Wideband Circularly Polarized Stacked Microstrip Antennas

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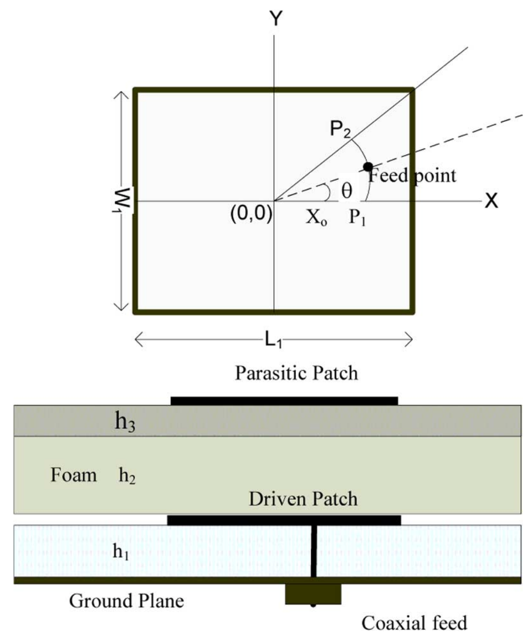
***Abstract*—A simple technique is developed to improve the axial ratio (AR)-bandwidth and quality of circularly polarized stacked microstrip antennas (CPSMAs) using a new C-type single feed. The proposed antenna has been optimized and fabricated, and the computed results agree very well with measurements. The antenna has a 3 dB AR bandwidth of 13.5%, gain is more than 7.5 dBi over the 3 dB AR bandwidth and the 10 dB return-loss bandwidth is 21%. The proposed feed optimization technique is useful for rapid design of circular polarized stacked microstrip antennas.**

***Index Terms*—Axial ratio (AR), circular polarization (CP), coaxial feed, microstrip antenna, patch antenna, optimization, stacked.**

I. Introduction

CIRCULARLY polarized (CP) antennas are required for many applications, including satellite communications. CP microstrip antennas, which need two orthogonal field components with a 90° phase difference, have been developed with both dual [1] and single feed arrangement [2]. The single feed system is more compact. However, one of the serious disadvantages of the single-feed CP antennas is that their impedance and axial-ratio (AR) bandwidths are narrow compared to dual-feed or hybrid-phase-shifter-feed CP antennas. Egashira and Nishiyama [3] have used triple stacked circular patches with a dual-feed to achieve a directivity of 10.6 dBi, AR bandwidth of 8.5% and impedance bandwidth of 10%. However, total thickness of this antenna is more than $\lambda/2$. Herscovici *et al.* used a probe-fed rectangular patch (aspect ratio $\sim$1.21) with an almost square parasitic element (aspect ratio $\sim$1.06) to achieve 13% AR bandwidth [4]. Their main patch is on a 0.04054-λ-thick foam substrate and total thickness of the antenna is 0.085 λ. However, the fabrication of the parasitic patch on foam is difficult and so is its alignment with the driven patch. The paper also does not provide information on the directive gain or the process required to properly locate the feed point to achieve good quality circular polarization. Haneishi *et al.* [2] have classified two types of single feed locations: A-type when feed is located on the X- or Y-axis parallel to the edge of a square patch, B-type when feed is located on the diagonal of a square patch.

In this letter, we report a method to improve the AR bandwidth of a single-feed circularly polarized stacked microstrip antenna (CPSMA) by optimizing the feed location and the foam thickness between the main (driven) and parasitic patches. We have used the C-type feed location where the feed is neither on an axis nor on a diagonal of the patch. The proposed antenna has



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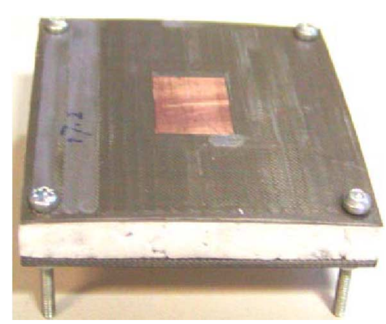

(b)

Fig. 1. (a) Circularly polarized stacked patch antenna with C-type feed. (b) CPSMA prototype.

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Color versions of Fig. 1(a) and (b) are available online at http://ieeexplore.ieee.org

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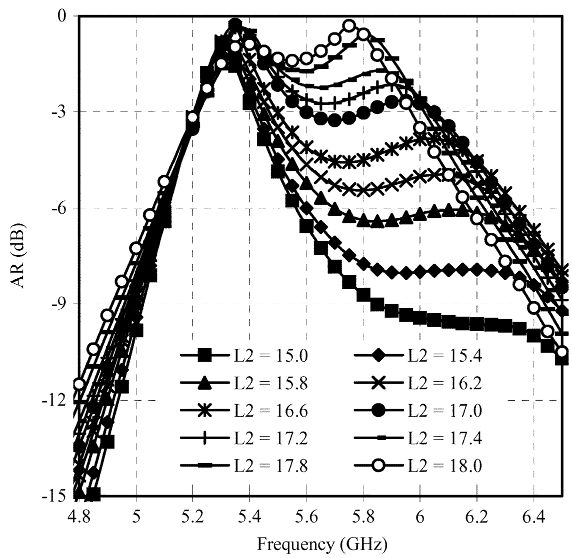


Fig. 2. Variation of AR with frequency and length of the parasitic patch.

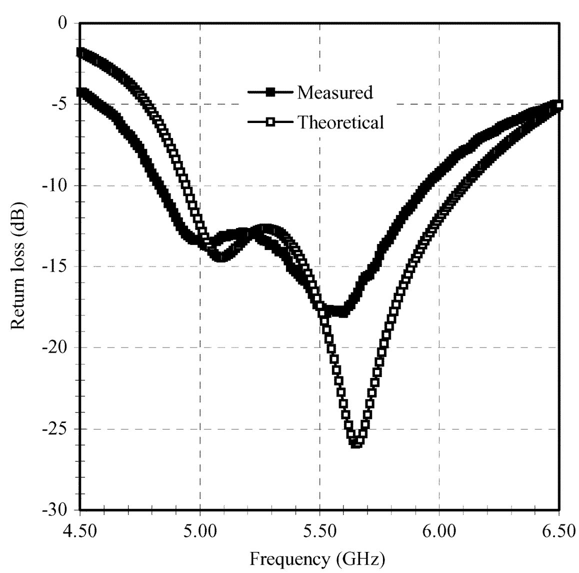


Fig. 3. Return loss of the CPSMA versus frequency.

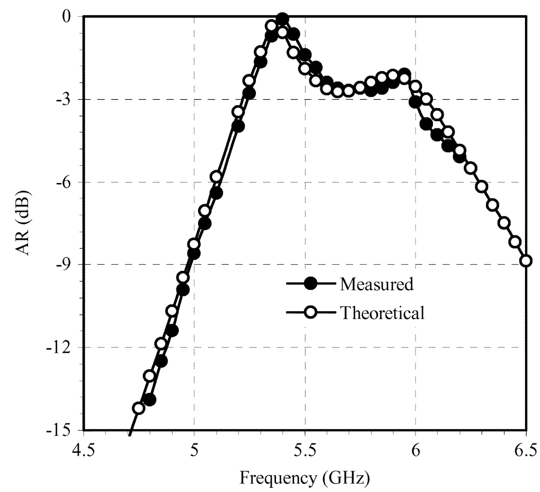


Fig. 4. AR of the CPSMA versus frequency.

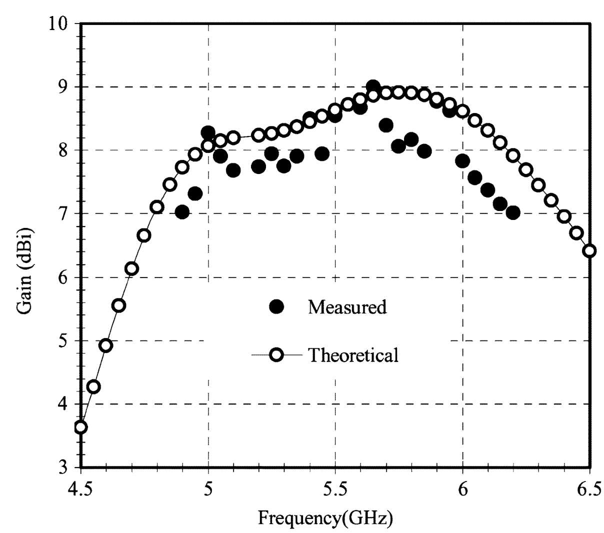


Fig. 5. Gain of the CPSMA versus frequency.

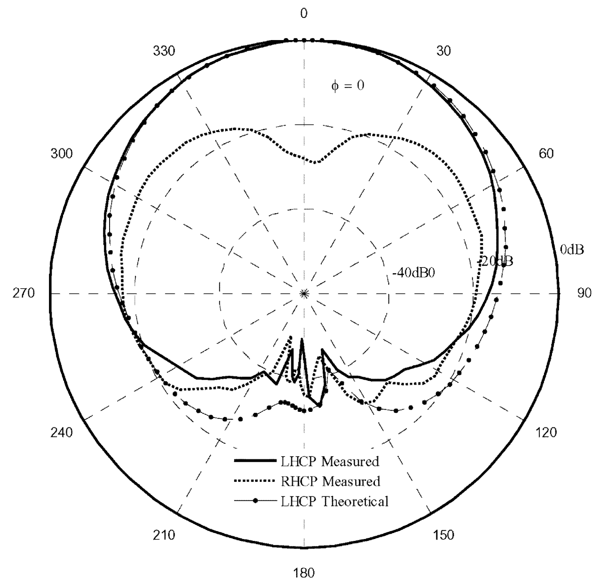
been designed and optimized with the help of CST Microwave Studio software [5], which takes 4-5 min for this simulation.

II. Design of Antenna

The antenna consists of a probe-fed stacked patch configuration; the parasitic rectangular patch is over the driven patch, with a C-type feed located in the first quadrant of driven patch as shown in Fig. 1. To enhance impedance/AR bandwidths, a foam layer of thickness $\mathrm{h_2}$ is sandwiched between the two patches. The second patch (parasitic patch) is etched on a thin dielectric sheet $(\mathrm{h_3})$ of low dielectric constant. In our design, to achieve impedance match, first we locate point $\mathrm{P_1}$ $(\mathrm{X_o}, 0)$, however at this feed location the antenna has linear polarization. In order to achieve the circular polarization, we then move the feed position along the circular arc (with radius $\mathrm{X_o}$), between points $\mathrm{P_1P_2}$. At certain rotation angle (θ) of coaxial feed, the polarization of the antenna is changed to circular. For a given substrate, the size of the rectangular patch is obtained by using well-known design equations [1]. In order to achieve good circular polarization, we need to move the location of coaxial feed position on the arc by changing the feed position (X, Y) according to $X = X_o\cos(\theta), Y = X_o\sin(\theta)$.

We have fixed the aspect ratio of the driven patch (Length $(\mathrm{L_1})/\mathrm{Width}\ (\mathrm{W_1})$) to 1.143 because we found in [6] that this value is suitable to achieve the circular polarization. To achieve optimum AR bandwidth, we need to determine the relative size $(\mathrm{L_2} \times \mathrm{W_2})$) of the parasitic rectangular patch with respect to the size $(\mathrm{L_1} \times \mathrm{W_1})$ of the driven patch. The feed rotation angle (θ) is selected such that the 3 dB AR bandwidth falls within the 10 dB return loss bandwidth [6]. In order to simplify the optimization with Microwave Studio, first we set $\mathrm{W_2} = \mathrm{W_1}$. The antenna structure has been optimized for wideband AR and minimum AR over the frequency band of interest by varying the feed location point (θ), aspect-ratio of the parasitic patch $(\mathrm{L_2}/\mathrm{W_2})$ and thickness of the foam substrate $(\mathrm{h_2})$.

The final dimensions of the optimized antenna are: parasitic patch: $\mathrm{L_2} = 17.2$ mm, $\mathrm{W_2} = 14.0$ mm, $\mathrm{h_3} = 0.508$ mm,



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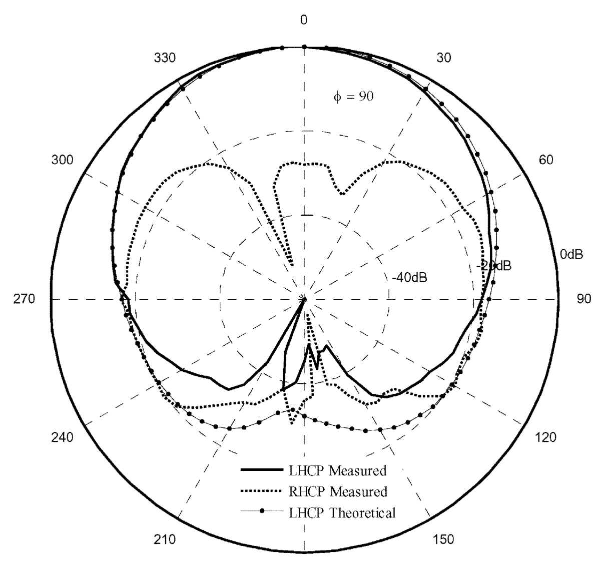
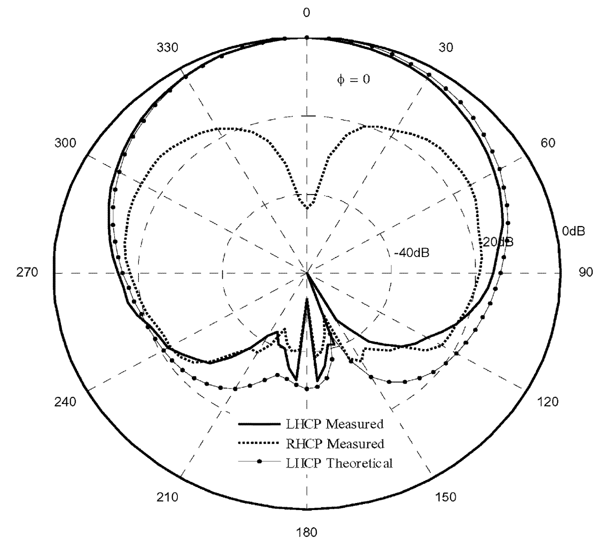


(b)

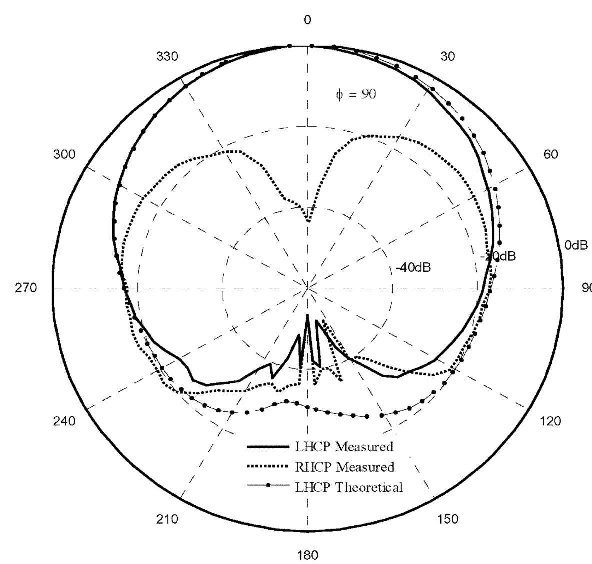
Fig. 6. (a) Radiation pattern ($\phi = 0$) at 5.35 GHz. (b) Radiation pattern ($\phi = 90$) at 5.35 GHz.

$\varepsilon_{r3} = 2.17$, tan $\delta_3 = 0.0017$, driven patch: $L_1 = 16.0$ mm, $W_1 = 14.0$ mm, $h_1 = 1.575$ mm, $\varepsilon_{r1} = 2.2$, tan $\delta_1 = 0.0009$. The thickness of foam ($\varepsilon_{r2} = 1.07$) between driven patch and parasitic patch (h_2) is 5.8 mm and the feed location angle (θ) is 37°. This antenna design has a theoretical 3 dB AR bandwidth of 14.7% and a 10 dB return loss bandwidth of 21%.

The 3 dB AR bandwidth increases with increase of the length of parasitic patch (L_2) up to 17.2 mm and then decreases because the two AR minima come closer. However, the quality of circular polarization improves, i.e., the best AR value decreases. For parasitic patch length of 17.2 mm there two AR minima points, giving wider AR bandwidth. We have selected $L_2 = 17.2$ mm, which is a compromise between the best 3 dB AR bandwidth and the best minimum AR. The fabricated CPSMA prototype is shown in Fig. 1(b) and its performances has been measured by an Agilent vector network analyzer and an NSI spherical near-field antenna range.



(a)



(b)

Fig. 7. (a) Radiation pattern ($\phi = 0$) at 5.4 GHz. (b) Radiation pattern ($\phi = 90$) at 5.4 GHz.

III. Results and Discussions

The theoretical and measured return loss of the CPSMA is presented in Fig. 3. The measured 10 dB return loss bandwidth is 21% (4.83 GHz to 5.96 GHz) and theoretical bandwidth is 21% also (from 4.95 to 6.1 GHz). A little shift in the bandwidth is due to the fabrication tolerances. Fig. 4 shows the theoretical and measured axial ratio at boresight. The measured 3 dB AR-bandwidth is 13.5% (5.24 GHz to 6.0 GHz) and theoretical bandwidth is 14.7% (5.22 GHz to 6.05 GHz). The left hand circular polarized gain of antenna is shown in Fig. 5 at boresight. The maximum gain of 9.0 dB was measured at 5.65 GHz and it is

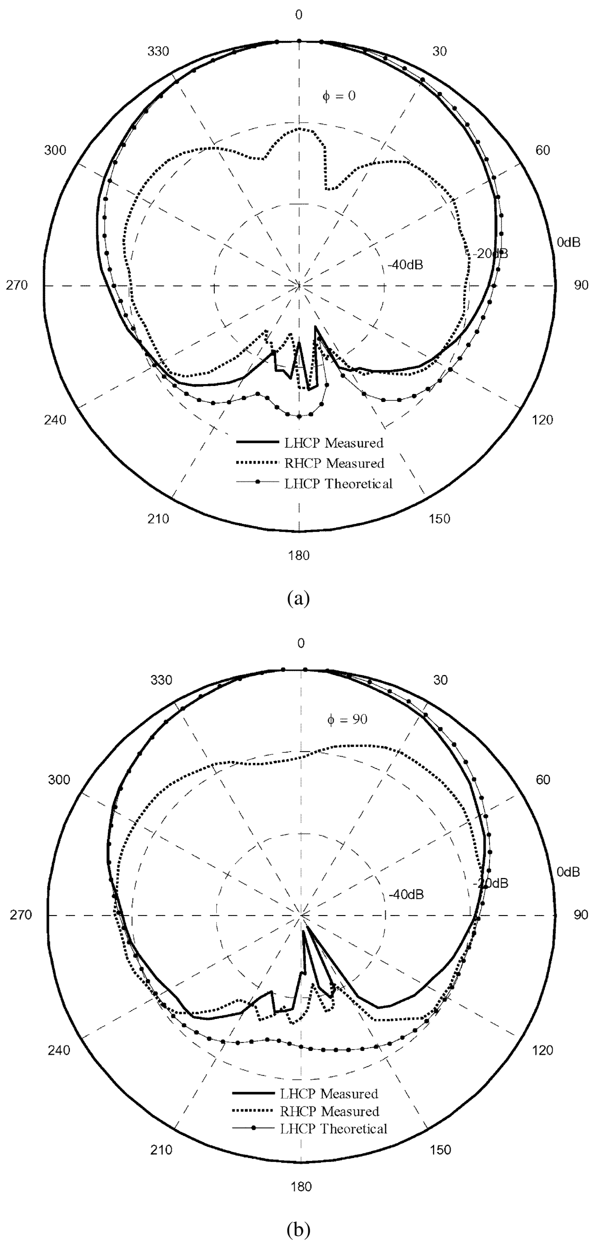


Fig. 8. (a) Radiation pattern ($\phi = 0$) at 5.5 GHz. (b) Radiation pattern ($\phi = 90$) at 5.5 GHz.

more than 7.5 dBi over the 3 dB AR bandwidth. The radiation patterns were measured at 5.35, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, and 5.95 GHz and good agreement with the theoretical patterns is observed for left-hand circular polarization (LHCP) over the 3 dB beamwidth. The measured and theoretical patterns at 5.35, 5.4, and 5.5 GHz in both principle planes ($\phi = 0°$ and $90°$) are shown in Figs. 6–8, respectively.

The measured radiation performance parameters such as the 3 dB beamwidth of LHCP, right-hand circular polarization

TABLE I
MEASURED RADIATION PERFORMANCE PARAMETERS

Freq. (GHz)	RHCP at bore sight (dB)	LHCP 3dB beamwidth (degrees)		RHCP within 3dB beamwidth (dB)	
		ϕ = 0°	ϕ =90°	ϕ = 0°	ϕ =90°
5.35	-28	70	64	-15	-20
5.40	-44	66	62	-17	-18
5.50	-22	66	60	-19	-15
5.60	-20	68	56	-17	-14
5.70	-17	70	57	-15	-17
5.80	-16	72	59	-16	-13
5.90	-15	75	63	-15	-13
5.95	-15	77	64	-14	-14

(RHCP) level and RHCP levels within the 3 dB beamwidth are shown in Table I. The overall RHCP level at boresight is less than -15 dB and RHCP within the 3 dB beamwidth is better than -13 dB. The LHCP 3 dB beamwidth at $\phi = 0°$ is larger than that at $\phi = 90°$ because the dimension of antenna in the x direction larger than that in the y direction. The 3 dB beamwidth of LHCP is also shown in Table I.

IV. Conclusion

A novel technique is presented to improve the AR bandwidth and the gain of the single-feed CPSMAs by following a new C-type feed optimization process. The design process is simple because the return loss and AR requirements are achieved at different stages almost independently. The return loss, axial ratio, gain and radiation patterns of the antenna have been measured and presented. Further optimization of the substrate thickness and the aspect ratio of the driven patch may provide even wider AR bandwidth.

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References

[1] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*. Norwood, MA: Artech House, 2001.
[2] M. Haneishi and S. Yoshida, "A design method of circularly polarized rectangular microstrip antenna by one-point feed," in *Microstrip Antenna Design*, K. C. Gupta and A. Benalla, Eds. Norwood, MA: Artech House, 1988, pp. 313–312.
[3] S. Egashira and E. Nishiyama, "Stacked microstrip antenna with wide bandwidth and high gain," *IEEE Trans. Antennas Propag.*, vol. 44, no. 11, pp. 1533–1534, Nov. 1996.
[4] N. Herscovici, Z. Sipus, and D. Bonefacic, "Circularly polarized single-fed wide-band microstrip patch," *IEEE Trans. Antennas Propag.*, vol. 51, no. 6, pp. 1277–1280, 2003.
[5] *"Computer Simulation Technology,"* ver. 5.1 Microwave Studio™, .
[6] Nasimuddin, K. P. Esselle, and A. K. Verma, "Optimization of stacked microstrip antenna for circular polarization," in *Proc. WARS2006 Conf.*, Sydney, Australia, Feb. 15–17, 2006.