Design of an Orthogonal Feed Circularly Polarized Microstrip Array Antenna Suitable for Large Scale Extensible Arrays

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***Abstract*— This paper presents a circularly polarized 1×2 array antenna for X-band applications. Both-sided MIC technology is effectively used to design this array antenna as the array antenna consists of both microstrip lines and slot lines to realize the feed network. Patch elements and microstrip lines are placed on the top surface of the substrate and slot lines on the reverse surface (ground plan) of the substrate. Each of the patches is excited by two orthogonal feed lines. One of the feed lines is ahead by an odd multiple of quarter wavelength than the other feed line. This strategy makes the each patch circularly polarized. The impedance bandwidth is about 630 MHz and the 3-dB axial ratio bandwidth is more than 1%. This array antenna is very suitable to make large scale extensible array antennas by using it as a unit array.**

Keywords-circular polarization; microstrip antenna; array antenna; axial ratio

I. Introduction

In recent years, circular polarization (CP) antennas have received attention due to their inherent ability to reduce polarization losses [1] and losses due to multipath propagation [2]. Low profile characteristics make microstrip antennas attractive for various microwave wireless applications such as RFID tag, radar, WLAN and various types of sensors [3-4]. Generally the microstrip patch antenna is classified as a low to moderate gain antenna [5], but many applications need high gain characteristics. To overcome this problem, array construction can be a suitable way and extensible capability of the array is the most preferable to increase the gain of the antenna.

In case of a single patch, creating perturbation in the patch is the main technique to generate CP. Another way is to create two equal orthogonal degenerate modes using orthogonal feed lines. Several methods have been reported to generate circular polarization. A microstrip CP patch antenna has been reported in [6] where two opposite corners of the patch are truncated to excite two near-degenerate orthogonal resonant modes. In [7], a CP cut ring microstrip antenna has been demonstrated. In this antenna, a ring plane cut by sector is used as a patch and an air layer is loaded between the patch and the ground plane. Another antenna fed by a 3-dB substrate integrated coaxial line (SICL) coupler has been proposed in [8] to radiated circularly polarized wave. A circularly polarized patch antenna with a feed circuit that consists of a 90º broadband balun and two L-shaped probes has been demonstrated in [9]. A small metal sheet that is inserted between two probes reduces the cross-polarization level and hence this method improves the axial ratio of the antenna. A microstrip circularly polarized planar slot antenna fed by microstrip-coplanar waveguide (CPW) has been reported in [10]. A microstrip to CPW transition is used to excite the even and odd modes of the CPW with 90º phase difference and these even and odd modes are coupled to the wide rectangular slot antenna to radiate circularly polarized waves. A dual-reverse-arrow fractal (DRAF) has been introduced in [11] to obtain CP radiation.

On the other hand, singly fed or dual fed patch antennas can be arrayed [12-16]. A serial feed sequentially rotated technique has been used to design a CP array antenna [12] where each patch element is singly fed. In this array, feed network is designed using microstrip lines only. A single layer microstrip array antenna for CP has been proposed in [13] where a 90° hybrid circuit is used to achieve circular polarization. A design of the CP array antenna using linear polarization patches has been proposed in [14] where each patch is placed at either +45º or -45º. Another CP array has been presented in [15] using an orthogonal feed circuit, but this array can't be used as a unit array to extend the array size. Both-sided MIC technology is used to design the array antennas of [13-15] as the feed network in each array consists of microstrip lines and slot lines. Another 128-element CP array antenna subdivided into four two-by-four subarrays is demonstrated in [16] where a one-by-four corporate feed network of hollow metallic waveguides is used to excite the subarrays.

In this paper, an orthogonal feed 1×2 microstrip array antenna is discussed. The feed network is formed by microstrip lines and slot lines where the microstrip lines are on the obverse side and the slot lines are on the reverse side of the

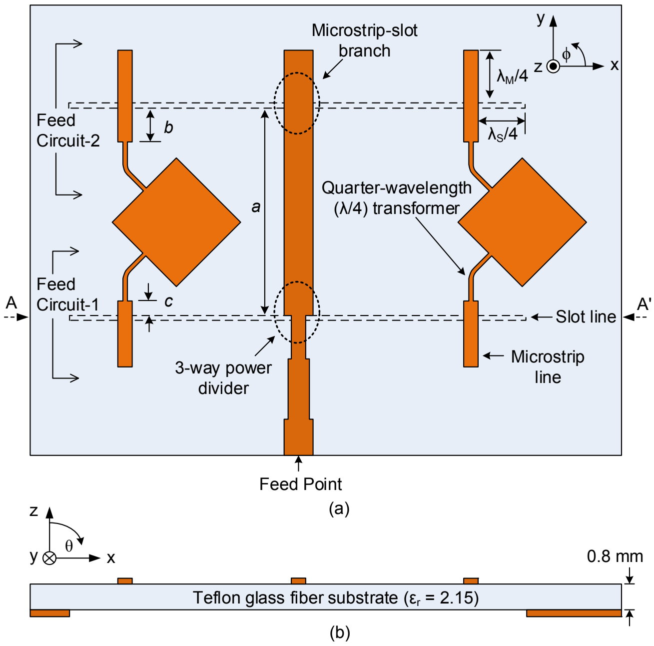


Figure 1. Complete configuration of the proposed array antenna. (a) Top view (b) cross sectional view (A-A′).

substrate. Both-sided MIC technology is successfully utilized to design the feed network. The main feature of this array is its extensible capability and this proposed array antenna can be used to overcome the drawback of the antenna presented in [15] easily. The complete array antenna structure along with antenna performances is presented and discussed in subsequent sections.

II. Antenna Design

Fig. 1 shows the configuration of the proposed array antenna. The array is designed on a Teflon substrate whose different parameters are dielectric permittivity (ε_r) = 2.15, thickness = 0.8 mm and loss tangent = 0.001. The array antenna consists of two patch elements. Each of the patch elements is aligned at 45° with respect to the x axis. Two separate feed lines are used to excite each patch. So there are two separate feed circuits for each patch to excite the patches. A common microstrip line is used as a feed line for both feed circuits.

The feed network is composed of two feed circuits (Feed Circuit-1 and Feed Circuit-2). Microstrip lines and slot line are used to design each feed circuit. Both-sided MIC technology is employed to obtain feed network as it gives the opportunity to use different types of transmission lines on both sides of the substrate [17]. The microstrip lines are on the obverse side of the substrate and the slot lines on the reverse side. Ease of impedance matching to design the feed network is the main benefit of using such type of feed network [18]. The common feed microstrip line and slot line of each feed circuit make a microstrip-slot branch circuit.

Fig. 2 shows the structure of the microstrip-slot branch of Feed Circuit-1 and its equivalent circuit. The microstrip-slot branch acts as a 3-way power divider where half of the total

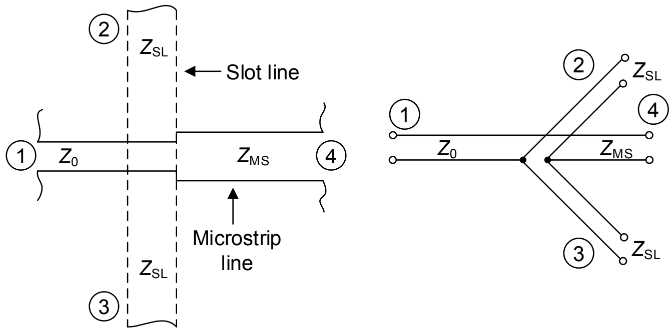


Figure 2. 3-way power divider used in Feed Circuit-1 and its equivalent circuit.

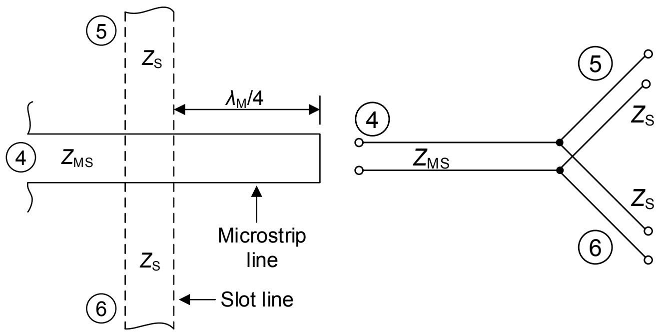


Figure 3. Microstrip-slot branch used in Feed Circuit-2 and its equivalent circuit.

power is divided between two slot branches and remaining half power goes through the microstrip line. The impedances of the microstrip lines and slot line should be chosen according to the following equations for 2:1:1 power division between microstrip line output port (4) and slot line output ports (2 and 3) because the two outputs (2 and 3) located at the two ends of the same slot line form a parallel branch and the output (4) microstrip line creates a series branch with the parallel branch of the slot line:

$$Z_{MS} = Z_{SL} / 2 \tag{1}$$

$$Z_0 = Z_{MS} + Z_{SL} / 2 \tag{2}$$

Fig. 3 illustrates the microstrip-slot branch of Feed Circuit-2 and its equivalent circuit. As the microstrip-slot branch acts as a 2-way parallel power divider, the characteristic impedance of the slot line should be double of the microstrip line impedance ($Z_S = 2Z_{MS}$). The extended microstrip line over the slot line is used as an open-circuit stub whose length should be quarter wavelength at the design frequency.

In both feed circuits, a microstrip line is used at the both ends of the slot line to transfer the signal from the slot line to the patch where the characteristic impedance of these microstrip lines should be equal to the slot line impedance for proper impedance matching. A quarter-wavelength (λ/4) impedance transformer is used between the patch and microstrip line. Feed Circuit-2 is arranged in such a way so that the length of it is an odd multiple of quarter wavelength greater

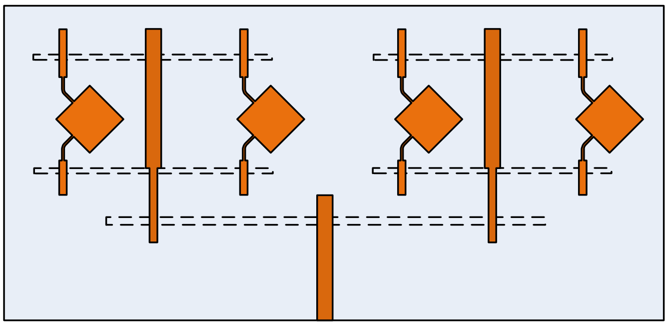


Figure 4. Extension of the array.

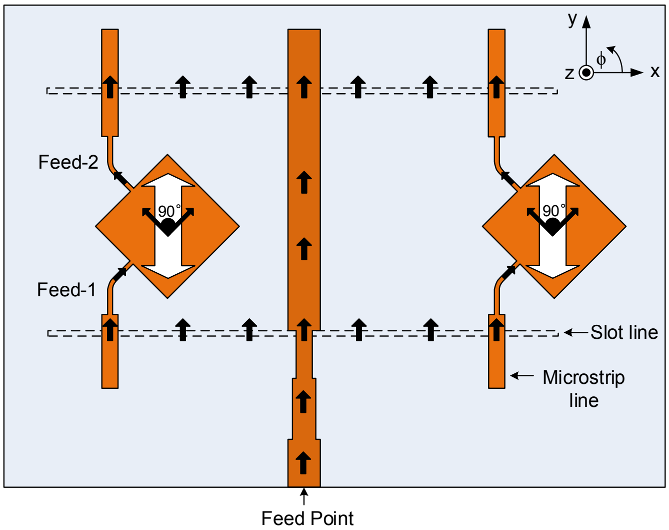


Figure 5. Basic behavior of the array.

than that of Feed Circuit-1. The relation among different lengths to make this arrangement feasible should be according to (3):

$$(a + b) - c = n \times \text{quarter wavelength at design frequency} \qquad (3)$$

where n is an odd number.

In [15], the feed point was on the microstrip line of the microstrip-slot branch circuit. So this configuration is not suitable to make extensible antenna. The feed port of the present antenna is on the edge of the microstrip line. Therefore, it is possible to make this antenna extensible by using another microstrip-slot feed circuit as shown in Fig. 4.

III. Basic Behavior

Fig. 5 can be used to describe the basic behavior of the proposed array antenna. To generate circularly polarized waves, two orthogonal signals with 90° phase shift between them are required. The RF signal of Feed-1 is at an angle of +45° with respect to the x axis. On the other hand, when the RF signal is fed to Feed-2, the signal is -45° with the axis. Combining the signals of Feed-1 and Feed-2, both signals are orthogonal with respect to each other.

To create 90° phase difference between two orthogonal signals, the total length of the upper feed circuit is an odd multiple of quarter wavelength greater than that of the lower feed circuit.

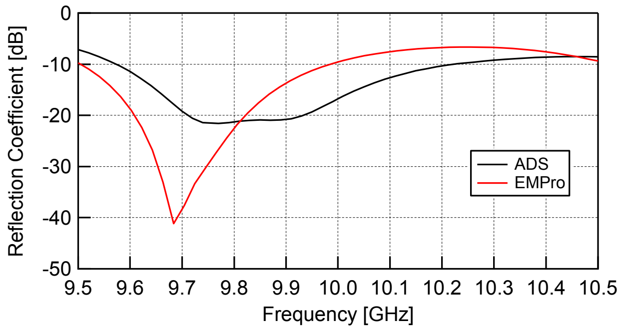


Figure 6. Reflection coefficient of the proposed array.

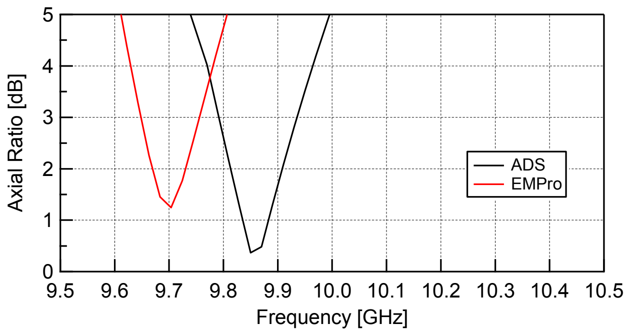


Figure 7. Axial ratio of the proposed array.

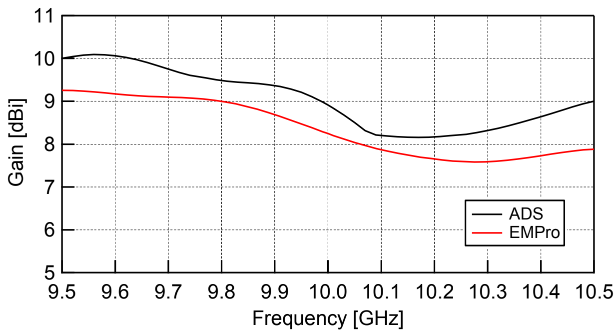


Figure 8. Gain of the proposed array.

Therefore, theoretically two orthogonal signals are formed with 90° phase difference in the proposed array structure that is the main condition to excite circularly polarized signal.

IV. Simulation Results and Discussions

The proposed array antenna is designed and simulated using Keysight Technologies' Advanced Design System (ADS) Momentum. The performance is also verified using the FEM of another EM simulator, EMPro.

Fig. 6 shows the reflection coefficient of the proposed array. The figure indicates that the reflection coefficient is smaller than -10 dB from 9.58 GHz to 10.21 GHz. So the impedance bandwidth according to ADS simulation is 630 MHz or 6.37% with respect to the center frequency of 9.895

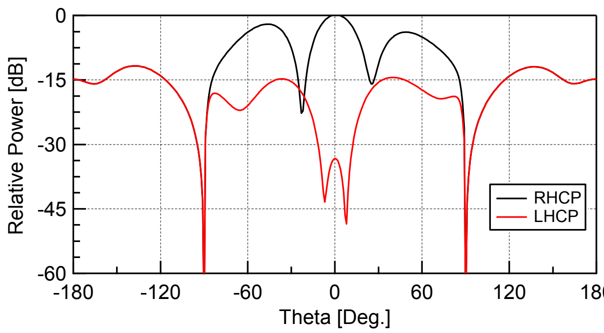
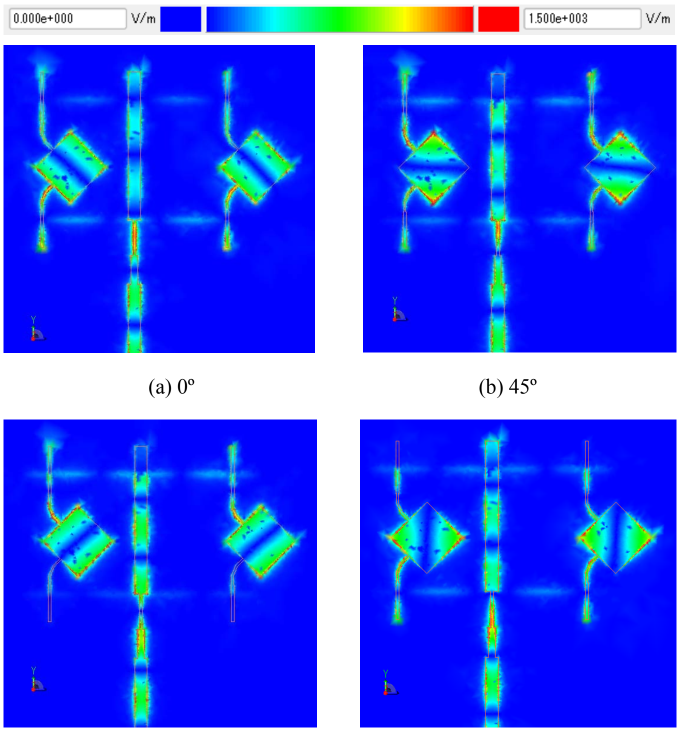


Figure 9. Radiation patern of the proposed array simulated by ADS at 9.85 GHz ($\phi = 0°$).



(a) 0º (b) 45º

(c) 90º (d) 135º

Figure 10. Electric field distribution at different phase instant at 9.85 GHz.

GHz. The result of EMPro also agrees well with ADS except only a slight shift to the lower frequency.

Fig. 7 illustrates the axial ratio of the proposed array antenna. The 3-dB axial ratio bandwidths of the array from ADS and EMPro simulation results are about 150 MHz or 1.52% (center frequency = 9.87 GHz) and about 100 MHz 1.03% (center frequency = 9.70 GHz), respectively.

Fig. 8 plots the gain of the proposed antenna. It is observed that a flat gain is obtained and the gain is greater than 8 dBi for whole bandwidth.

Fig. 9 shows the radiation pattern of the designed array antenna at 9.85 GHz. It is found that the antenna is right hand circularly polarized (RHCP). The cross polarization level of the antenna is better than -30 dB. The side lobes of the pattern are high and it is a constraint of this antenna. These high side lobes reduce the gain of the antenna. Fig. 10 illustrates the electric field distribution at 9.85 GHz. From the figure, it is observed that at the different phase instant from 0° to 135° with an interval of 45°, the electric field of the patches rotates in a counterclockwise (CCW) direction with phase. So it indicates that the radiation of the array is RHCP.

The performance of the proposed antenna is quite better than other types of the CP antennas designed by other different methods. Besides, the structure of this antenna is simple. For conventional CP antennas using the perturbation technique, the design process is not straight forward as perturbation is needed to create in the patch. Moreover, axial ratio bandwidth is narrow and most of the cases, it is less than 1%. On the other hand, CP antennas constructed as arrays using linear polarization patches take the larger size to excite CP radiation and gain is lower than the CP arrays designed using CP patches. So considering these points, the proposed antenna is a good candidate for various communication applications.

V. CONCLUSION

A design of a 1×2 circularly polarized array antenna has been presented in this paper. It is easy to design and suitable for using it as a unit array to design extensible array antennas. Both-sided MIC technology is successfully applied to design this array antenna to take its inherent advantage of using several types of transmission lines on both the sides of the substrate. Orthogonal feed is used and one of the feed lines is made odd multiples of quarter wavelength at design frequency greater than the other feed line of the patch. This strategy makes each patch circularly polarized. The 3-dB axial ratio bandwidth of the antenna is more than 100 MHz and the radiation is right hand circularly polarized (RHCP). The designed antenna is suitable for different X-band applications such as radar, amateur radio, various motion detectors etc.

REFERENCES

[1] J. Garcia, A. Arriola, F. Casado, X. Chen, J. I. Sancho, and D. Valderas, "Coverage and read range comparison of linearly and circularly polarized radio frequency identification ultra-high frequency tag antennas," IET Microw. Antennas and Propag., vol. 6, no. 9, pp. 1070–1078, Jun. 2012.

[2] Y. Qin, S. Gao, and A. Sambell, "Broadband high-efficiency circularly polarized active antenna and array for RF front-end application," IEEE Trans. Microw. Theory Tech., vol. 54, no. 7, pp. 2910–2916, Jul. 2006.

[3] M. A. Kossel, R. Kung, H. Benedickter, and W. Biichtokd, "An active tagging system using circular-polarization modulation," IEEE Trans. Microw. Theory Tech., vol. 47, no. 12, pp. 2242–2248, Dec. 1999.

[4] S.-T. Fang, "A novel polarization diversity antenna for WLAN application," 2000 IEEE Antennas and Propag. Soc. Int'l Symp. Dig. (AP-S2000), pp. 282–285, Jul. 2000.

[5] R. B. Waterhouse, Microstrip Patch Antennas: A Designer's Guide, Springer Science+Business Media, LLC, New York, 2003.

[6] W. S. Chen, C. K. Wu, and K. L. Wong, "Single-feed square-ring microstrip antenna with truncated corners for compact circular polarization operation," Electron. Lett., vol. 34, no. 11, pp. 1045–1047, May 1998.

[7] Y. Yi, L. J. Ying, W. Kun, X. Rui, and Y. G. Wei, “Circularly polarised cut ring microstrip antenna,” Electron. Lett., vol. 51, no. 3, pp. 199-200, Feb. 2015.

[8] Q. Wu, H. Wang, C. Yu, X. Zhang, and W. Hong, “L/S-Band dual-circularly polarized antenna fed by 3-dB coupler,” IEEE Antennas and Wireless Propag. Lett., vol. 14, pp. 426-429, Oct. 2014.

[9] J. Zhuang, Y. Zhang, W. Hong, and Z. Hao, “A broadband circularly polarized patch antenna with improved axial ratio,” IEEE Antennas and Wireless Propag. Lett., vol. 14, pp. 1180-1183, Jan. 2015.

[10] H.-G. Xue, X.-X. Yang, and Z. Ma, “A novel microstrip-CPW fed planar slot antenna with broadband and circular polarization,” IEEE Antennas and Wireless Propag. Lett., vol. 14, pp. 1392-1395, Mar. 2015.

[11] H. Orazi and H. Soleimani, “Miniaturisation of the triangular patch antenna by the novel dual-reverse-arrow fractal,” IET Proc. Microw. Antennas and Propag., vol. 9, issue 7, pp. 627-633, May 2015.

[12] M. N. Jazi and M. N. Azarmanesh, “Design and implementation of circularly polarized microstrip antenna array using a new serial feed sequentially rotated technique,” IEE Proc. Microw. Antennas Propag., vol. 153, no. 2, pp. 133-140, Apr. 2006.

[13] Y. Ushijima, E. Nishiyama, and M. Aikawa, “Single-layer integrated microstrip array antenna for dual circular polarisation,” IET Proc. Microw. Antennas and Propag., vol. 6, no. 8, pp. 962-968, Jun. 2012.

[14] M. A. Rahman, Q. D. Hossain, M. A. Hossaina, E. Nishiyama, and I. Toyoda, “Design and parametric analysis of a planar array antenna for circular polarization,” Int’l J. Microwave and Wireless Technologies, pp. 1-9, Mar. 2015. [doi: 10.1017/S1759078715000264]

[15] M. A. Rahman, Q. D. Hossain, M. A. Hossaina, and P. Chowdhury, “Design of a circular polarization array antenna with dual-orthogonal feed circuit,” Int’l Conf. of Informatics, Electronics & Vision (ICIEV2014), pp. 1-5, May 2014.

[16] M. Shahabadi, D. Busuioc, A. Borji, and S. Safavi-Naeini, “Low-cost, high-efficiency quasi-planar array of waveguide-fed circularly polarized microstrip antennas,” IEEE Trans. Antennas and Propag., vol. 53, no. 6, pp. 2036-2043, Jun. 2005.

[17] M. Aikawa and H. Ogawa, “Double-sided MIC’s and their applications,” IEEE Trans. Microw. Theory Tech., vol. 37, no. 2, pp. 406–413, Feb. 1989.

[18] K. Kodama, E. Nishiyama, and M. Aikawa, “Slot array antenna using both-sided MIC technology,” Proc. 2004 IEEE Int’l symp. on Antennas and Propag. (ISAP2004), vol. 3, pp. 2715-2718, Jun. 2004.