Wide-Band SIW Cavity-Backed Circular Polarized Array Antennas with Sequential Rotation Technique

Dong-Fang Guan[1], Can Ding[2], Haihan Sun[2], and Feng Yuan[1]

***Abstract* – A circularly-polarized (CP) array antenna based on the substrate integrated waveguide (SIW) technology is proposed. The 2×2 linearly polarized SIW sub-arrays with 90° sequential rotation are employed as the radiating elements on the top layer. The sequential rotation technique is introduced to design SIW corporate-feed network on the bottom layer to realize wideband circular polarized characteristic. The network and the radiating elements of the array are both designed on close SIW structure with low cost printed circuit board (PCB) technology. The simulated results show that, the proposed 4×4 array has a large axial ratio (AR) bandwidth of 14% from 18.3 GHz to 21.1 GHz with a gain above 13 dBi.**

1 INTRODUCTION

Circularly polarized (CP) antenna is widely used in wireless communication systems due to its better resistance to polarization mismatch and multi-path effects. In order to boost coverage and data rate, latest demands on communication services require antennas to provide excellent radiation characteristics, such as high gain, broadband, circular polarization. Other favorable features such as low profile, light weight, simplified structure and low cost are also desired [1]-[2]. The planar array antenna is substituting for the reflector or lens antenna for its merits of much lower low-profile and greater agility. The combined design considerations of the axial ratio (AR) bandwidth, gain, and radiation efficiency become the current technology trends and challenges for the planar CP array antennas.

Microstrip array antennas have been extensively employed in CP applications, due to the advantages of compact size and ease of fabrication. The sequential rotation technique has been extensively employed in microstrip arrays to realize CP operations for the considerable AR bandwidth enhancing capability [3]-[4]. In fact, the AR bandwidth is mainly dependent on the feed network rather than the antenna elements. However, the radiation efficiency and gain enhancement of a microstrip array is much limited by the undesirable radiation leakage of the microstrip line feed network. Especially when the size of the array becomes large to achieve high gain, the loss in the feed network gets significant. Metallic waveguide or hollow waveguide with minor dielectric and radiation losses can achieve high radiation efficiency [5]-[6]. However, the design complexity of the metallic waveguide makes it difficult to design sequential rotation feed network.

Recently, the substrate integrated waveguide (SIW) line as another preferred choice over the conventional microstrip line has been proposed [7]. SIW series-feed arrays [8] and corporate-feed arrays [9] with CP characteristic both have been developed but suffered from narrow AR bandwidth, because the feed networks were in phase and the circular polarization was only developed in the radiation elements.

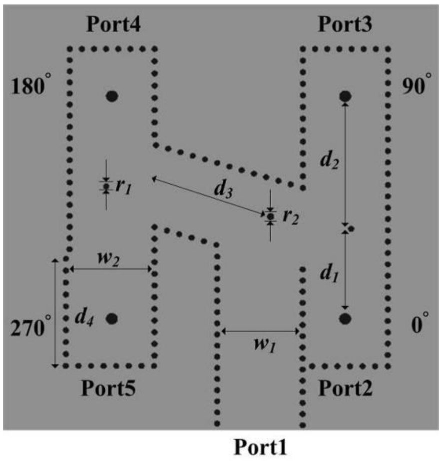


Figure 1: Geometry of sequential feed network.

In this paper, a novel compact 4×4 SIW CP cavity-backed array is proposed. The wideband circular polarization characteristic is obtained by combining a specifically designed sequential feed network on the bottom layer and four LP SIW 2×2 sub-arrays on the top layer. The array features compact structure and good radiation performance.

2 4×4 ARRAY DESIGN

2.1 Sequential four-way power divider

The 2×2 compact sequential feed network is shown in Fig. 1. It is designed on a Rogers-Duroid 5880 substrate with the dielectric constant of ε_r = 2.2, the loss tangent of $\tan\delta$ = 0.0009, and the substrate thickness of h = 0.5 mm. The input port is feeding at the side face. Four pins are distributed symmetrically as the outputs and employed to feed the radiating elements in the next design. The phase sequential rotation is realized by adding delay lines. The network can be seen as an unsymmetrical H-type four-way power divider.

The optimization procedure is given as follows. Firstly, tune the length of the output branches, d_1 and d_2 to get a 90^0 phase shift between Ports 2 and 3. Same phase shift can be realized between Ports 5 and

---

[1] College of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China
e-mail:gdfguandongfang@163.com.
[2] Global Big Data Technologies Centre, University of Technology Sydney (UTS), Australia
e-mail: can.ding@uts.edu.au. Phone: +61 0466527721.

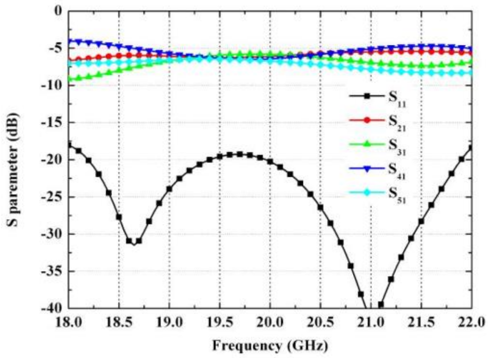


Fig. 2 Amplitude characteristic of the sequential feed network.

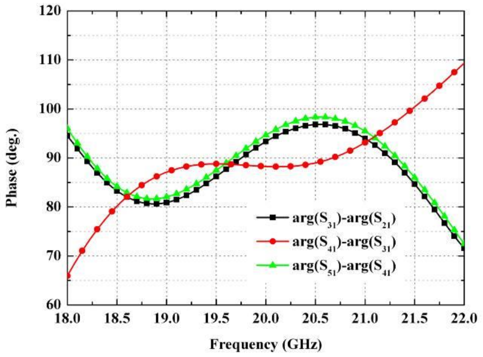


Fig. 3 Phase characteristic of the sequential feed network.

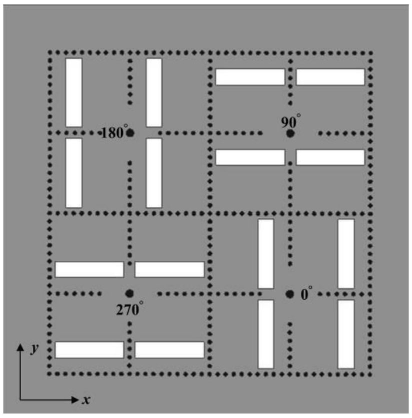


Fig. 4 Geometry of the 4×4 array.

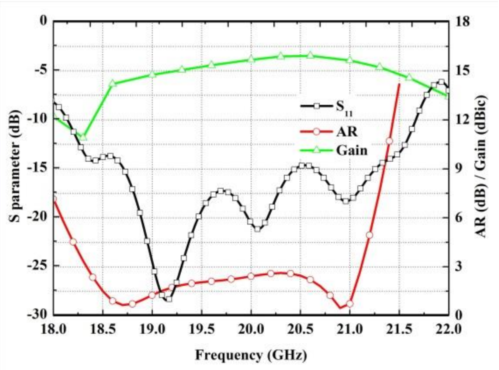


Fig. 5 Simulated reflection coefficient, AR, and gain of the 4×4 array.

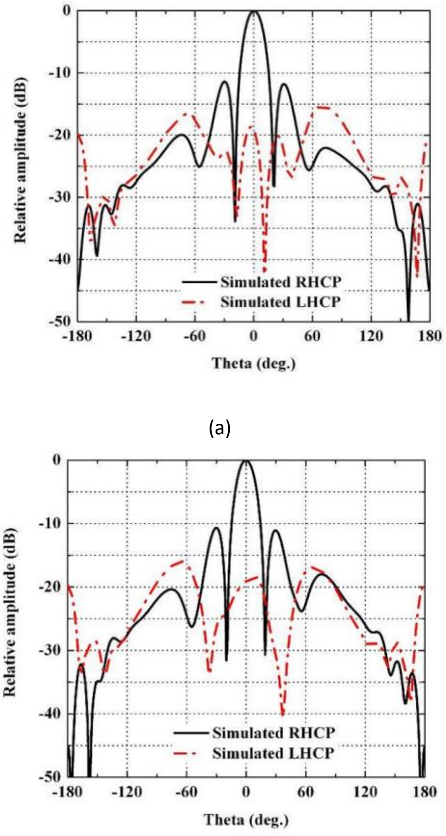
4 since the structure is rotational symmetric. Subsequently, place the input SIW line inclining to the right side to produce a phase delay for the left branch. By adjusting d_3, a 180° phase delay can be obtained between the left and right branches. The design of the first class T-junction will introduce the phase difference to the former procedure, so lastly, an unequal-width phaser with the width of w_2 and the length of d_4 need to be inserted in the port5 branch to compensate the phase error. By optimizing the length of the delay lines (d_1, d_2 and d_3), the parameters of the built-in phaser (d_4 and w_2), and the radius of the metallic posts (r_1 and r_2), a 1-to-4 power dividers with 90° sequential rotation phase is achieved. The optimized dimension values are d_1=8.1 mm, d_2=11.9 mm, d_3=10.6 mm, d_4=9.6 mm, w_1=6.8 mm,w_2 =7.1 mm, r_1 =0.3 mm,r_2 = r_3=0.25 mm

Figs. 2 and 3 show the simulated output amplitude and phase characteristics of the feed network, respectively. As shown in Fig. 2, the S_{n1} (n=2, 3, 4, 5) is nearly the theoretical value of -6 dB at the centre frequency 20 GHz and the amplitude imbalance is within ± 2 dB from 18 to 22 GHz. The return loss is better than 15 dB over the work band. The results of phase difference between adjacent output ports are shown in Fig. 3. The 90° phase difference is obtained at the centre frequency 20 GHz and the phase error is within ±10° from 18 GHz to 22 GHz covering a 20% relative bandwidth. The results indicate that the feed network can work over a wide bandwidth as well as maintain a compact structure.

2.2 Array design and radiation performance

The radiating layer of the proposed 4×4 array is presented in Fig. 4. It is also designed on the Rogers-Duroid 5880 substrate with the thickness h = 1.5 mm. Although the feed network in the former part is compact, the width of SIW feed line is so wide that the distance between the adjacent output pins is still more than a free-space wavelength. Using 2×2 sub-array as the radiating element is a perfect method to solve this problem. In our previous work [11], a novel 2×2 SIW array has been employed as the cell unit to constitute a 16×16 large-scale linearly polarized array antenna. Due to its excellent radiation performance such as wideband, high gain, and low loss, the proposed 2×2 array is used in this CP array design. As shown in Fig. 4, four sub-arrays are placed with 90° sequential rotation in correspondence with the network in the bottom layer. The sub-arrays are fed at the center by the PINs with 90° phase delay in the counterclockwise direction, thus right-hand circularly polarized (RHCP) characteristic can be achieved by the 4×4 array.

Simulated reflection coefficient S_{11}, AR, and gain of the proposed array are presented in Fig. 5. The 3-dB AR bandwidth of the array is 14% from 18.3 GHz to 21.1 GHz. In this band, the S_{11} is < -14 dB and the realized gain is > 13 dBic with a peak gain of 15.9 dBic at 20.6 GHz. Fig. 6 shows the simulated normalized radiation patterns in *xz*- and *yz*-planes at 20 GHz. As observed from Fig. 6, the 3-dB beamwidths in both *xz*-and *yz*-planes are about 18°, the side lobe levels (SLL) and the cross-polarization levels are < -11 dB and < -18 dB, respectively. The results show that the CP array has a wide AR bandwidth with superior radiation performance.



(a)

(b)

Fig. 6 Simulated radiation patterns of the 4×4 array at 20 GHz, (a) xz-plane, (b) yz-plane.

3 CONCLUSION

An SIW CP array antenna using linear polarized 2×2 sub-arrays as radiating elements and a novel sequential rotation SIW feed network is proposed in this paper. The obtained 4×4 array has a wide AR bandwidth and satisfactory radiation performance, which can be an alternative design for applications in wireless communications.

References

[1] Yahya Rahmat-Samii and Arthur C. Densmore, “Technology trends and challenges of antennas for satellite communication systems,” IEEE Trans. Antennas Propag., accepted.

[2] S. Ye, X. L. Liang, W. Z. Wang, R. H. Jin, J. P, Geng, T. S. Bird, and Y. J. Guo, “High-gain planar antenna arrays for mobile satellite communications,” IEEE Antennas and Propagation Magazine, vol. 54, no. 6, pp. 256–268, Dec. 2012.

[3] C. J. Deng, Y. Li, Z. J. Zhang, and Z. H. Feng, “A wideband sequential-phase fed circularly polarized patch array,” IEEE Trans. Antennas Propag., vol. 62, no. 7, pp. 3890–3893, Jul. 2014.

[4] S. K. Lin and Y. C. Lin, “A compact sequential-phase feed using uniform transmission lines for circularly polarized sequential-rotation arrays,” IEEE Trans. Antennas Propag., vol. 59, no. 7, pp. 2721–2724, Jul. 2011.

[5] D. Kim, J. Hirokawa, M. Ando, J. Takeuchi and A. Hirata, “64×64-element and 32×32-element slot array antennas using double-layer hollow-waveguide corporate-feed in the 120 GHz band,” IEEE Trans. Antennas Propag., vol. 62, no. 3, pp. 1507–1512, Mar. 2014.

[6] T. Tomura, Y. Miura, M. Zhang, J. Hirokawa and M. Ando, “A 45° linearly polarized hollow-waveguide corporate-feed slot array antenna in the 60-GHz band,” IEEE Trans. Antennas Propag., vol. 60, no. 8, pp. 3640–3646, Aug. 2012.

[7] W. Hong, K. Wu, H. J. Tang, J. X. Chen, P. Chen, Y. J Cheng, and J. F. Xu, “SIW-like guided wave structures and applications,” IEICE Trans. Electron., vol. E92-C, no. 9, pp. 1111–1123, Sep. 2009.

[8] P. Chen, W. Hong, Z. Q. Kuai and J. F. Xu, “A substrate integrated waveguide circular polarized slot radiator and its linear array,” IEEE Antennas Wirel. Propag. Lett., vol. 8, pp. 120-123, 2009.

[9] A. B. Guntupalli and K. Wu, “60-GHz circularly polarized antenna array made in low-cost fabrication process,” IEEE Antennas Wirel. Propag. Lett., vol. 13, pp. 864-867, 2014.

[10] D. F. Guan, C. Ding, Z. P. Qian, Y. S. Zhang, W. Q. Cao, and Eryk Dutkiewicz, “A SIW Based Large-Scale Corporate-Feed Array Antenna,” IEEE Trans. Antennas Propag., vol. 63, no. 7, pp. 2969–2976, Jul. 2015.