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Design and Simulation of Circularly Polarized Pentagonal Shaped Micro-Strip Antenna Array

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ABSTRACT
Pentagon circular polarization micro-strip antenna has good broadband performance and circular polarization characteristics but it is difficult to design. A new circular polarized micro-strip antenna with a pentagonal shape patch is designed for wide band operation at 5.6 GHz for WLAN. In this paper, the antenna is designed and simulated using HFSS9 analyzer. Feed point selection criteria for single ended side feeding method is presented, simulated and results for main parameters such as return loss, impedance bandwidth, radiation patterns and gains are measured and discussed here. The electric current distributions on the patch and the radiation patterns are also demonstrated in this paper. Based on the simulation of pentagon antenna unit, a four element antenna array is presented. The design method for feed net of the array is given. Simulation results show that proposed antenna array obtains a 4% 3dB bandwidth, and 12 dB gain.

Keywords – Micro-Strip antenna, Circular Polarization, Axial Ratio, Pentagon, Antenna Pattern, VSWR

I. INTRODUCTION

Currently, micro-strip patch antennas are most widely used antenna particularly because of their light weight, compactness and are cost effective [1, 2]. In recent years, research on 5 GHz band is increased due to its utilization to small area network systems such as Wireless Local Area Network (WLAN). The system often requires antennas with compactness and broadband characteristic. Therefore, various designs have been proposed for the size reduction and the bandwidth enhancement. Soliman presented a conventional bow-tie slot antenna that is having broadband characteristic which need a quite large dimension [3].

On the other hand, most meander slot antennas have small size, but its bandwidth is relatively narrow [4]. Circularly polarized micro-strip antenna, which is one of the most popular research area for micro-strip antenna, recently is employed in the wireless local area network applications [5, 6]. Tang presented a new design of compact circularly polarized patch antenna with two sets of vertical right-angle bended stubs attached to the diagonal corners of the slotted square patch [7]. Bahl proposed a method that can achieve the circular polarized by an off-set pentagon patch structure [8]. In [9], **Chen** shows a single-fed circular micro-strip patch antenna with switchable polarization. In [10], **Wei He** realized circular polarization by E-Shape patch whose geometry size is relatively large.

Pentagonal micro-strip patch antenna supports both linear and circular polarization. It gives better performance compared to the rectangular patch antenna. The pentagonal patch antenna gives circular polarization with only one feed where as rectangular patch antenna requires multiple feeds to get circular polarization [11]. The pentagonal patch antenna can have multiband operations. In single-fed CP pentagonal patch antenna, the generated mode usually is smooth in an electrically thin cavity region of the micro-strip antenna. Accordingly, the operations principle of this antenna is based on the fact that the generated mode can be separated into two orthogonal modes [12]. Feed Techniques Micro-Strip patch antennas can be fed by a variety of methods. These methods can be classified into two categories: Contacting and non- Contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a micro-strip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the micro-strip line and the radiating patch [13, 14, 15]. The four most popular feed techniques used are the micro-strip line, co-axial probe (both contracting schemes), aperture coupling and proximity coupling (both non-contacting schemes). The advantage inherent in patch antennas is the ability to have polarization diversity. It means patch antennas can easily be designed to have Right Hand Circular Polarization (RHCP) or Left Hand Circular Polarization (LHCP), using multiple feed points or single feed point with asymmetric patch structures [16, 17].

In this paper, a new design method of pentagon circularly polarized patch antenna is proposed. This antenna has reasonable axial ratio bandwidth and radiation gain of over 5.36% and 7.5 dB respectively. Based on the proposed patch unit, a 2*2 micro-strip line fed pentagon circularly polarized antenna array is designed. Simulation results show that the array obtain a 4% 3dB bandwidth, and 12dB gain.

The rest of the paper is organized as follows: The theory of pentagon antennas based on FEM is given in section II. The design method of pentagon patch unit is presented in section III while the antenna array design is put forward in section IV. Simulation model and results is shown in section V and conclusions are made in section VI.

II. FEM FOR PENTAGON ANTENNA

In order to fulfill circularly polarized, pentagon micro-strip antenna employ an irregular shape that cannot be analyzed by classical electromagnetic method [18]. One of the feasible ways to analyze the irregular micro-strip antenna is finite element method (FEM) that divides the whole solving area into several units. A basis function is resolved in corresponding unit and set to zero, and for other regions it is specified for each unit. Then piecewise analytic function instead of global analytic one, is used to realize the antenna. In this paper, a triangular unit is selected to fulfill FEM. Pentagon micro-strip antenna is divided into several smaller units as shown in Figure 1 [1]. The boundary admittance is given by equation:

$$Y = H_t / E_t \tag{1}$$

Where H_t is the tangential magnetic field on the boundary. The electric field function can be obtained easily for cavity micro-strip. Assume the substrate is very thin, set $\frac{\partial E_z}{\partial z} = 0$, electric field function can be regarded as scalar functions which is easy to calculate. Electric field for cavity is defined as:

$$\nabla^2 E_z + k^2 E_z = j\omega\mu J_z \tag{2}$$

Where $k = \omega\sqrt{\mu\varepsilon}$ and J_z is density of incentive current. On the periphery, it is obtained by:

$$H_t = \frac{1}{j\omega\mu} = \frac{\partial E_z}{\partial \hat{n}}$$

Where $\hat{n}$ is outwards normal unit vector direction. The boundary admittance is obtained as:

$$\frac{\partial E_z}{\partial n} = j\omega\mu Y E_z \tag{3}$$

The corresponding function for Equation (2) and Equation (3) is defined as:

$$J(E_z) = \frac{1}{2}\int_S [|\nabla_t E_z|^2 + k^2 |E_z|^2] ds + \int_L j\omega\mu J_z J_z^* dl - \frac{j\omega\mu}{2} Y \int_C |E_z|^2 dl \tag{4}$$

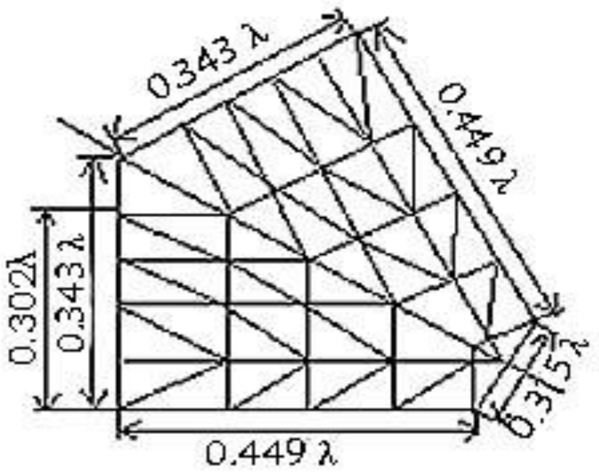


Figure 1. Pentagon Micro-Strip Antenna units Divide

Where $\nabla_t E_z = \hat{x}\frac{\partial E_z}{\partial x} + \hat{y}\frac{\partial E_z}{\partial y}$, and S is the area of micro-strip slice, C is the perimeter while L is the perimeter of excitation source J_z. Variation function J is given by:

$$[k][p] - k^2[H][p] = [T] \tag{5}$$

Where $[p]$ is the column matrix which represents E_z values for crunnodes. Both $[k]$ and $[H]$ are zero coefficient matrix, $[T]$ is the constant coefficient matrix that relate to source integral component. Input impedance can be obtained by solving Equation (4). Considering passive condition, $J_z = 0$ which means $[T] = 0$, Equation (4) can be changed into characteristic equation which will be the function for resonant frequency and resonant mode.

III. OFF-SET PENTAGON ANTENNA

A circular polarization micro-strip antenna [20, 21] operating at 5.6 GHz [19] is designed in this paper. Initially side length which is treated as a reference for engineering design is calculated by FEM as shown in Figure 2, and the side length is listed in Table 1.

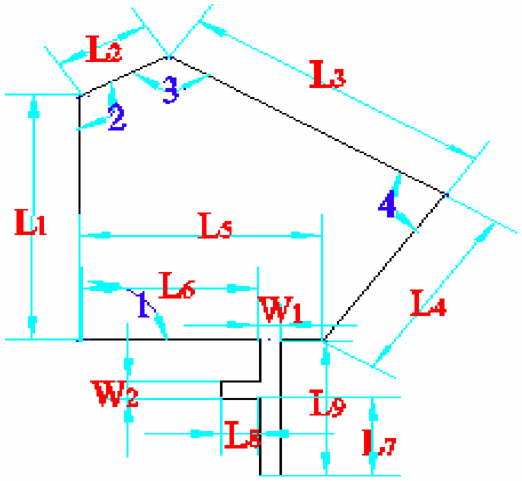


Figure 2. Side length of the pentagon antenna

It is a key idea to choose the location of feed point in design of micro-strip antennas for which feed point determine the excitation modes as well as its affect on the radiation characteristic of the antennas. After that, it required for us to consider all the amplitude of radiation field, the phase and the resonant frequency of the antenna. Therefore, it is hard to ensure the feed point.

Table 1. Size of antenna references

$L_1 = 14.817mm$	$L_2 = 4.785mm$
$L_3 = 15.343mm$	$L_4 = 10.464mm$
$L_5 = 11.319mm$	$L_6 = 7.123mm$
$\angle 1 = 90^{\circ}$	$\angle 2 = 120^{\circ}$
$\angle 3 = 118^{\circ}55'43''$	$\angle 4 = 90^{\circ}28'22''$

With the help of fundamental formula, we can get the length of the medium wavelength $\lambda_g = 32.6$ mm. Through proper optimization and debugging, medium wavelength is shifted to 33.1mm. According to dimension of medium wavelength the length of each sides are $L_1 = L_2 = 14.817$ mm, $L_2 = 4.785$ mm, $L_4 = L_5 = 11.319$ mm and $L_6 = 9.966$ mm. All the values are obtained through calculation by fundamental formula. However, the pentagon antenna with those sides cannot achieve circular polarization (CP) radiation simulated by HFSS software, therefore we have to adopt "Manually Adjustment Method" in order to achieve CP radiation. The point of intersection l_3 & l_4 is reduced by 1mm, respectively; then alternate position of feed point is tried further in order to get a better CP radiation pattern. But length of L_1, L_3, L_4, and L_5 are no more equal. In spite of those changes, the structure of pentagon differs very little with typical structure. Although the angle of some corner are little changed, but the variation amplitude nearly can be ignored. For this reason, it is basically same with typical structure.

The detailed dimensions of the proposed pentagon units are shown in Table 1. All the above changes are not based on any fundamental theory, but it is inevitable. Theoretically, after the dimensions of pentagon are confirmed, CP radiation can be achieved by slightly changing the position of feed point. However, it is difficult to overcome this problem and make it possibly true due to the fact that dimensions of each sides of pentagon or the feed lines are not calculated by accurate theoretical formula. Therefore, it is hard to achieve CP [21] radiation by changing the dimension of feed point only. In order to achieve CP radiation, it required us to change the dimension of pentagon or feed line while altering the location of feed point. We carried out a series of simulation to choose position of feed point, as shown in Figure 3, Figure 4, and Figure 5. Figure 3 shows the change curves of axial ratio and feed point location when the feed point 2mm offset of the center fed or not. It changes from 1.5 dB to 5dB when the feed point move away from the center fed at the 5.6 GHz [10]. Figure 4 shows space on the hemisphere, the average increment of axial ratio is 2-3 dB when feed point 2mm offset of the center fed. Those data suggest that changes in the feeding point have important influence on the axial ratio.

Figure 5 shows the change curves of S parameters and feed point position, when the feed point move away from the center fed, S parameters increase from -36 dB to -12 dB at 5.6 GHz. From the simulated data we can see that even minute changes of the feeding point can affect the performance of antenna a lot which leads to repeated modification and repeated optimization which is one of the most difficult task while designing pentagon circularly polarized antenna.

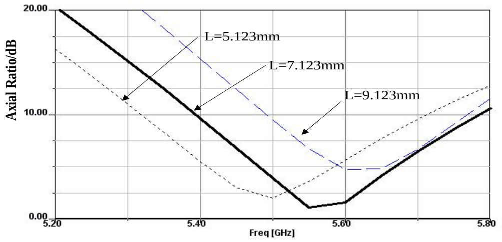


Figure 3. Simulated axial ratio for feed points.

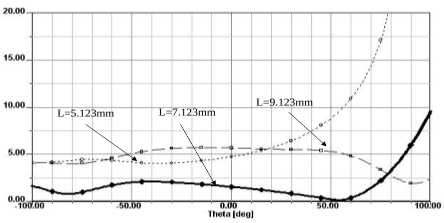


Figure 4. Simulated axial ratio for feed points

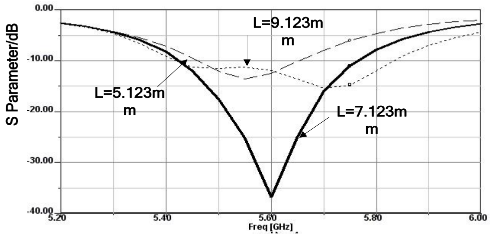
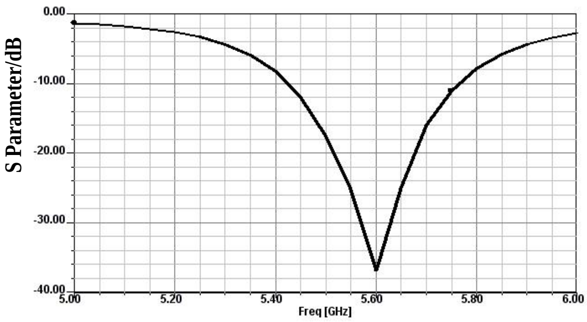
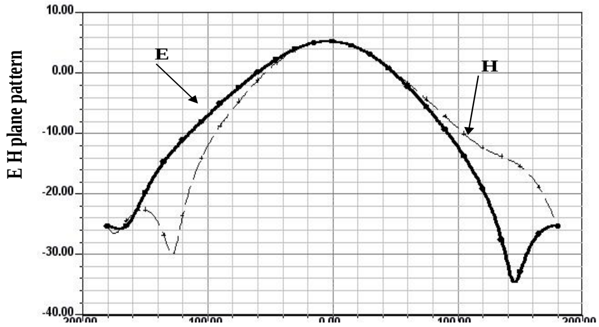


Figure 5. Simulated S parameter for feed points

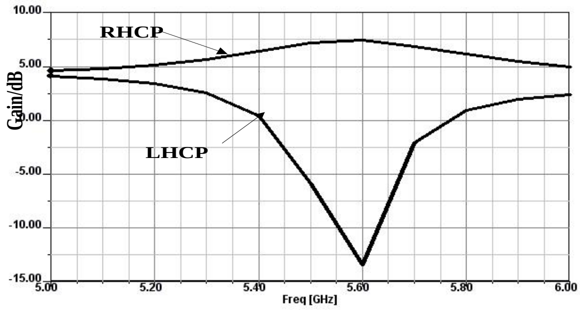
The graphs shown in Figure 6 is the simulation results of the pentagon micro-strip antenna using HFSS9 analyzer.



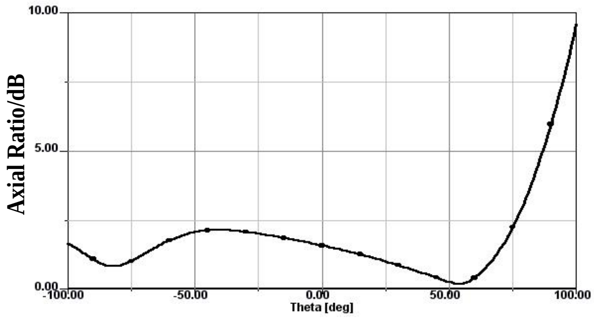
(a)



(b)



(C)



(d)

Figure 6. Simulated results of the single pentagon patch antenna:

(a) Return loss, (b) EH plane pattern, (c) Gain and (d) axial ratio

It is obvious from Figure 3 that the index of antenna as follows:

- **Axial Ratio:** The angle range for axis ratio less than 3 dB is -90°~80°, which means it can achieve good circular polarization almost in the half of up space. Wide axis ratio is one of the outstanding advantages of the pentagon micro-strip antenna and then as the array element of the antenna, it concludes to eliminate the scanning blind spots of the matrix.

- **Bandwidth:** The reflection coefficient reaches to -37 dB at mid frequency 5.6 GHz, the bandwidth is 5.36% when reflection coefficient is -15 dB and the bandwidth turns into 3.1% when reflection coefficient is -20 dB. Compared with the ordinary rectangular corner cut circular polarized antenna, when adopting single deck and using single point feed method, pentagon antenna has more advantages, it obtains a wide bandwidth by only changing the shape of the patch.

- **Gain:** Though the area of pentagon patch is smaller than rectangular patch, the gain at mid frequency 5.6 GHz can achieve 7.5 dB, which means the performance of this antenna is up to standard.

IV. PENTAGON ANTENNA ARRAY

After determining structure and sizes of the element, in this section, we introduce how to design planar array antenna and the steps are shown as follows:

Step 1: Confirm the number of the elements. In this paper, we design 2*2 circular polarization plane micro-strip array by the use of pentagon patch.

Step 2: Confirm the distance of each radiation elements. While forming arrays, mutual coupling must be considered and the element spacing is between $0.5\lambda_0$ to λ_0. In real project design, it is regulated according to the various parameters such as antenna size, feed networks and the actual performance of the antenna networks.

Step 3: Confirm the feed. In this paper, the feed network is fed by micro-strip, which realizes the broadband impedance matching by using a half multi stage power divider. So the antenna structures become simple and easy to manufacture as product. In actual design, in order to reduce feed line loss, we need to propery make each feeder joint, feed lines and each elements should be matched properly, then the hole feed network and the antenna elements match properly [18].

The geometry of the proposed 2*2 pentagon circular polarization antenna array is shown in Figure 7.

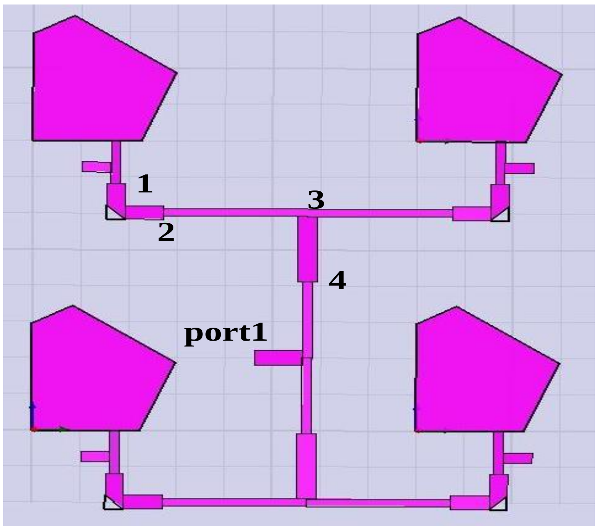


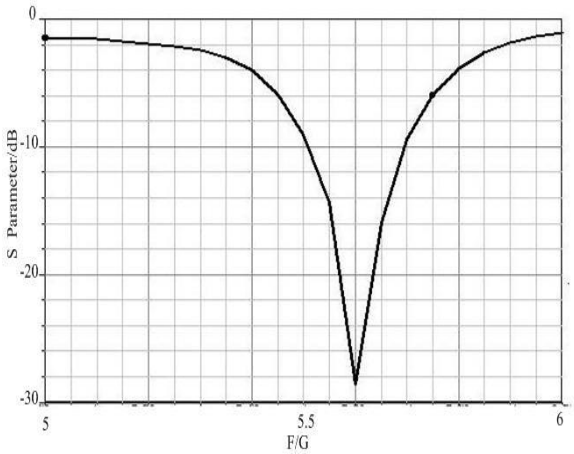
Figure 7. The geometry of the array and its elements

The array is composed of 4 single elements fed by a T-shaped branch and it is printed on a Teflon substrate of thickness 2mm and relative permittivity of 2.7. The operating frequency is 5.6 GHz. At present, there is no exact formula to calculate characteristic impedance of micro-strip patch, but have empirical formula and simulation results. We cannot know exact input impedance of the antenna, causing it more difficult to design. Calculated by ADS software, the widths of the signal strips of the 100, 70.7,50 ohms micro-strip feed lines are 1.41 mm, 2.98 mm, and 5.41 mm respectively. Similarly, corresponding quarter wavelength is 9.32 mm. The calculated data are used as the original value for simulation optimization, simulating the antenna array and feed networks by HFSS. After simulating, it shows that the real part of the port impedance is very small whereas the imaginary part is negative and large. Hence, it is not optimized matching and the impedance character is capacitive. Thus in order to get a good matching, we need to reduce width of micro-strip line to cut down the capacitance value. Finally, we have good matching.

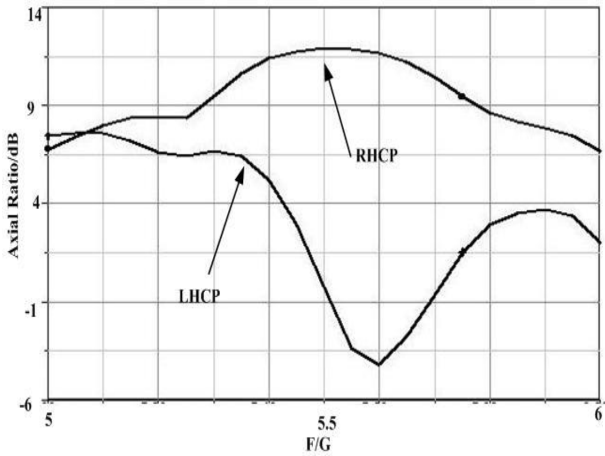
A parallel feeding network including three T-shaped branches is designed. A 50 ohm micro-strip feed line is arranged to feed the whole array for measurement, whereas the input impedance of the element is about 50 ohm. Taking a single patch as an example, the structures of the feed network is that the port 1 via a quarter wavelength transformation line to port 2 and then via a T-shaped branches to port 3 and between port 4 and the feed port there is a quarter wavelength transformation line with 70.7 ohm, it is the same to feed the other patch. Such feed network structure is simple, as long as each port is matching well when all the elements can be realized through the equal amplitude in-phase.

V. SIMULATED RESULTS

Figure 8 shows the simulated results of the antenna array. Figure 8 (a) shows the simulated return loss, at the operating frequency 5.6 GHz [19] reach to -28 dB. Figure 8 (b) shows the simulated gain for the array and the radiating element, at the operating frequency, the gain of right-hand circular polarization (RHCP) reach to 12 dB and when it is left-hand circular polarization (LHCP) then it is -3 dB, the difference of 15 dB means the array achieves a good circularly polarize. Figure 8 (c) shows the simulated radiation patterns at E, H planes of the array and the 3 dB bandwidth of the array reaches to 4%. All of the simulated results show that the proposed antenna array is effective and efficient and has be successfully designed.



(a)



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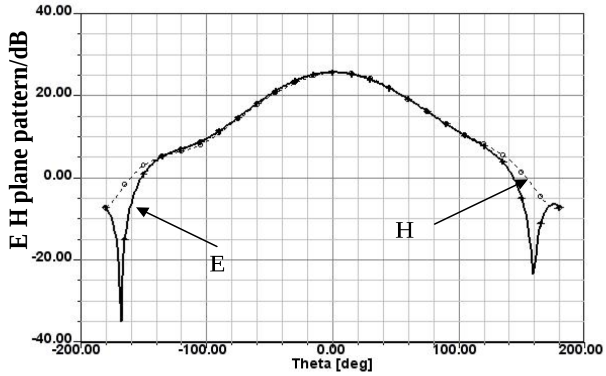
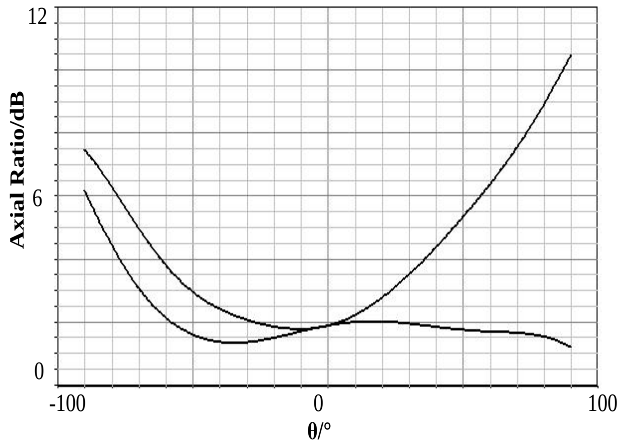


(c)



(d)

Figure 8. Simulation results of the 2*2 pentagon micro-strip antenna array:
(a) Return Loss, (b) EH Plane Pattern, (c) Gain, and (d) Axial Ratio

VI. CONCLUSION

A micro-strip line fed 2*2 antenna array composed of circularly polarized patch element is proposed. Through the design, we researched the dimensions of off-set pentagon antenna; the pentagon patch element achieves circular polarization and a broad bandwidth. Through a parallel feeding network, the array achieves 4% 3 dB bandwidth. This study on circular polarization antenna array design provides a feasible method for the design of circular polarization micro-strip antenna array. The proposed design method can be used as a unit building block to implement a large array to achieve the circular polarization as the higher antenna gain level is required.

REFERENCES

[1] Kabacik, P. Wincza, K. Kamaszuk et al, "Optimizing Circular Polarization in Broadband Light Weight Patch Antennas," Antennas and

Propagation Society International Symposium, IEEE, Washington, USA, Vol. 2A, pp. 258-261, July 2005.

[1] Zhang Y.P., Wang J.J.,"Theory and Analysis of Differentially-Driven Micro-Strip Antennas," IEEE Transactions on Antennas and Propagation, Vol. 54, no. 4, pp. 1092-1099, 2006.

[2] E. A. Soliman, S. Brekls. Delmoue. GA. E. Vandenbasch and E. Beyne,"Bow-Tie Dot Antenna Fed by CPW," Eisctmnics Letrers Vol. 35, pp. 514-515, Apr. 1999.

[3] Jung-Mi" Kim, Jong-Gwan Ycmk, Woo-Young Song, Young-Joong Ymn, Jae-Yeong Park, and Han-Kyu Park,"Compact Meander-Type Slot Antennas" APS 2001 IEEE hfernafionol Sym, Vol.2, pp. 724-721, Jun. 2001.

[4] Lau K.L., Luk K.M., Lee K.L.,"Design of a Circularly-Polarized Vertical Patch Antenna," IEEE Transactions on Antennas and Propagation, Vol. 54, no. 4, pp. 1331-1335, 2006.

[5] Kamaszuk M., Hornik P., Guzda D. et al,"Optimizing Circular Polarization Within a Beam of Patch Antenna Elements," International Conference on Radar & Wireless Communications, Vol. 1, pp. 951-954, May 2006.

[6] Xihui Tang, Ka-Leung Lau, Quan Xue, and Yunliang Long,"Design of Small Circularly Polarized Patch Antenna," IEEE Antennas and Wireless Propagation Letters, Vol. 9, pp. 728-731, 2010.

[7] Bahl I.J., and P. Bhartia,"Microstrip Antennas," MA: Artech Hosue, Dedham, 1980.

[8] Rui-Hung Chen and Jeen-Sheen Row,"Single-Fed Micero-Strip Patch Antenna with Switchable Polarization," Transactions on Antenna and Propagation, IEEE, Vol. 5, pp. 922-926, 2008.

[9] Wei He, Ronghong Jin, and Junping Geng,"E-Shape Patch with Wideband and Circular Polarization for Millimeter- Wave Communication," Transactions on Antenna and Propagation, IEEE, Vol. 3, pp. 893-895, 2008.

[10] He Haidan,"A Novel Wide Beam Circular Polarization Antenna-Microstrip-Dielectric Antenna," Proceedings in Microwave and Millimeter Wave Technology, pp.381-384, 2002.

[11] Associate Professor Ir. Dr. Wan Khairuddin Ali,"Wideband Microstrip Antenna for Land Based Vechicles-Research Article," RESEARCH VOT: 74038.

[13] Han Qingwen, Yi nianxue, Li Zhongcheng et al,"Design and Realization of Circular Polarization Micro-Strip Antenna," Journal of Chongqing University (Natural Science Edition), Vol. 4, pp. 57-60, 2004.

[14] Wi S. H., Kim J. M., Yoo T. H. et al,"Bow-Tieshaped Meander Slot Antenna for 5 GHz Application," Antennas and Propagation Society International Symposium, IEEE, Vol. 2, pp. 456-459, 2002.

[15] Deng Yundan, Yan Liping, Dong Jinsheng,"Design of a Novel UWB Antenna with Band-Notch Characteristic," Journal of Sichuan University (Natural Science Edition), Vol. 2, pp. 382-394, 2009.

[16] Matin M. M., Sharif B. S., Tsimenidis C. C.,"Probe fed Stacked Patch Antenna for Wideband Applications," IEEE Transactions on Antennas and Propagation, Vol. 55, no. 8, pp. 2385-2388, 2007.

[17] He W., Jin R., Geng J.,"E-Shape Patch with Wideband and Circular Polarization for Millimeter-Wave Communication," IEEE Transactions on Antennas and Propagation, Vol. 56, no. 3, pp. 893-895, 2008.

[18] Tariqul Islam M., Misran N., Ng K. G., "A 4×1 L-Probe Fed Inverted Hybrid E-H Micro-Strip Patch Antenna Array for 3G Application," American Journal of Applied Sciences, Vol. 4, no. 11, pp. 897-901, 2007.

[19] Aline Coelho de Souza, Tan Phu Vuong and Christian Defay, "High Gain Circular Polarization Antenna for 5.8 GHz with Left Handed Material," 6th European Conference on Antennas and Propagation (EUCAP), pp. 2908-2910, 2012.

[20] Rahman M. A., Hossain D., Hossain A., Chowdhury P., "Design of a Circular Polarization Array Antenna With Dual-Orthogonal Feed Circuit," Informatics, Elcetronics & Vision (ICIEV), 2014.

[21] Senic D., Zivkovic Z, Simic M., Sarolic A., "Rectangular Patch Antenna: Design, Wideband Properties and Loss Tangent Influence, Software, Telecommunications and Computer Networks (SoftCOM), 2014 22nd International Conference on 17-19 Sept. 2014.

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