs of proposed antenna. It also shows that the axial ratio improved as the number of patch increase.

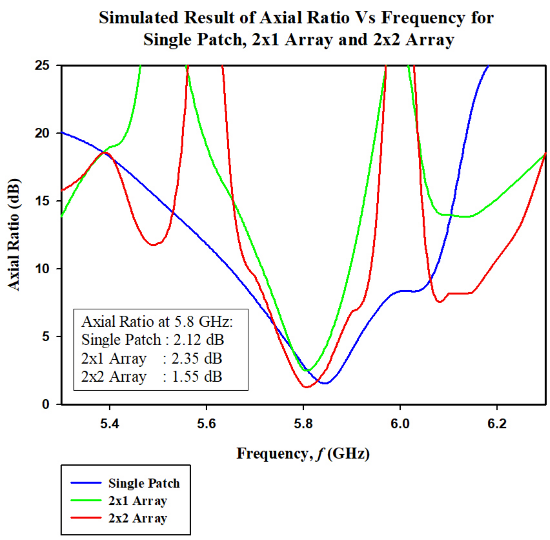

Fig. 10. Result of Axial Ratio Vs Frequency

Table 5 tabulate the comparison of microstrip array antenna from (1x1), (2x1), and (2x2) design. The array is the most concerned criteria during the design stage of the antenna as the application is focused on point-to-point communication. The return loss is varied for each of the designs due to the complexion of the design itself. All the antennas were created with circular polarization.

Table 5
Summary for all antenna array simulation result

Array Antenna	S_{11}	Gain	AR	Polarization
Single patch (1x1) array	Frequency: 5.8 GHz Return Loss: -28.23 dB	8.455 dB	2.12 dB	Circular (RHCP)
2 Patch (2x1) array	Frequency: 5.8GHz Return Loss: -24.63 dB	10.77 dB	2.35 dB	Circular (RHCP)
4 Patch (2x2) array	Frequency: 5.8 GHz Return Loss: -28.21 dB	13.27 dB	1.55 dB	Circular (RHCP)

5. Conclusions

In this paper, the mathematical calculations, and methods for the designs of single element, 2x1 and 2x2 array of rectangular microstrip antennas resonating at 5.8 GHz is presented. The antennas performance characteristics such as return loss, gain and axial ratio were obtained in the simulation using CST. To realize the circular polarization and increase the gain, some modification of antenna patch is done to obtain CP rotation as well as the antenna gain. The simulation results of the single element rectangular microstrip antenna and 2x1 rectangular microstrip antenna produced a good return loss at 5.8 GHz. Although, the farfield result showing a positive result of gain for both antennas, the gain should be improved to make it suitable in base station application. The 2x2 rectangular microstrip antenna array is design and produced a return loss of – 28.21 dB at 5.8 GHz and the axial ratio result is 1.55 dB which is below 3 dB. The gain is improved to 13.27 dB. The simulation results show that the gain of an array antenna is improved using the novel designed 2x1 and 2x2 rectangular microstrip antenna arrays. Good results for return loss, resonant frequency, gain and axial ratio for single element and array antennas have been achieved. The problem of low gain by single element antenna has been addressed by the new design of 2x2 array antenna designs presented in this research work.

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