

# A Dual-Band Circularly-Polarized Patch Antenna with a Novel Asymmetric Slot for WiMAX Application

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**Abstract.** *A compact design of a circularly-polarized (CP) microstrip antenna to achieve dual-band behavior for WiMAX applications is presented. A single-layered feed is used to excite a single square patch integrated with a novel asymmetrical slot and two different truncated corners to achieve CP polarization in both bands. Besides its structural simplicity, ease of fabrication and low cost, the proposed antenna features a satisfactory impedance bandwidth of 7.2 % in the lower band (2.53 GHz) and 3.6 % in the upper band (5.73 GHz). The measured radiation pattern of the proposed antenna demonstrates directional patterns in both E- and H-planes with a 3 dB axial ratio of 2 % and 3.2 % in the lower and upper band, respectively.*

## Keywords

Asymmetrical slot, circularly polarized (CP), dual-band, microstrip antenna.

## 1. Introduction

In recent years, the evolution in wireless communications necessitates dedicated and compact antennas. The limitation of the transmitter-to-receiver orientation can be effectively solved when antennas with circular polarization (CP) are utilized [1]. Moreover, it is of great importance to design CP microstrip antenna structures with a single-feed mechanism to keep the configuration compact. In the past decade, various single- and dual-band CP patch antennas have been investigated. In [2], a single-feed square patch was truncated at its corners to obtain CP, which typically results in narrow axial-ratio bandwidths. This design involves four slits incorporated into a square patch for circular polarization at 2.2 GHz with an axial ratio bandwidth of about 1.62 %. In [3], another truncated-corner antenna with the aid of several slits produced CP and an axial ratio bandwidth of around 1.45 % at 2.45 GHz. This structure offers a size reduction of about 36 % compared to conventional truncated corner CP antenna designs. A new C-type single feed introduced in [4] successfully enhanced the axial ratio bandwidth to about 13.5 % at 5.4 GHz. Meanwhile, in [5], a new dual-band CP slot antenna design inserted with

metallic strips was introduced. CP was obtained by loading the square slot with a T-shaped strip and two microstrip T-junctions. This resulted in an axial ratio bandwidth of about 19.6 % at 2.54 GHz. In [6-8], variations of the U-slot were introduced as a new technique to achieve CP, besides simultaneously broadening the impedance bandwidth. On the other hand, researchers in [9] investigated a set of single-feed, corner-truncated patch antennas with various thicknesses. The U-slot patch with an L-probe effectively improved impedance matching to 28.1 % and the CP bandwidth to 14 %. To achieve dual-band CP, most of the previously proposed structures utilized two patches [6], [10], [11]. In [10], for instance, to obtain a dual-band CP antenna, two different truncated-corner square patches are stacked. The result showed an impedance bandwidth of 3.43 % and 4.91 % at 2.45 GHz and 5.7 GHz, respectively.

To achieve simultaneous dual-band CP and a wide impedance bandwidth, researchers in [6] proposed the asymmetrical U-slot. Axial ratio bandwidths of 1 % and 3.1 % in lower and higher bands were achieved in. A larger 4 % single-band CP bandwidth is obtained using this similar structure at 2.4 GHz in [7]. In [12], a compact, aperture-coupled, stacked CP antenna structure was presented. A perturbed square loop resonator was applied to excite dual- and orthogonal-modes simultaneously, achieving the desired CP at 2.42 GHz with 2.5 % axial ratio bandwidth. Asymmetrical slits incorporated in the diagonal direction of a single, square patch in [13] enabled a compact antenna size, a measured impedance bandwidth of 2.5 % and an axial ratio bandwidth of 0.5 %. Therefore, the asymmetrical slit structure has been found to effectively realize compact, circularly polarized microstrip patch antennas.

In this paper, a new configuration to achieve dual-band circular polarization is presented. Unlike previous designs, the proposed structure uses a simple microstrip feed to excite the microstrip patch to enable dual band resonance on a single layered structure. Moreover, the antenna is optimized to resonate in two WiMAX bands, i.e. at 2.53 GHz and 5.73 GHz with simultaneous circular polarization at both frequencies. Its low-cost and compactness makes it especially easy to be embedded into portable devices such as WiMAX routers. It may also be integrated into larger handheld devices such as smart phones and

portable WiMAX video/TV receivers. The paper is organized as follows. The next section will first introduce the antenna topology, presents its design procedure and details its optimized dimensions. The following section 3 analyzes and discusses the results for electric and magnetic fields, resonance frequencies, axial ratios, and radiation patterns. Our concluding remarks are summarized in section 4.

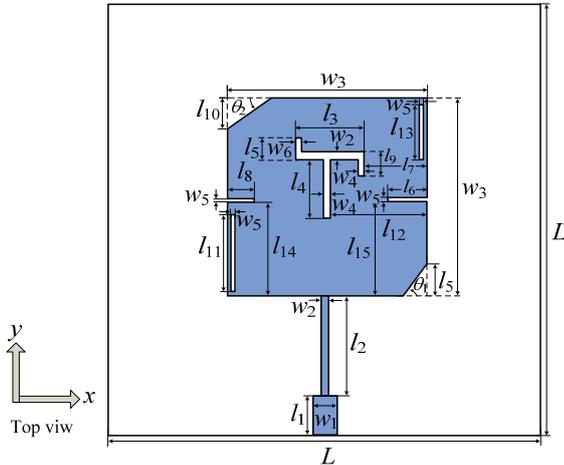


Fig. 1. Geometry of the circularly-polarized antenna.

### 2. Antenna Design

The geometry is shown in Fig. 1. The asymmetrical structure is realized through the use of various slots and two truncated corners. Once integrated onto the square patch, two orthogonal modes with a quadrature phase for CP generation are enabled. A  $55 \times 55 \text{ mm}^2$  (denoted as  $L \times L \text{ mm}^2$ ) FR4 substrate with a relative permittivity,  $\epsilon_r$  of 4.5, loss tangent,  $\tan \delta$  of 0.019 and height,  $h$  of 1.6 mm is used, with a fully-metalized reverse side as its ground. To enable a  $50 \Omega$  input impedance, two microstrip lines dimensioned at  $l_1 \times w_1 = 5 \times 3 \text{ mm}^2$  and  $l_2 \times w_2 = 13 \times 1 \text{ mm}^2$ , respectively, are combined to feed a square patch sized at  $w_3 \times w_3 = 25.5 \times 25.5 \text{ mm}^2$ . As shown in Fig. 1, a quasi T-shape slot is used to tune the resonant frequencies as well as to enable circular polarization.

A good CP bandwidth is also effectively enabled by the conventional technique of edge-chamfering at the two resonator patch corners. It is observed from simulations that creating asymmetrical corners facilitates the lowering of the axial ratio. Moreover, the corners are also utilized to reverse the negative effect of the parasitic slots on the axial ratio, where their angle optimization enabled the highest possible CP bandwidth for this structure. The widest simultaneous axial ratio bandwidth within the two bands is achieved by cutting a corner length of  $l_5 = 4 \text{ mm}$  and angle of  $\theta_1 = 37^\circ$  for the bottom right chamfer, and a corner length of  $l_{10} = 4 \text{ mm}$  and angle of  $\theta_2 = 55^\circ$  for the top left chamfer. The antenna is designed to have an LHCP radiation in the lower band and an RHCP pattern in the higher band. The CP orientation can be controlled by changing the truncated corners and asymmetrical slots  $l_5$  and  $l_9$ .

$l_3$	$l_4$	$l_6$	$l_7$	$l_8$	$l_9$	$l_{11}$
8.7	7.5	5	8	3.5	3	10
$l_{12}$	$l_{13}$	$l_{14}$	$l_{15}$	$w_4$	$w_5$	$w_6$
12.3	7	12	12.1	0.8	0.5	2.8

Tab. 1. Optimized slot dimensions (in millimeters).

To enable CP at both frequencies, asymmetrical slots and the truncated corners are introduced onto the radiator. Results from our parametric investigation indicated that CP at the lower frequency is facilitated by the center asymmetrical T-slot and two diagonally-located, truncated corners. On the other hand, two vertical slits located at the bottom right and top left corners of the patch radiator, besides the truncated corners are imperative elements in allowing CP in the upper band. Meanwhile, LHCP and RHCP orientations can be controlled by first changing the truncated corner's angle and length. Next, a steady symmetry increase to the two vertical T-slot arms at the patch center will also enable control of the antenna's CP characteristics. The optimal slot dimensions enabling the best impedance matching and axial ratio are shown in Tab. 1.

### 3. Results and Discussion

Simulations of the proposed antenna were conducted using CST Microwave Studio, while return loss and radiation pattern measurements were obtained using a Vector Network Analyzer and an anechoic chamber. The simulated and measured antenna return loss, optimal at 2.53 GHz and 5.73 GHz, is shown in Fig. 2. As observed, the antenna shows a dual-band impedance bandwidth and measurements are in good agreement with simulations. The antenna features a measured impedance bandwidth of 186 MHz between 2.494 GHz and 2.680 GHz for the lower 2.53 GHz band. Meanwhile, an impedance bandwidth of 206 MHz is generated for the higher 5.73 GHz WiMAX band, between 5.610 GHz and 5.816 GHz. Tab. 2 shows the comparison between measured and simulated impedance bandwidth at both resonant frequencies.

Simulated				Measured			
Freq (GHz)	S <sub>11</sub> (dB)	BW (MHz)	BW (%)	Freq (GHz)	S <sub>11</sub> (dB)	BW (MHz)	BW (%)
2.53	-20	127	5	2.50	-27	186	7.2
5.73	-17	246	4.20	5.73	-17	206	3.6

Tab. 2. Simulated and measured return loss and bandwidth.

As shown in Fig. 3, measurements indicated a dual-band CP operation with good axial ratio bandwidths within the antenna's operating bandwidth. For the lower band, about 52 MHz of 3 dB axial ratio bandwidth is achieved from 2.50 GHz to 2.557 GHz, while for the upper band, a 180 MHz bandwidth is observed between 5.610 GHz and 5.790 GHz. Note that this design is concentrated on achieving a dual-band CP performance rather than widening the axial ratio bandwidth in each of the bands. To investigate the role of the slots and truncated corners in facilitating the dual-band CP, surface current densities of the proposed antenna are given at 2.53 GHz and 5.73 GHz.

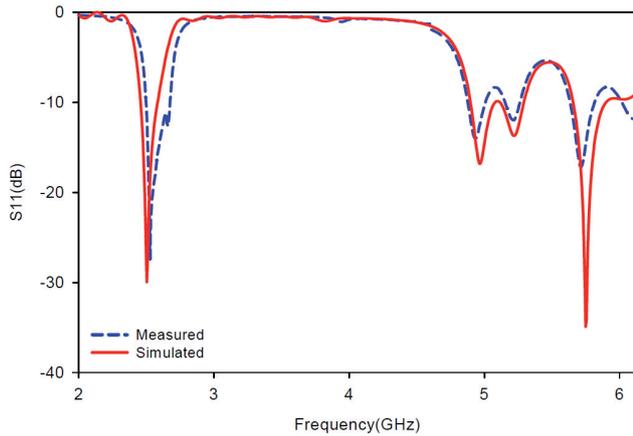


Fig. 2. Simulated and measured return loss.

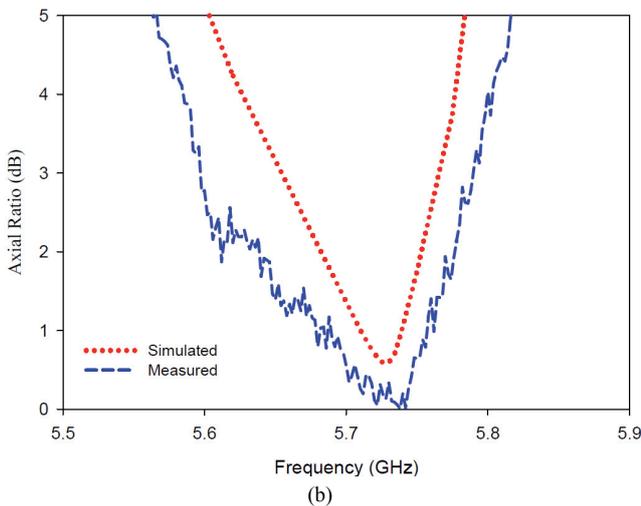
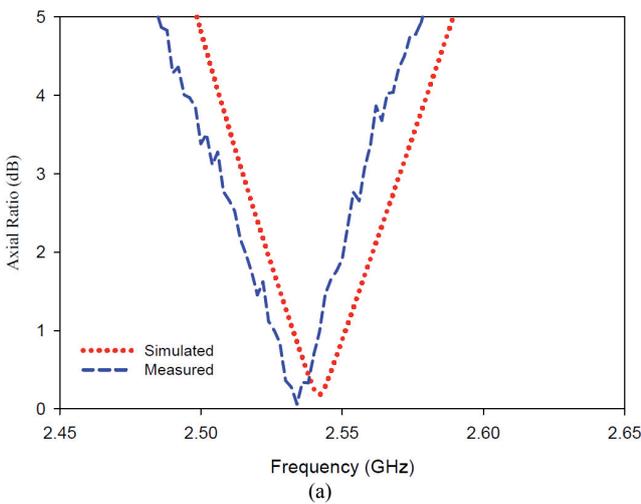


Fig. 3. Measured versus simulated axial ratio at (a) 2.53 GHz, and (b) 5.73 GHz.

Fig. 4 shows the surface current densities for the two resonant frequencies of 2.53 GHz and 5.73 GHz. In Fig. 4 (a), it is observed that the current density in the asymmetrical T-slot and the two connected horizontal slits to its right and left are stronger. In addition, they have a higher density in the vertical slot.

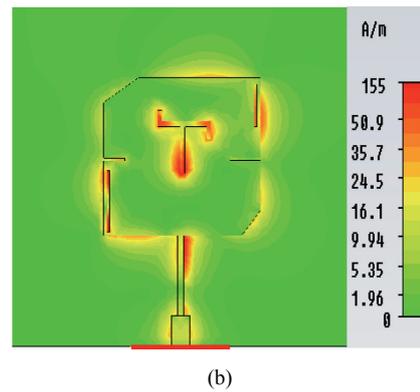
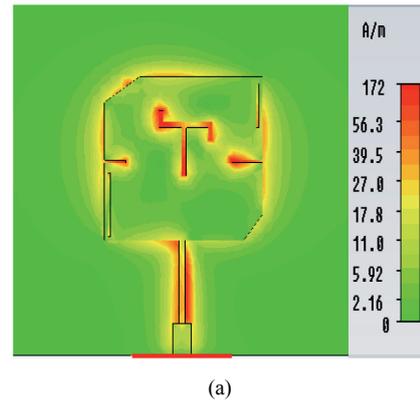


Fig. 4. Surface current distribution for the proposed antenna at: (a) 2.53 GHz and (b) 5.73 GHz.

In parallel Fig. 4(b) shows stronger surface currents in the vertical parts of the asymmetrical T-slot. This enables a low axial ratio level at the higher resonant frequency because the slots have equal electrical length with quadrature phase difference. The surface currents show more density at the two vertical slits at the opposite diagonal corners (bottom left and top right). Based on our observation, although truncated corners enable a lower axial ratio, the T-asymmetrical slot arms are the main enabling factor for the antenna to radiate circular waves at both resonant frequencies. The fabricated antenna prototype is shown in Fig. 5. An SMA connector is soldered to the microstrip line.

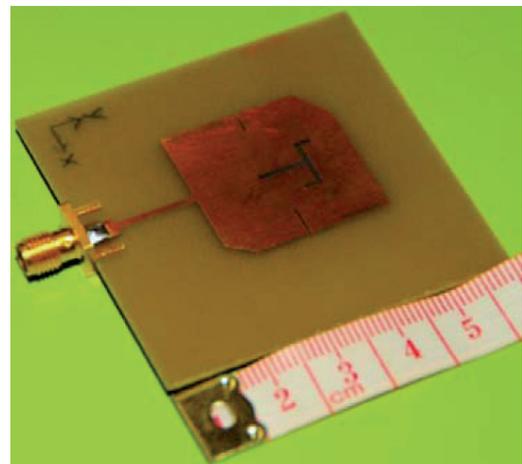
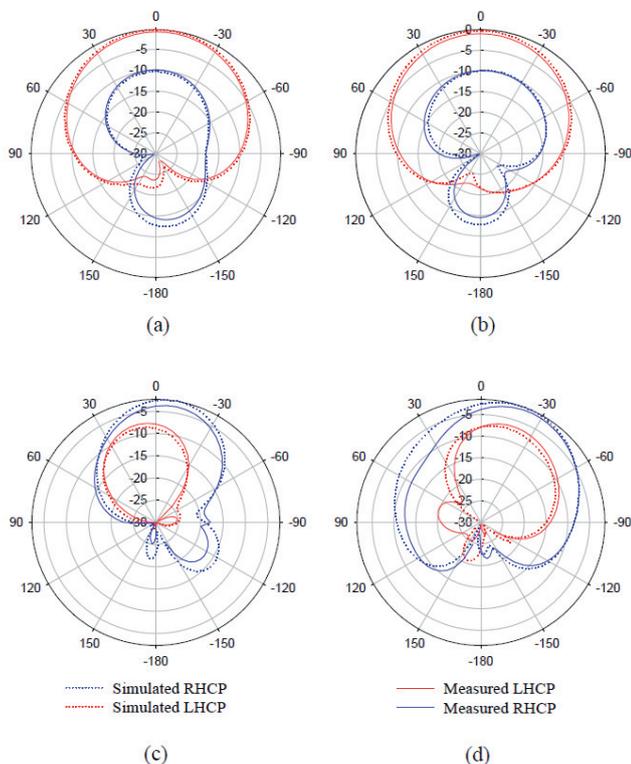


Fig. 5. Photograph of the fabricated prototype.

Fig. 6 illustrates the measured and simulated radiation pattern of the proposed antenna at 2.53 GHz and 5.73 GHz. A directional antenna radiation pattern is seen in both E- and H-planes, with good agreements in both bands. On the other hand, the gain is slightly reduced in the upper band due to the expected additional FR4 losses at higher frequencies especially for a dual-band, single-patch antenna [14]. As shown in Figs. 6(a) and (b), the measured 3-dB beamwidths at the lower resonance for the y-z (E-plane) and x-z (H-plane) planes are about  $90^\circ$ . From Figs. 6(c) and (d), the measured 3-dB beamwidths at the upper resonance for E- and H-plane are  $38^\circ$  and  $52^\circ$ , respectively. It can be clearly observed that for  $\phi = 0^\circ$  and  $90^\circ$ , the cross-polarization is 10 dB below the co-polarization for both E- and H-planes at 2.53 GHz. Meanwhile, for 5.73 GHz in both x-z and y-z plane, the co-polarization at broadside is around 8 dB above the cross polarization. The maximum measured gain at the resonant frequencies is around 5 dBi and 4 dBi in the lower and upper band, respectively.



**Fig. 6.** Measured versus simulated radiation patterns at: (a) 2.53 GHz (E-plane), (b) 2.53 GHz (H-plane), (c) 5.73 GHz (E-plane), (d) 5.73 GHz (H-plane).

## 4. Conclusion

A new configuration for a single feed, dual-band, circularly-polarized patch antenna is presented. The use of the novel asymmetrical slot generated 2% and 3.2% CP axial ratio bandwidth in two desired bands, 2.53 GHz and 5.73 GHz. Besides, the slot has also facilitated impedance bandwidth broadening starting from a conventional, single-patch topology. Two orthogonal modes are produced to allow circular polarization through the optimization of the

slot and chamfer dimensions. Moreover, the CP can be easily controlled through minor slot and slit modifications. Besides featuring a simple and compact topology, the antenna is also low-cost and suited for WiMAX applications.

## Acknowledgements

The work is financially supported by the Malaysian Ministry of Higher Education (MOHE). The authors would like to acknowledge Jan Maes and ESAT-CDE for their technical contributions.

## References

- [1] SOLIMAN, E. A., BREBELS, S., BEYNE, E., VANDENBOSCH, G. A. E. Circularly polarized aperture antenna fed by CPW and built in MCM-D technology. *Electronics Letters*, 1999, vol. 35, p. 250-251.
- [2] WONG, K. L., WU, J. Y. Single-feed small circularly polarised square microstrip antenna. *Electronics Letters*, 1997, vol. 33, p. 1833-1834.
- [3] CHEN, W. S., et al. Novel compact circularly polarized square microstrip antenna. *IEEE Transactions on Antennas and Propagation*, 2001, vol. 49, p. 340-342.
- [4] NASIMUDDIN, N., et al. Wideband circularly polarized stacked microstrip antennas. *IEEE Antennas and Wireless Propagation Letters*, 2007, vol. 6, p. 21-24.
- [5] ZHAO, G., et al. Design of a broadband dual circularly polarized square slot antenna. *Microwave and Optical Technology Letters*, 2008, vol. 50, p. 2639-2642.
- [6] NAYERI, P., et al. Dual-band circularly polarized antennas using stacked patches with asymmetric U-slots. *Antennas and Wireless Propagation Letters, IEEE*, 2011, vol. 10, p. 285-288.
- [7] TONG, K. F., WONG, T. P. Circularly polarized U-slot antenna. *IEEE Transactions on Antennas and Propagation*, 2007, vol. 55, p. 2382-2385.
- [8] LAM, K. Y., et al. Small circularly polarized U-slot wideband patch antenna. *IEEE Antennas and Wireless Propagation Letters*, 2011, vol. 10, p. 87-90.
- [9] YANG, S. S., et al. Design and study of wideband single feed circularly polarized microstrip antennas. *Progress in Electromagnetics Research*, 2008, vol. 80, p. 45-61.
- [10] OOI, T.S, RAHIM, S. K. A., KOH, B. P. 2.45 GHz and 5.8 GHz compact dual-band circularly polarized patch antenna. *Journal of Electromagnetic Waves and Applications*, 2010, vol. 24, p. 1473 to 1482.
- [11] ZAKARIA, N., RAHIM, S. K. A., OOI, T. S., TAN, K. G., REZA, A. W., RANI, M. S. A. Design of stacked microstrip dual-band circular polarized antenna. *Radioengineering*, 2012, vol. 21, p. 875-880.
- [12] LIU, J. C., et al. Single-feed circularly polarized aperture-coupled stack antenna with dual-mode square loop radiator. *IEEE Antennas and Wireless Propagation Letters*, 2010, vol. 9, p. 887-890.
- [13] NASIMUDDIN, N., et al. Compact asymmetric-slit microstrip antennas for circular polarization. *IEEE Transactions on Antennas and Propagation*, 2011, vol. 59, p. 285-288.
- [14] KUO, J. S., HSIEH, G. B. Gain enhancement of a circularly polarized equilateral-triangular microstrip antenna with a slotted ground plane. *IEEE Transactions on Antennas and Propagation*, 2003, vol. 51, p. 1652-1656.

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