A Circularly Polarized Miniaturized Antenna Array Using Sequential Phase Feed Structure for S-band Applications

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Abstract
In this article, a circularly polarized (CP) sequential phase (SP) feed antenna array is presented. The feeding network consists of two 90˚ sectors and several rectangular lines which are connected to the four arms of feeding network. The array elements are corner truncated patches. With combination of the sectors and rectangular lines, the overall size of the feeding network has been reduced. By a comparison, it has been made clear that the size of the antenna is decreased about 67% and the antenna bandwidth is increased about 8%. To validate the results, the prototype of the antenna is built. The results of the measured 10 dB impedance bandwidth is 0.5 GHz (3.45 GHz - 3.95 GHz), and the measured 3-dB AR bandwidth is 0.3 GHz (3.45 GHz - 3.75 GHz). According to the desired frequency range of the bandwidth, it is clear that the proposed array antenna is suitable for S-band applications.
Keywords:
Sequential Phase Feed Structure, S-band Applications, circularly polarized (CP), feeding network

1. Introduction

One of the most important subjects to design an antenna array is to achieve circular polarization (CP) characteristic. Sequential rotation (SR) technique is a way to achieve the optimal CP bandwidth [1].

Single layer, circular polarized antenna arrays with use of corner-truncated radiating elements, have a narrow axial ratio bandwidth due to the nature of the radiating elements. Several examples of these kinds of antennas have been introduced in [2-4]. Other examples [5-12] which have better bandwidth are presented, but these examples have more cost and more complex structure. In [5-8], the samples which are using this technique with the proximity-coupled feed method are investigated. Another model which is used the sequential rotation technique, has been introduced in [9-10] and the aperture coupled manner is used to motivate patch elements. Also, a sample of cpw-fed has been studied in [11]. According to the examples which are introduced, it is understandable that these antennas, due to their multi-layer structures, have the complexity and high cost of construction. To fix this problem, designers are concentrated on single layer array antennas with the sequential rotation technique.

According to this theorem, designing a single layer antenna array with acceptable AR bandwidth is really important. Another issue that must be considered is dimensions of the antenna. A large feeding network leads to the large antenna. Also, design a feeding network with a simple structure is as important as the other characteristics that have been mentioned.

In addition, in designing a miniaturized antenna we should be careful about the characteristics of the antenna such as gain and AR bandwidth. In the following, the proposed system has been introduced which includes array element and compact feeding network design.

2. Antenna Design

Fig.1 (a) shows the structure of the presented antenna array. The feeding network is located at the center of substrate. The radiation elements are corner truncated in order to achieve circular polarization characteristic. The proposed antenna is a single-layer antenna array which is printed on the FR4 substrate with ϵ_r=4.4, tanδ=0.02 and thickness of h=1.6mm. The antenna dimension has been optimized by the HFSS full wave simulator and details of the antenna array are shown in table (1). Furthermore, details of the feeding network are shown in table (2).

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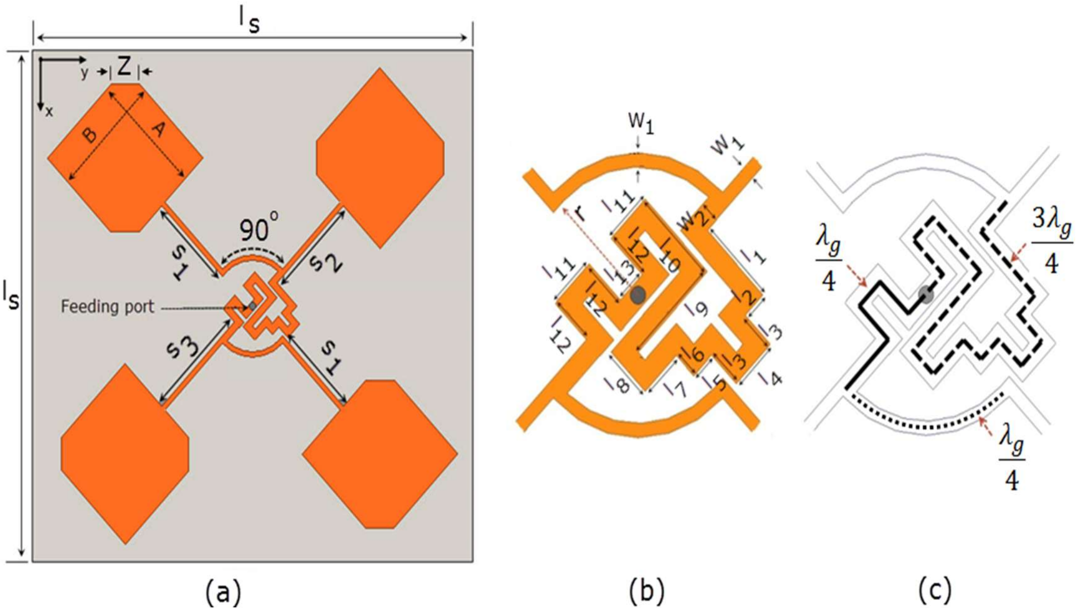


Fig.1. Geometry of the proposed 2×2 array (a) dimensions of the antenna array, (b) dimensions of the feeding network, (c) length of paths.

Table 1: Dimensions of the antenna array

parameter	mm	parameter	mm	parameter	mm
L_s	80	S_1	15.6	Z	5.3
A	19.9	S_2	17		
B	20	S_3	18.625		

Table 2: Dimensions of the feeding network

Parameter	mm	Parameter	mm
w_1	0.8	l_6	1.625
w_2	1.25	l_7	2.86
l_1	5.2	l_8	3.225
l_2	1.625	l_9	6.36
l_3	2.28	l_{10}	5.735
l_4	3.125	l_{11}	3.125
l_5	1.625	l_{12}	2.86
		l_{13}	2

According to the equation (1) and due to the center frequency of 3.6 GHz, The value of λ_g is 3.12mm. (in this equation, (w) is the width of the microstrip line in feeding network and (h) is the height of the substrate).

$$\lambda_g = \frac{v_p}{f} = \frac{c}{f\sqrt{\epsilon_{eff}}}$$

$$\text{If } \frac{w}{h} < 1 \rightarrow \epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\frac{h}{w}}} + 0.04\left(1-\frac{w}{h}\right)^2\right] \tag{1}$$

$$\text{If } \frac{w}{h} \geq 1 \rightarrow \epsilon_{eff} = \frac{\epsilon_r+1}{2} + \left[\frac{\epsilon_r-1}{2\sqrt{1+12\frac{h}{w}}}\right]$$

The feeding network create a 90˚ phase differences, consists on the paths with the multiple of $\frac{\lambda_g}{4}$ which is shown in Fig.1-c. According to the center frequency of 3.6 GHz and the value of the sectors with the length of $\frac{\lambda_g}{4}$, radius of the sector is, r=7.15 mm. By creating different paths, sequential phases of 0˚, 90˚, 180˚, 270˚ will be achieved at the four outputs of feeding network. The current distribution on the array at the frequency of 3.6 GHz is shown in Fig.2. The figure shows that the clockwise direction of current distribution at the phases of 0˚, 90˚, 180˚, 270˚, leads to circular polarization in far fields.

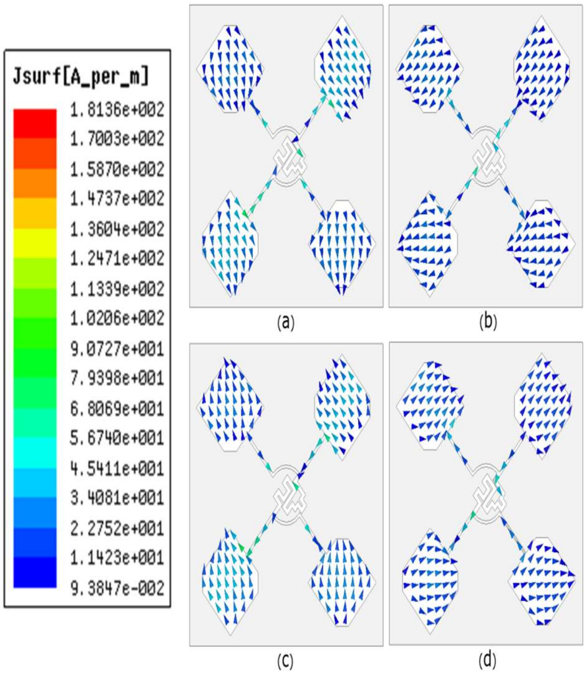


Fig.2. Current distribution on the proposed array at 3.6 GHz with different phases: (a)0^0 , (b)90^0 , (c)180^0 , (d)270^0.

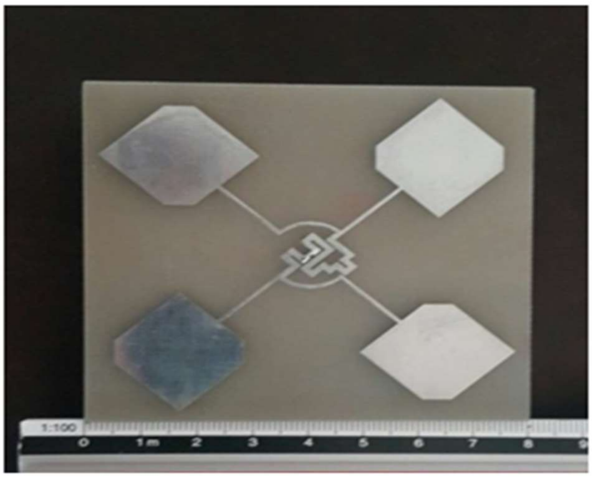
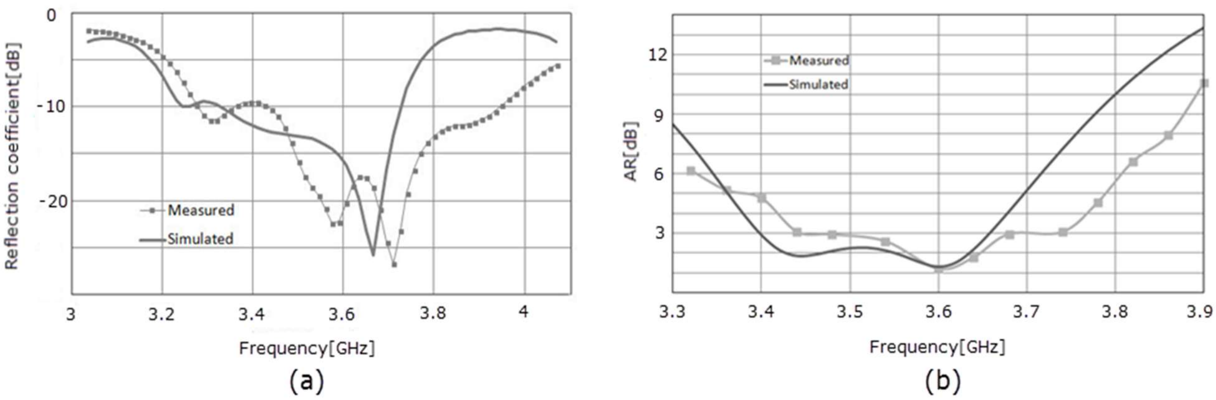


Fig.3. Prototype of the proposed 2×2 antenna array

3. Experiment Results

Fig.3 shows the prototype of the antenna array. The reflection coefficient is shown in Fig .4(a) and the reflection coefficient bandwidth is from 3.45 GHz to 3.95 GHz, it can be seen that there is a good matching between simulated and measured results. The simulated and measured results of the axial ratio (AR) are shown in Fig. 4(b) and the AR bandwidth is from 3.45 GHz to 3.75 GHz. The simulated and measurement results of the gain are shown in Fig .5. The gain in the desired frequency range is more than 4 dB and the maximum gain is 7.8 dB, at the frequency of 3.7 GHz. The radiation pattern at the frequency of 3.6 GHz and in the X-Z and Y-Z planes is given in Fig.6. According to the measured results, at the (+z) direction, the gain of co-polarization (RHCP) is about 25 dB higher than the cross-polarization (LHCP) at X-Z and Y-Z planes. These results lead to the production of a broadside pattern.



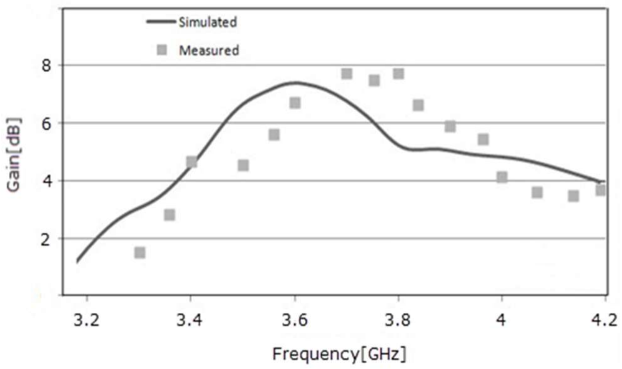


Fig.5. Simulated and measured gain of the 2×2 antenna array.

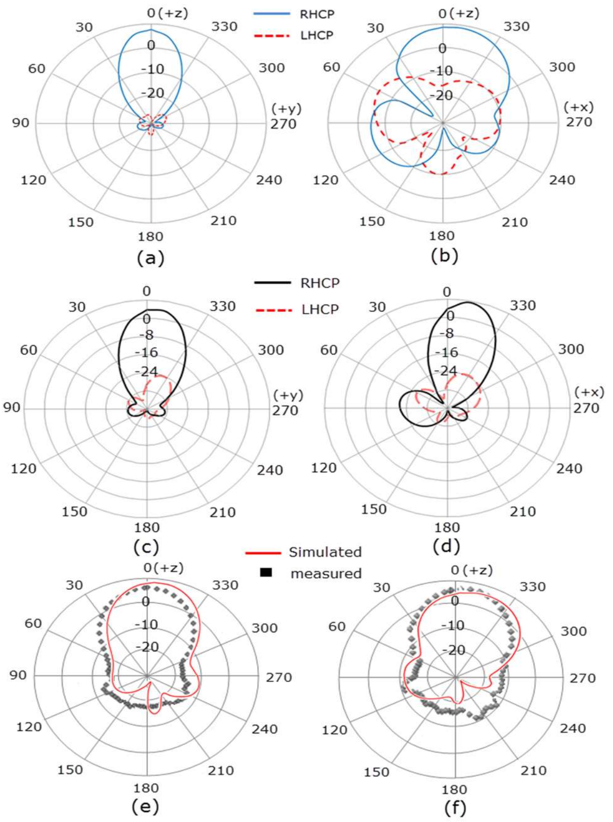


Figure 6. Normalized radiation pattern at 3.6 GHz, a) simulated RHCP and LHCP in y-z plane, b)simulated RHCP and LHCP in x-z plane, c) measured RHCP and LHCP in y-z plane, d) measured RHCP and LHCP in x-z plane, e) simulated and measured radiation pattern at $\varphi = 90^0$ (H Plane), f)simulated and measured radiation pattern at $\varphi = 0^0$ (E Plane).

Table (3), shows a comparison is concentrated on dimensions, and desired frequency range of the antenna.

By using compact and uniform structure, the larger scale 2N ×2N arrays can be derived from the reported 2×2 SP feed array element. For instance, the structure of 4 × 4 arrays which have extended feeding network based on the proposed SP feed is shown in Fig.7.

Table 3: A comparison between the proposed patch array and the other single-layer patch arrays

2×2 single layer arrays	Ref.[3]	Ref.[4]	Proposed antenna
Bandwidth of s_{11}<-10 dB (%)	15.45	8	13.9
Bandwidth of AR<3 dB (%)	5.4	7.5	8.3
Substrate	FR4	FR4	FR4
Total size (λ_g)	1.95×1.95×0.031	2.13×2.13×0.01	1.69×1.69×0.034

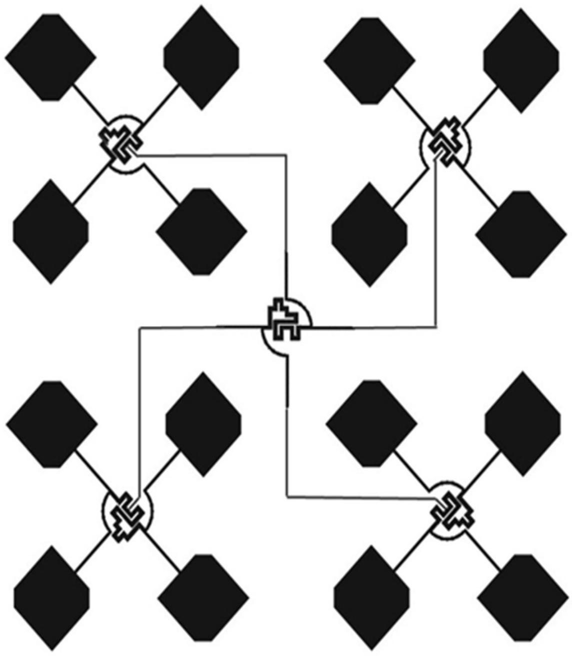


Fig.7. Extended feeding network to achieve 4×4 SR array.

4. Conclusion

In this paper a compact size, CP polarized array antenna is proposed. The feeding network and radiating elements are in the same layer of a PCB. Radiating elements are well-known truncated patches, and feeding networks have been designed using the equal width microstrip lines. These microstrip lines are shaped so as the size of the feeding network becomes small, in comparison width similar structures. The most advantage of proposed antenna is simplicity in designing and small size. The common 10dB impedance bandwidth and 3dB AR bandwidth is 300 MHz or 8.3% corresponding to the center frequency of 3.6 GHz. The maximum gain is 7.8 dB at the frequency of 3.7 GHz. The aim is to design an antenna with a small size and acceptable performance. Base on the comparison, it can be seen that the size of the antenna has greatly decreased (about 67%) while the common bandwidth of 10dB reflection coefficient and 3dB AR is increased about 8%.

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