Broadband Circularly Polarized Microstrip Antenna Element and Array with a New Feed

Nasimuddin[1] and Karu P. Esselle[2]
[1]*Institute for Infocomm Research, Singapore 119613*
[2]*Department of Electronics, ICS Division, Macquarie University, Sydney, Australia*
email: nasimuddin@i2r.a-star.edu.sg, karu@ieee.org

Abstract

A new feed is presented for circularly polarized stacked rectangular microstrip antenna elements and their arrays. It consists of a combination of a microstrip line and a via pin. We also present a systematic process to optimise the axial ratio (AR) bandwidth and ellipticity of these antennas. To realize a wide band circularly polarised stacked microstrip patch antenna (CPSMA), a driven patch and a parasitic patch of identical size are considered and the driven patch is fed using the new feed. The gap between them and location of the feed are optimized to achieve a good CP performance. Our single element design has a 3dB AR bandwidth of 17.6% and a gain of more than 8 dBic. A 2 × 2 sequentially rotated array design has a 3dB AR-bandwidth of about 33% and a gain of about 13 dBic. The new feed system is very useful to achieve high gain and wideband CP from a CPSMA array in a space-limited environment.

1. INTRODUCTION

Circularly polarized (CP) antennas are particularly useful in communication systems where the orientation of antennas is variable or is unknown. Circular polarization is usually achieved by combining two orthogonal linearly polarized waves radiating in phase quadrature. There are currently two techniques commonly used in CP microstrip antennas. In the single feed technique, asymmetry is introduced into the geometry of the microstrip radiator so that, when the antenna excited at a carefully selected feed point, the antenna radiates two degenerated orthogonal modes with a 90^o phase difference. In the dual feed technique, two separate and spatially orthogonal feeds are excited with a relative phase shift of 90^o. The dual feed approach requires the use of a 90^o hybrid or power splitter with unequal lengths of transmission line to provide the necessary phase shift. This method generally gives a larger AR bandwidth if both the microstrip radiator and feeding network are broadband. This technique, however, suffers from poor polarization purity due to the cross-polarized components generated by the asymmetrical feed structure. Furthermore, dual-feed technique results in a complicated antenna structure and higher cost, in particular when stacked patches are used for achieving broadband CP operation. In addition they require larger feed structures, which leave less space for other circuit components in the feed layer. On the other hand, single-feed circularly polarized microstrip antennas can be arrayed and easily fed like any linearly polarized patch antenna. Single feed leads to a reduction in complexity, weight, and RF loss of the feed when these elements are used in an array. In these antennas, a perturbed symmetrical patch cavity, for example of square or circular shape, supports two orthogonal modes, which are excited with a single feed. Haneishi et al. [1] have classified two types of feed locations for single-feed CP microstrip antennas: A-type when the feed point is located on the X or Y-axis parallel to an edge of a square patch, and B-type when the feed point is located on the diagonal of a square patch. Several designs of single-feed aperture-coupled CP antennas have been reported, however, their AR bandwidths are usually not sufficient [2].

It is common practice to use stacked patches and electromagnetically coupled patches to increase the gain and/or impedance bandwidth of patch antennas [3,4]. Egashira and Nishiyama [5] have used triple stacked circular patches with a dual feed to achieve a directivity of 10.6 dBi, an AR bandwidth of 8.5% and an impedance bandwidth of 10%. However, the total thickness of this antenna is more than $\lambda/2$. They have further investigated this structure using the FDTD method [6]. Herscovici et al. used a probe-fed rectangular patch with an almost square parasitic element to achieve an excellent AR bandwidth of 13% [7] by using a co-axial feed. Their main patch is on a 0.041λ thick foam substrate and the total thickness of the antenna, including the parasitic patch, is 0.085λ. Nevertheless, the design process required to properly locate the feed point of this antenna in order to achieve an AR around unity is not known yet. The authors of this paper have recently presented a new feed location optimization method to improve the AR bandwidth and quality of circularly polarized coaxial-fed stacked microstrip antennas [8], and achieved around 15% 3dB AR bandwidth with a single element stacked patch antenna.

However, the coaxial feed in this antenna makes it unsuitable for low-cost array applications.

Sequentially rotated feeding systems employed in circularly polarized arrays lead to several advantages, such as polarization purity in the main beam and wide bandwidth [9-11]. A broadband CP 2×2 sequentially-rotated antenna array has been reported in [9], where an impedance bandwidth of 25.6% and a 3-dB AR bandwidth of 23.5% have been achieved. However, the antenna in [9] uses stacked electromagnetically coupled patches, which may mean higher cost and a complicated antenna structure. Herscovici et al. [7] also used their stacked microstrip patch antenna element for 2×2 sequentially rotated array. However, the details of the feeding system, the gain and the AR bandwidth of this antenna are not available.

The purpose of this paper is to propose a new feed system and to present an optimization method for feed location. The new feed arrangement, consisting of a pin connecting the microstrip feedline to the driven patch of the CPSMA, is shown in Fig. 1. We demonstrate how one can design wideband, high-gain CPSMA elements using the methods presented here. We also present the performance of new CPSMA elements in a 2×2 array configuration. First we report a method to improve the AR bandwidth of a single-feed CPSMA by optimizing the feed location and the foam thickness between the main (driven) and parasitic patches. In this process we use what we call a C-Type feed location where the feed is neither on an axis nor on a diagonal of the patch. Next, a 2 ×2 sequentially rotated array is designed to enhance the gain and circular polarization bandwidth. The feed rotation angle (θ) and the separation between the driven and parasitic patches are optimized to achieve a 17.6% AR bandwidth from a single element. The 2×2 array has a 3dB AR bandwidth of 33.3%. This design and optimization was conducted with the help of CST Microwave Studio commercial software [12].

2. DESIGNING A WIDEBAND CP ANTENNA ELEMENT

The configuration of the new CP stacked microstrip patch antenna element is shown in Fig. 1. Note the pin connecting the microstrip feedline to the driven patch. The distance from the microstrip feed line to the centre of the driven patch, d, can be varied for tuning and matching the antenna impedance to the feed line impedance. The feed rotation angle θ can be adjusted to improve ellipticity of polarization and also to bring the AR bandwidth within the 10dB return-loss bandwidth of the antenna. These two parameters are very useful in the design and optimization of an antenna element for wideband, high-gain applications. The parasitic patch may be positioned over the driven patch with help of a foam layer. The foam layer thickness h_3 is optimized to achieve better impedance and AR bandwidths. The second (parasitic) patch is etched on a thin dielectric sheet (of thickness h_4). For simplicity we assume that its dielectric constant is the same as the dielectric constant of the driven patch substrate.

For a given substrate and frequency of operation, the sizes of the two rectangular patches (assumed identical) are obtained by using well-known design equations [1]. In the design process, we first locate the feed point at P_1 (X_o, 0) on the X-axis so that good impedance matching is achieved at the operating frequency. However, with this feed location the antenna is linearly polarized. Then, in order to achieve circular polarization, we move the feed point along the circular arc with radius X_o, between points $P_1(X_o,0)$ and $P_2\left(\frac{X_o}{\sqrt{2}},\frac{X_o}{\sqrt{2}}\right)$. At a certain feed rotation angle (θ), optimum circular polarization is achieved. A generic feed position (X, Y) is given by $X = X_o \cos(\theta)$ and $Y = X_o \sin(\theta)$.

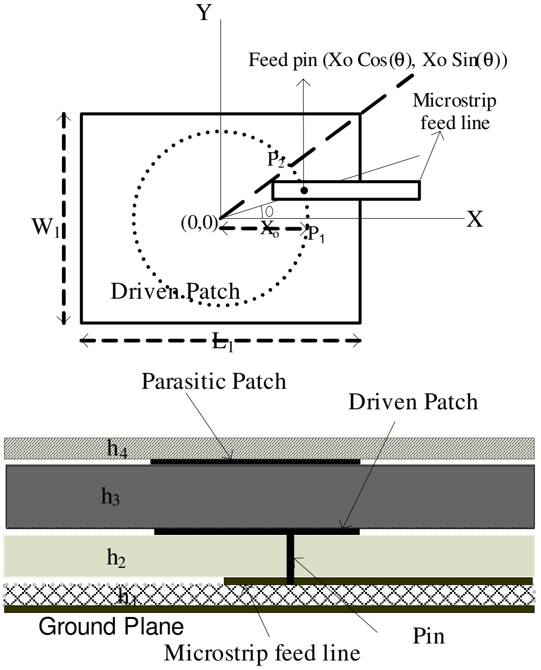

Fig. 1: Configuration of the new CPSMA element. The location of the feed point (pin) is determined by X_o and θ.

A systematic process has been developed for designing the proposed wideband circularly polarized antenna element. First we select the aspect ratio of main and parasitic patches (assumed to be the same) and then we optimize the gap between them and the feed location for good circular polarization [8]. The variation of the return loss, axial ratio and gain with the thickness of the air/foam layer between the driven patch and the parasitic patch is shown in Figs. 2-4, respectively. The return loss does not much significantly with thickness h_3 and 10dB return-loss bandwidth is almost constant for h_3 from 5.4 mm to 6.4 mm. As shown in Fig. 3, the 3dB AR bandwidth and the quality of circular polarization depend on the thickness h_3. For h_3 = 5.8 mm, the best AR is 2.6dB and 3dB AR bandwidth is 18.0% and for h_3 = 6.1 mm best AR is 1.7 dB and the bandwidth is 16.4%. Hence, one can compromise the best AR to obtain wider AR bandwidth.

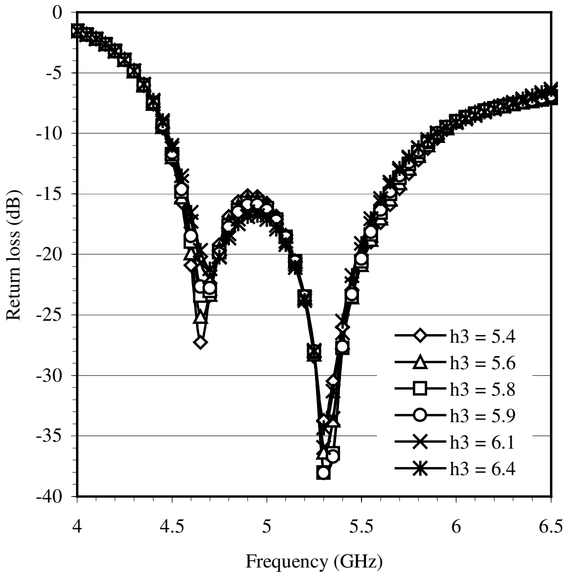

Fig. 2. Return loss versus frequency for different values of foam thickness.

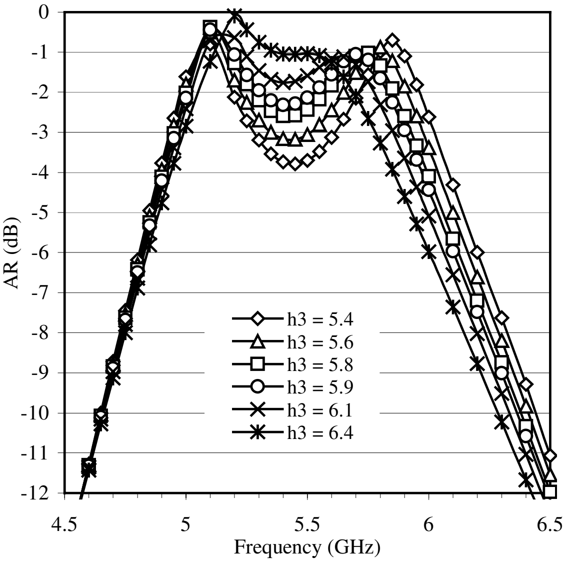

Fig. 3. The AR versus frequency for different values of foam thickness.

The designer and may optimise the antenna for minimum best AR or maximum AR bandwidth. We have selected a thickness (h_3) of 5.9 mm as a compromise (between 5.8 mm and 6.1 mm). As shown in Fig. 4, the circular polarization gain depends slightly on the thickness h_3. The peak gain decreases with increasing h_3.

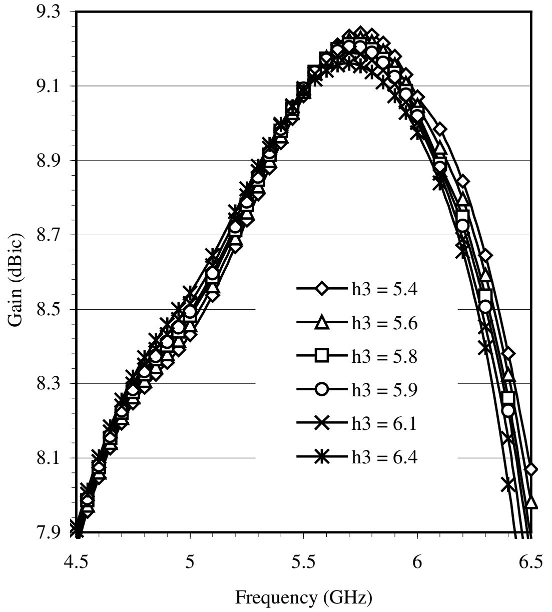

Fig. 4. Gain versus frequency for different values of foam thickness.

The optimized dimensions are- Driven patch: L_1 = 17.5 mm, W_1 = 14.0 mm; Parasitic patch: L_1 = 17.5 mm, W_1 = 14.0 mm; Substrate/foam thicknesses: h_1 = 0.508 mm, h_2 = 1.52 mm, h_3 = 5.9 mm, h_4 = 0.508 mm; Dielectric constant and loss tangent of layers: $\varepsilon_{r1} = 3.02$, $\tan\delta_1 = 0.0015$, $\varepsilon_{r2} = 3.02$, $\tan\delta_2 = 0.0015$, $\varepsilon_{r3} = 1.07$, $\tan\delta_3 = 0.0$, $\varepsilon_{r4} = 3.00$, $\tan\delta_4 = 0.0017$; Feed details: rotation angle $\theta = 35^o$, arc radius (X_o) = 4.5 mm, (x = 3.686 mm, y = 2.58 mm), d = 1.0, microstrip line width = 1.28 mm. This antenna has a theoretical 3dB AR-bandwidth of 17.8% and its gain is more than 8 dBic over the impedance bandwidth.

3. WIDEBAND HIGH-GAIN CP SEQUENTIALLY ROTATED ARRAY

To further improve the gain, AR and impedance bandwidths of the CPSMAs, the antenna proposed in the previous section is employed as an element in a 2 ×2 sequentially rotated array. Each array element is fed by the new feed configuration, consisting of a pin and a microstrip line, described in the previous section. A typical sequentially rotated array, with a 90° rotation between elements, is shown in Fig. 5(a). The new feed makes arraying into sequential rotation more efficient when space is limited. The new circularly polarized stacked microstrip array is shown in Fig. 5(b).

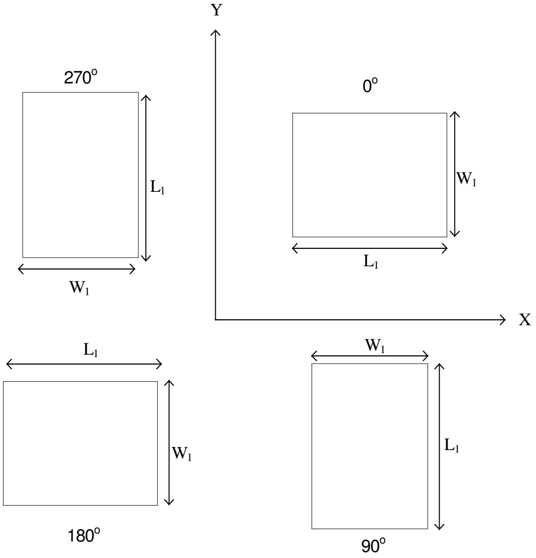

Fig. 5(a). A typical sequentially rotated CPSMA array.

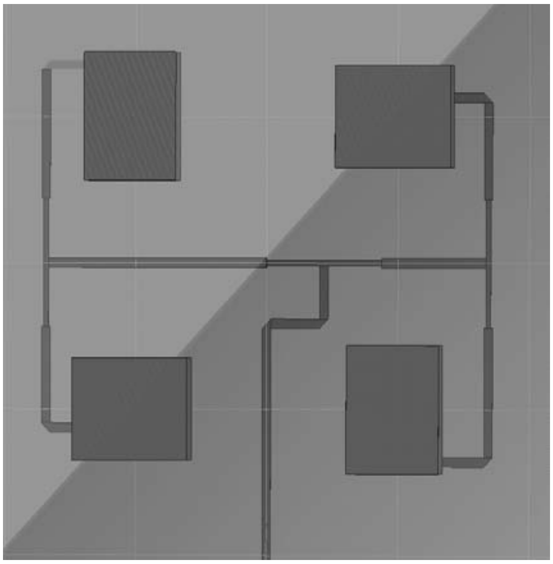

Fig. 5(b). The 2 × 2 sequentially rotated CP array.

The feed network consists of three power dividers, which are designed to produce an impedance match at the array input. Each element is fed with equal amplitude. To produce a 90° phase difference between adjacent elements we added extra microstrip line lengths. The power splitter consists of two quarter-wave transformers at the centre frequency with characteristic impedance of $Z_o\sqrt{2}$, where Z_o = 50Ω. The antenna elements used for the array design are identical to the antenna described in the previous section. The power divider section width (Wt) is 0.75 mm. The distance between adjacent elements in the array is 40 mm (~$0.73\lambda_o$). The guided wavelength (λ_g) is around 35 mm. This CP array has a gain of more than 13 dBic within the impedance bandwidth. We note an improvement of the gain by about 5 dB over a single element. The 3dB AR bandwidth of the array is 33.3%, which is almost two times the bandwidth of a single element.

4. RESULTS AND DISCUSSION

Fig. 6 shows the return loss of a single element and the array. The 10dB return-loss bandwidth of the array is almost double that of the single element. The element 10dB return-loss bandwidth is 27.3% (4.48 GHz – 5.90 GHz) and array bandwidth is 47.8% (4.16 GHz – 6.78 GHz). The ground plane of the single element is 60 mm × 60 mm and array is 100 mm × 100 mm. The axial ratio of the element and the array are shown in Fig. 7. The 3dB AR bandwidth of array is just double compare to the single element. The 3dB AR bandwidth of the single element 17.6% (4.94 GHz to 5.9 GHz) and array it is 33.3% (4.45 GHz to 6.22 GHz).

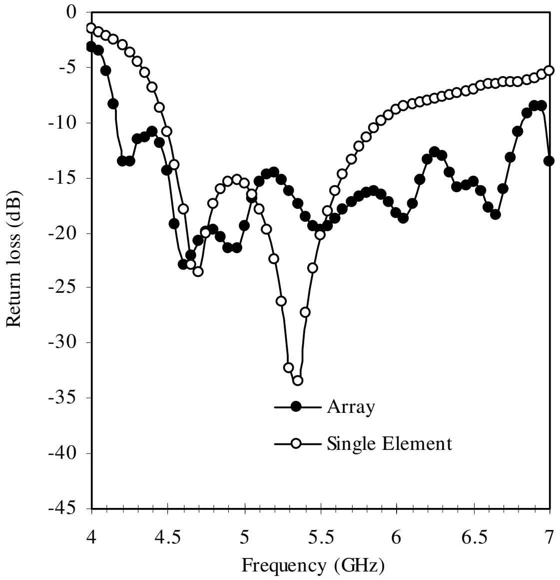

Fig. 6. Return loss of an element and the array.

The gain of an element and the array are shown in Fig. 8. The gain of an element is around 8 dBic over the 3dB AR bandwidth and the gain of the array is around 13 dBic. For single element the gain is more than 8 dBic over the frequency range from 4.55 GHz to 6.45 GHz and the array gain is more than 13 dBic over the frequency range from 4.85 GHz to 6.20 GHz. Thus the gain improvement due to arraying is more than 5 dB over the frequency range from 5.05 GHz to 6.15 GHz.

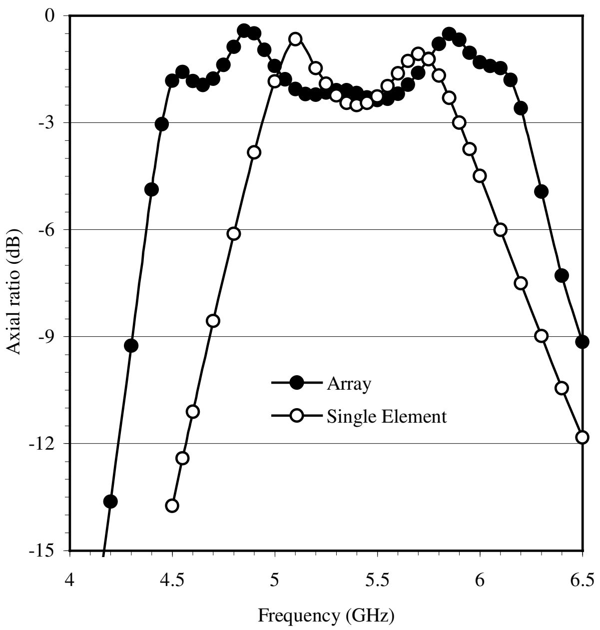

Fig. 7. Axial ratio of an element and the array.

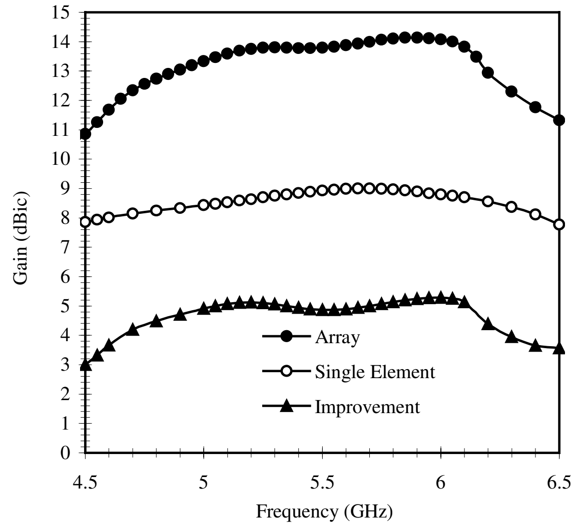

Fig. 8. The gain of an element and the array.

5. CONCLUSION

The new feed arrangement and the C-type feed location optimisation scheme has resulted in wideband CP antenna element designs with 3dB AR bandwidths as large as 17%. The 4-element array of these antenna elements has an AR bandwidth of 33% and its gain over the impedance bandwidth is over 13 dBic. This enhancement of the AR bandwidth and gain has been theoretically obtained by simple sequential arraying, without changing the parameters of the antenna element. These presented new techniques simplify the design of wideband CP antennas for medium-to-high-gain applications. The proposed single feed system consisting of a microstrip-pin combination is desirable to achieve high gain and wide bandwidth in a space-limited environment.

ACKNOWLEDGEMENT

This research is supported by an Australian Research Council (ARC) Discovery Project grant and fellowship. The authors would like to thank Professor A. K. Verma from University of Delhi, India and Dr. Andrew Weily for numerous discussions on this work.

REFERENCES

[1] M. Haneishi and S. Yoshida, "A design method of circularly polarized rectangular microstrip antenna by one-point feed", Microstrip Antenna Design, K.C. Gupta and A. Benalla (Eds), Artech House, Norwood, MA, USA, 1988, pp.313-321.

[2] H. Kim, and B. M. Lee, "A single-feeding circularly polarized microstrip antenna with the effect of hybrid feeding," *IEEE Antennas and Wireless Propagation Letters*, vol. 2, pp. 74-77, 2003.

[3] A. Sabban, "A new broadband stacked two-layer microstrip antenna," *Int Proc. IEEE AP-S International Symposium Digest*, 1983, pp. 63-66.

[4] R. Q. Lee and K. Lee, "Experimental study of the two-layer electromagnetically coupled rectangular patch antenna," *IEEE Trans. Antennas and Propagation*, vol. 38, pp. 1298-1302, August 1990.

[5] S. Egashira and E. Nishiyama, "Stacked microstrip antenna with wide bandwidth and high gain", *IEEE Trans. Antennas and Propagation*, vol. 44, no. 11, Nov. 1996, pp. 1533-1534.

[6] E. Nishiyama, M. Aikawa and S. Egashira, "Stacked microstrip antenna for wideband and high gain", *IEE Proc.-Microwave Antennas Propagation*, vol. 151, no. 2, 2004, pp. 143-148.

[7] N. Herscovici, Z. Sipus and D. Bonefacic, "Circularly polarized single-fed wide-band microstrip patch," *IEEE Trans. on Antennas and Propagation*, vol. 51, no. 6, 2003, pp. 1277-1280.

[8] Nasimuddin, Esselle, K. P., and A. K. Verma, Improving the Axial-Ratio Bandwidth of Circularly Polarized Stacked Microstrip Antennas and enhancing their Gain with Short Horns, accepted in *IEEE Antennas and Propagation Society (AP-S 2006) International Symposium,* 9-14 July 2006, New Mexico.

[9] K. L. Chung and A. S. Mohan, "A circularly polarized stacked electromagnetically coupled patch antenna," *IEEE Trans. Antennas and Propagation*," vol. 52, no. 5, pp. 1365-1369, May 2004.

[10] P. S. Hall, "Application of sequential feeding to wide bandwidth, circularly polarized microstrip patch arrays," *IEE Proceedings on Microwave, Antennas and Propagation*, vol. 136, Oct. 1989, pp. 390-398.

[11] U. R. Kraft, "An experimental study on 2 × 2 sequential-rotation arrays with circularly polarized microstrip

radiators," *IEEE Trans. on Antennas and Propagation*, vol. 45, no. 10, pp. 1459-1466, Oct. 1997.

[12] Computer Simulation Technology, Microwave Studio^{TM}, Version 5.1.