

A Broadband Singly-Fed Electromagnetically Coupled Patch Antenna for Circular Polarisation

Kwok L. Chung and Ananda S. Mohan

*Faculty of Engineering, Telecommunications Group
Cooperative Research Centre for Satellite Systems
University of Technology, Sydney
1 Broadway, Sydney, NSW 2007, Australia
E-mail: klchung@ieee.org, ananda@eng.uts.edu.au*

ABSTRACT

This paper presents a novel singly-fed patch antenna based on electromagnetically coupled patch concept using high and low permittivity substrates. The antenna is designed for right-hand circular polarisation at a center frequency of 2.4 GHz. The experimental results confirm that the antenna has an impedance bandwidth ($VSWR \leq 2$) of 22% and a 3-dB axial ratio bandwidth of 4.6%. The antenna gain bandwidth is also measured as broad as 23.9% with a mean gain level of 9.17 dBic. The cross-polarisation levels and radiation patterns are also reported.

INTRODUCTION

Traditional single layer singly-fed circularly polarised (SFCP) microstrip patch elements are classified as Type-A and Type-B in the literature [1] according to the polarity of perturbation, and the sense of circular polarisation is decided by the axis on which the feed is located. However, SFCP microstrip patch antenna has limited impedance bandwidth ($VSWR \leq 2$) and narrow 3-dB axial-ratio (AR) bandwidth especially at lower microwave frequencies such as in L- and S-band, typically less than 5% and 1%, respectively [2]. On the other hand, traditional two-layer electromagnetically coupled patch (EMCP) antennas have extra degrees of freedom and hence have been the focus of many studies [3]-[5].

In this paper, we present a novel 2.4 GHz SFCP patch antenna, which is an evolution of Type-A element, is based on two-layer EMCP designs by making use of layer separation (airgap) tuning [4], [5]. The objective of the present design is not limited to the improvement on the impedance and AR bandwidths of the traditional EMCP designs but also the radiation characteristics such as circular polarisation gain (CPG) and cross-polarisation (X-pol). The gain bandwidth and 3-dB beamwidths are also examined. Such an antenna element could be used for as an element in a phased array tracking system, as in RFID or tagging systems, as well as an element in a Minimum Redundancy Array (MRA) for radio-astronomy...etc. The details of the proposed antenna are described; the simulation and experimental results are also presented in the following sections.

ANTENNA DESIGN

It is well known that the impedance bandwidth can be broadened by making use of stacked patch concept [3] while the AR bandwidth can be enhanced by using substrates with high and low permittivity [6]. The main difference between the present design and the traditional EMCP antennas is a substitution of high permittivity

substrate for the bottom layer and an adoption of a higher airgap. The choice of a high permittivity substrate for the driven layer would be more suitable for the element to be integrated with microwave control devices as a compact antenna system at 2.4 GHz. An inverted parasitic patch of size 46x46 mm² with a perturbation of -3% is printed on the top layer. For the bottom layer, a square patch has a side of 20.60 mm with a perturbation of -5.66% that is fed by a 50Ω microstrip line with tuning stub on the top side, while the bottom side is being a ground plane for the element. The single feed is accomplished by means of an end launch SMA connector that is located on the y-axis, so that it is a right-hand circularly polarised (RHCP) design. Fig.1 illustrates the detailed antenna structure while in Table 1 the key parameters are listed.

Table 1

Layer	Substrate	ϵ_r	$\tan \delta$	Thickness [mm]
Top	RT5880	2.20 ± 0.02	0.0009	$d_1 = 1.575$
Separation	AIR	1.0	0.0	$d_2 = 8.50$
Bottom	RO3010	10.2 ± 0.30	0.0035	$d_3 = 1.270$

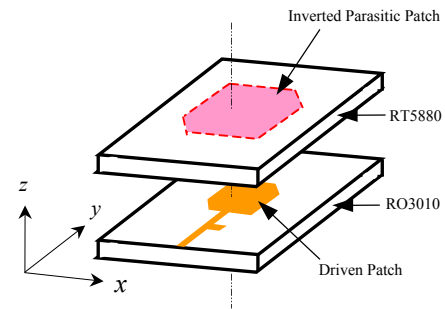


Fig.1 Geometry of the proposed antenna element without spacers shown.

SIMULATION AND EXPERIMENTAL RESULTS

The proposed antenna has been tuned and simulated by using Ansoft's Ensemble[®], and the bandwidths are fine-tuned empirically during the antenna testing. Fig.2 shows the measured return losses ($-S_{11}$ in dB) for various airgaps, namely, 7.5mm, 8.5mm and 10.1mm respectively while Fig.3 is showing the corresponding input impedance loci presented in a Smith Chart. The optimum impedance bandwidth of 22% with an input VSWR of 2:1 has been obtained when the airgap is 8.5mm ($\sim 0.07\lambda_0$). AR and CPG results obtained from simulation and experiment are shown together in Fig. 4 as a comparison. The experimental results confirm that the AR of less than 3 dB is in excess of 4.6% bandwidth while the CPG is measured over 8 dBic across a frequency band between 2.1 to 2.67 GHz. The broadside AR is obtained as 1.8 dB at 2.4 GHz while the maximum gain is recorded as high as 10.5 dBic at 2.55 GHz. Further, the measured radiation patterns at 2.40 GHz for both senses of circular polarisation (LH and RH) in two orthogonal planes are shown in Fig.5 and Fig.6, respectively. The front-to-back ratio for RHCP has been found to be very high while the X-pol at broadside for both LHCP and RHCP is about 20 dB in x-z and y-z planes. Finally, the measured half-power beamwidths (HPBW) are found to be about 60° in two orthogonal planes as shown in Fig. 7.

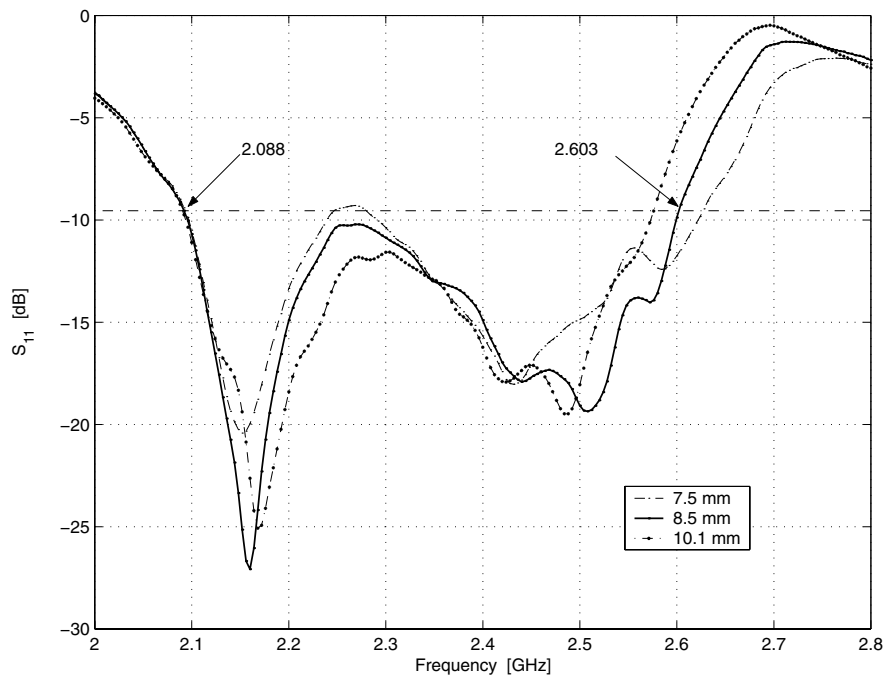


Fig.2 The measured S_{11} plots for three different layer separations, $d_2 = 7.5, 8.5$ and 10.1 mm.

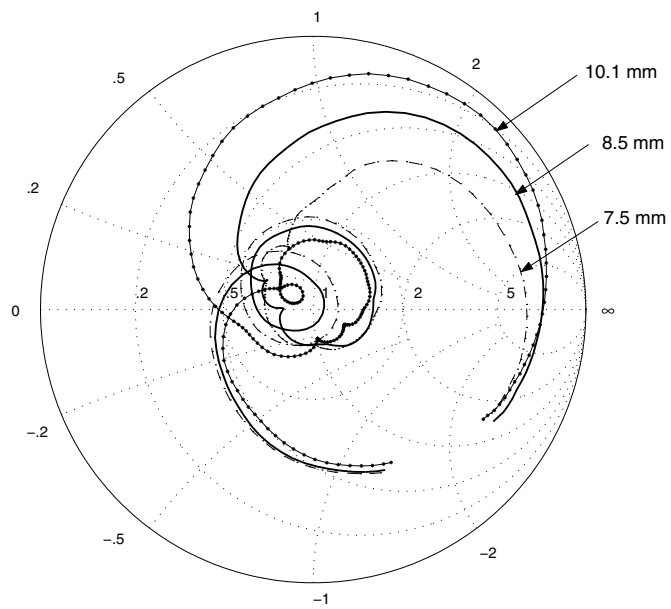


Fig.3 The measured input impedance loci for three different layer separations, $d_2 = 7.5, 8.5$ and 10.1 mm.

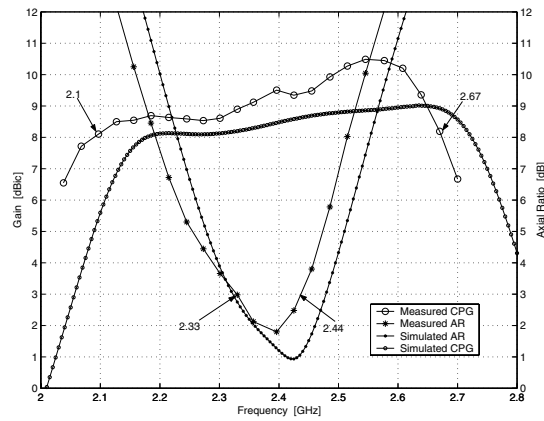


Fig.4 The simulated and measured axial ratios and circular polarisation gains versus frequency.

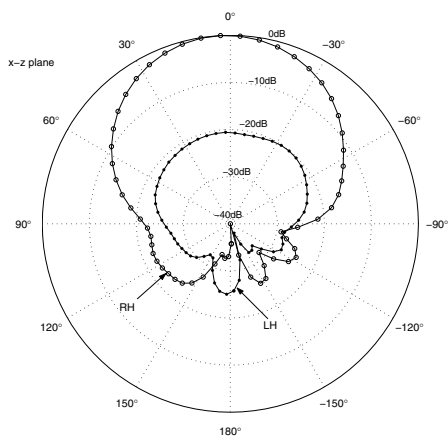


Fig.5 The measured radiation patterns of both senses at 2.40 GHz in x-z plane.

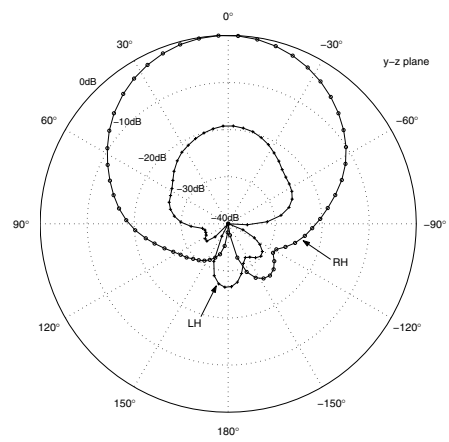


Fig.6 The measured radiation patterns of both senses at 2.40 GHz in y-z plane.

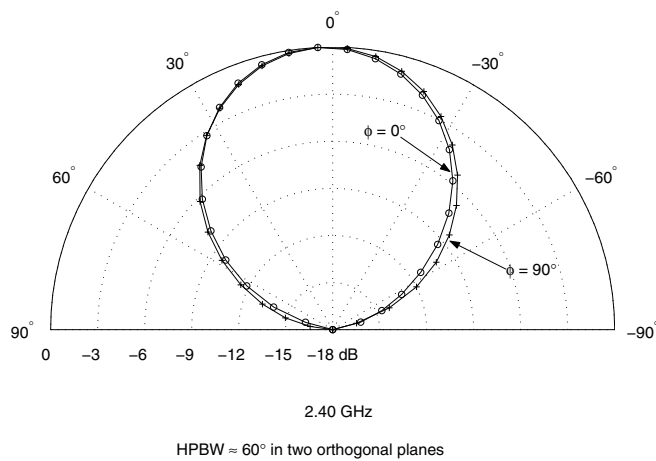


Fig.7 The reduced scale plot of RH radiation patterns in two orthogonal planes. The HPBW is about 60° in both planes.

CONCLUSION

A novel singly-fed broadband and high gain two-layer electromagnetically coupled patch antenna has been successfully fabricated and tested. The proposed antenna is right-hand circularly polarised and operates in the 2.4 GHz ISM-band frequency. The gain bandwidth of this antenna is measured as high as 23.9% with a mean gain of 9.17 dBic. The 3-dB axial ratio bandwidth is measured over 4.6% while the impedance bandwidth with an input VSWR of 2:1 is obtained as 22%. These measurement values together with the presented narrow beam values demonstrate that the present design has a significant improvement over the existing designs in the similar frequency range in the literature to date. Furthermore, the high gain with broadband values making this antenna element to be very suit as a key component in many applications.

ACKNOWLEDGMENT

We would like to thank CSIRO Telecommunications & Industrial Physics, for allowing us to use their anechoic chamber facility. Our appreciation and gratitude goes particularly to Ken Smart, Steve Barker and Kieran Greene of its Antenna Group for the sincere help during the measurement of this antenna element.

This work was carried out in the Cooperative Research Centre (CRC) for Satellite Systems with financial support from the Commonwealth of Australia through the CRC Program.

REFERENCES

- [1] M. Haneishi and S. Yoshida, "A design method of circularly polarised rectangular microstrip antenna by one-point feed", *Electronics and Commun. in Japan*, vol. 64-B, No. 4, pp. 46-54, 1981.
- [2] P. C. Sharma and K. C. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas", *IEEE Trans. Antennas and Propagat.*, vol. AP-31, pp. 949-955, 1983.
- [3] C. H. Chen, A. Tulintseff and R. M. Sorbello, "Broadband two-layer microstrip antenna", in *IEEE AP-S International Symposium Digest*, 1984, pp. 251-254.
- [4] R. Q. Lee and K. F. Lee, "Experimental Study of the Two-Layer Electromagnetically Coupled Rectangular Patch Antenna", *IEEE Trans. Antennas and Propagat.*, vol. 38, pp. 1298-1302, 1990.
- [5] R. Q. Lee, T. Talty, and K. F. Lee, "Circular Polarisation characteristics of stacked microstrip antennas", *Electronics Letters*, vol. 26, pp. 2109 -2110, December 1990.
- [6] R. B. Waterhouse, "Stacked Patches Using High and Low Dielectric Constant Material Combinations", *IEEE Trans. Antennas and Propagat.*, vol.47, pp. 1767-1771, Dec. 1999.