

Circularly polarised printed arrow headed modified cross slot antenna

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A compact circularly polarised printed slot antenna operating at 2.45GHz for rectenna and RFID applications is reported. The antenna consists of an arrow headed modified cross slot printed on the ground plane of a dielectric substrate. The slot is fed by using a microstrip transmission line etched on the other side of the substrate. The size of the antenna is $40 \times 40 \times 1.6 \text{ mm}^3$. By employing an arrow headed modified cross slot structure, the proposed slot antenna exhibits a measured -10dB impedance bandwidth of 14.4% (2.25-2.6 GHz) and a measured 3dB axial ratio (AR) bandwidth of 8.23% (2.38-2.58 GHz).

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1. Introduction

Printed slot antennas are extensively used in modern wireless communication systems due to their attractive features such as wide impedance bandwidth, planar structure, ease of fabrication and low cost [1]. The basic structure of a printed slot antenna consists of a slot printed on the ground plane of a dielectric substrate, which is fed electromagnetically by a microstrip transmission line. The idea of microstrip slot antenna was proposed by Yoshimura [2]. Many papers explaining the theoretical analysis of the microstrip slot antennas were also reported [3-5]. Tapan K Sarkar et al. presented an analysis of a wide radiating slot in the ground plane excited by a microstrip line [6]. Several wideband and narrowband printed slot antennas were investigated by many researchers [7, 8]. Nakano and Yamauchi reported a review on printed slot antennas in which techniques for enhancing the bandwidth of printed slot antennas fed by transmission lines and methods of generating circularly polarized waves were discussed [9]. Chien Yuan Pan et al. investigated a printed microstripline fed broadband rhombus slot antenna by employing offset feed and corner-truncated protruded ground plane, where bandwidth enhancement and reduction in slot size were achieved [10]. Recently, a dual band MIMO antenna system made up of microstrip annular rings excited by open ended microstrip transmission line were investigated [11].

In most of the portable wireless communication systems, compact low-profile antenna with circular polarisation is preferred. This is due to the fact that such type of antennas can fairly communicate with linearly polarised antennas with random orientations and also avoid the polarisation losses and mismatches caused by multipath effects. A typical way of generating circularly polarised radiation is by exciting two orthogonal

degenerate resonant modes with a 90° phase difference. Yeh et al. proposed a novel microstrip-to-slotline transition technique for coupling a single-layer circularly polarised annular-ring slot antenna operating in the UHF band [12, 13]. The asymmetry in the structure is created by introducing a meandered slot section and the circularly polarised design is achieved by the two orthogonal linear modes of the annular ring slot. A miniaturized design was proposed by Jeen Sheen Row et al. for circularly polarised square ring slot antenna with L-shaped coupling strip feed [14]. Later he proposed a conventional cross slot antenna excited by a microstrip line through coaxial coupling [15]. The antenna exhibits circular polarisation which depends on the aspect ratio of the slotted patch. Recently, Bo Xu et al. suggested a compact broadband square slot loaded ground plane with L-shaped metal strip where circularly polarised radiation is achieved by properly selecting the length and width of the L-shaped strips [16]. Among the circularly polarised planar antennas studied earlier, it is evident that the slot antennas exhibit good axial ratio bandwidth than other low-profile antennas. It is also noted from literature that in wireless communication systems such as radio frequency identification, wireless energy scavenging and wireless sensor networks, circularly polarised antennas operating at 2.45GHz are greatly preferred [17].

This paper presents the development of a novel circularly polarised compact printed arrow headed modified cross slot antenna operating at 2.45 GHz. The proposed antenna is compact, low-profile, low cost and light weight which exhibits circular polarisation suitable for rectenna and radio frequency identification applications.

2. Antenna geometry and design

Fig. 1 shows the configuration of the proposed printed arrow headed modified cross slot antenna. The antenna is fabricated on an FR-4 substrate having thickness of 1.6 mm and permittivity (ϵ_r) of 4.4. The structure consists of a modified cross slot loaded ground plane on one side of the dielectric substrate which is fed by a microstrip feedline on the other side. A conventional cross slot structure consists of two slots arranged perpendicular to each other. The proposed antenna structure is a modified cross slot which is obtained by incorporating arrow heads at the ends of each of the slots and changing the angle between the two slots from 90° to 60° . The geometric parameters are optimised through simulations with CST Microwave Studio Suite. The optimised parameters are $L=40$ mm, $W=40$ mm, $L_1=18$ mm, $L_2=15.8$ mm, $A_1=9$ mm, $A_2=7.9$ mm, $w_s=2$ mm, $l_f=23$ mm, $w_f=3$ mm, $\theta=60^\circ$.

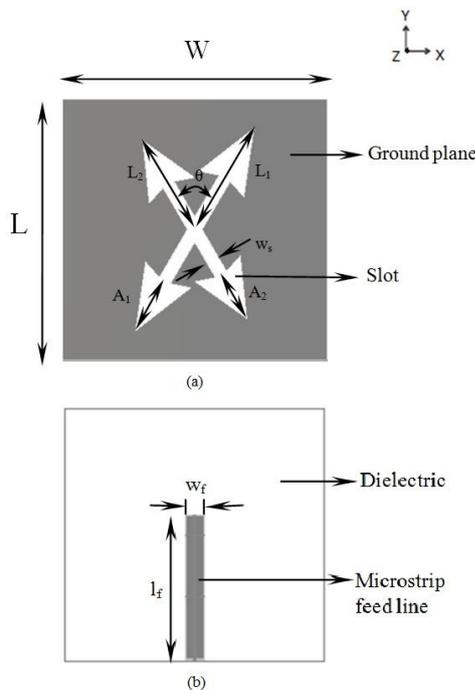


Fig. 1. Configuration of the proposed printed arrow headed modified cross slot antenna. ($L=40$ mm, $W=40$ mm, $L_1=18$ mm, $L_2=15.8$ mm, $A_1=9$ mm, $A_2=7.9$ mm, $w_s=2$ mm, $l_f=23$ mm, $w_f=3$ mm, $\theta=60^\circ$)
(a) Top view (b) Bottom view

The arrow headed modified cross slot employed is asymmetric with different lengths for the two slots with $L_1=18$ mm and $L_2=15.8$ mm. By introducing this asymmetry in the two slots, the fundamental resonant mode is split into two orthogonal degenerate modes of equal amplitude, with a phase difference of 90° , which results in circularly polarised radiation. The simulated surface current distributions of the proposed slot antenna is analysed to explain how the circularly polarised radiation is generated. The simulated surface current distribution of the proposed slot antenna for four different phase angle (ϕ) at the frequency 2.45 GHz are shown in Fig. 2 (a) to (d). It

is observed that the surface current distribution at $\phi=0^\circ$ is equal in magnitude and opposite in direction to that at $\phi=180^\circ$. Likewise the surface current distribution at $\phi=90^\circ$ and $\phi=270^\circ$ are also equal and opposite, thereby satisfying the criterion for circular polarisation. The direction of rotation of current is in anti-clockwise direction with respect to the $+z$ direction and the sense of polarisation is confirmed as left handed circular polarisation. The polarisation can be changed to right handed circular polarisation by interchanging the lengths of the two slots.

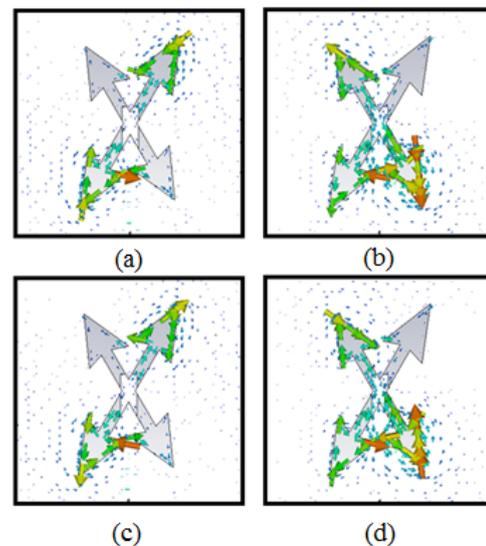


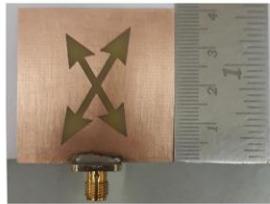
Fig. 2. Simulated surface current distributions of the proposed modified cross slot antenna for different phase angles (a) $\phi=0^\circ$; (b) $\phi=90^\circ$; (c) $\phi=180^\circ$; (d) $\phi=270^\circ$

3. Simulated and measured results

A prototype of the proposed antenna structure based on the optimised dimensions is fabricated and tested in an anechoic chamber using Agilent network analyser E5071C. The photograph of the fabricated antenna is shown in Fig. 3. Fig. 4 shows the simulated and measured return loss characteristics of the proposed antenna. The simulated return loss of -25.7 dB is obtained at a frequency of 2.45 GHz and the measured return loss of -23.9 dB is obtained at a frequency of 2.43GHz. The slight discrepancy in the results can be attributed to the fabrication tolerance. The simulated and measured -10 dB impedance bandwidths are 11.42% (2.3-2.58 GHz) centered at 2.45 GHz and 14.4% (2.25-2.6 GHz) centered at 2.43GHz respectively.

Fig. 5 shows the simulated and measured axial ratio versus frequency at the boresight for the proposed slot antenna. The simulated and measured 3dB axial ratio bandwidths are 7.75% (2.39-2.58 GHz) and 8.23% (2.38-2.58 GHz) respectively. The measured variation of axial ratio with frequency is almost in good agreement with the simulated result.

Fig. 6 shows the simulated variations of the return loss of the proposed slot antenna with frequency for different angles (θ) between the two cross slots. It is also evident from the figure that the angle between the two cross slots is significant in determining the resonant frequency. By varying the angle θ between the two cross slots from 50° to 90° , it is observed that the proposed cross slot antenna resonates for a frequency of 2.45 GHz at $\theta=60^\circ$.



(a)



(b)

Fig. 3. Photographs of the fabricated antenna
(a) Front view (b) Back view

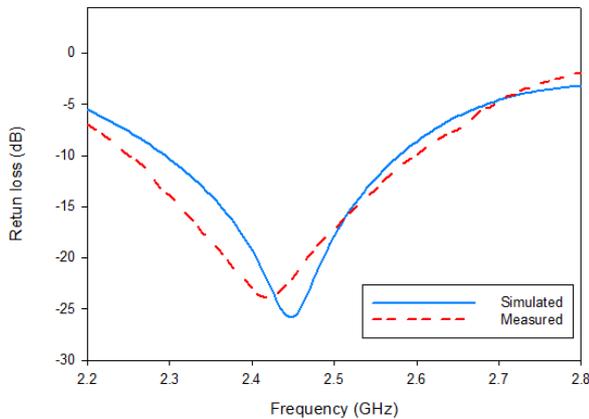


Fig. 4. Measured and simulated return loss characteristics of the proposed slot antenna

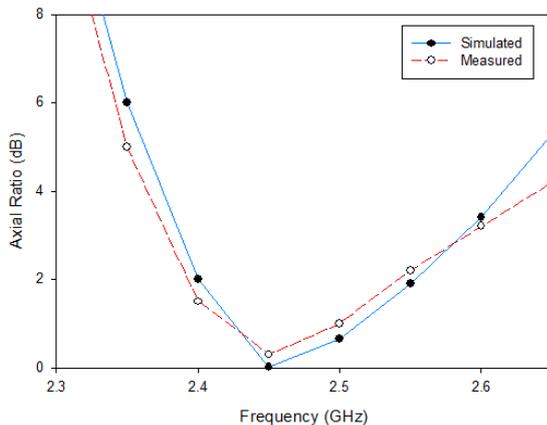


Fig. 5. Measured and simulated variation of axial ratio with frequency for the proposed slot antenna

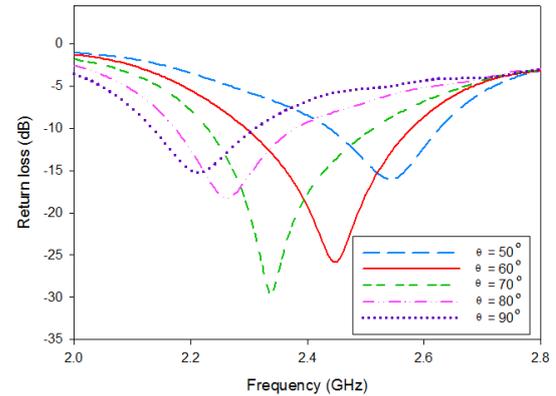


Fig. 6. Simulated variations of return loss against frequency for the proposed slot antenna for different angles (θ) of the cross slot

The proposed antenna structure is compared with a cross slot antenna without arrow head for the same operating frequency. Table 1 shows the comparison of the simulated radiation characteristics of printed cross slot antenna with and without arrow head. It is observed that the proposed arrow headed cross slot antenna has appreciable enhancement in axial ratio bandwidth compared to that of the cross slot antenna without arrow head.

Table 1. Comparison of the simulated radiation characteristics of the printed cross slot antenna with and without arrow head

Parameters	Cross slot without arrow head ($L_1=20$ mm, $L_2=17.8$ mm, $\theta=60^\circ$)	Arrow headed cross slot ($L_1=18$ mm, $L_2=15.8$ mm, $\theta=60^\circ$)
Resonant frequency (GHz)	2.45	2.45
Bandwidth (%)	9.7%	11.42%
Axial ratio bandwidth (%)	1.2%	7.75%

Fig. 7 shows the simulated and measured radiation patterns of the antenna at 2.45 GHz for E and H-planes. It is observed that the difference of co-polar and cross-polar components of the radiation patterns of E plane in the boresight direction is 0.02 dB in the simulated case and 0.31 dB in the measured case. Likewise, the difference of co-polar and cross-polar components of the radiation patterns of H plane in the boresight direction is 0.02 dB in the simulated case and 0.31 dB in the measured case. Hence it is clear that the difference between the co-polar and cross-polar components of both E and H planes is less than 3dB in the boresight direction for both the simulated

and measured cases which results in circularly polarised radiation.

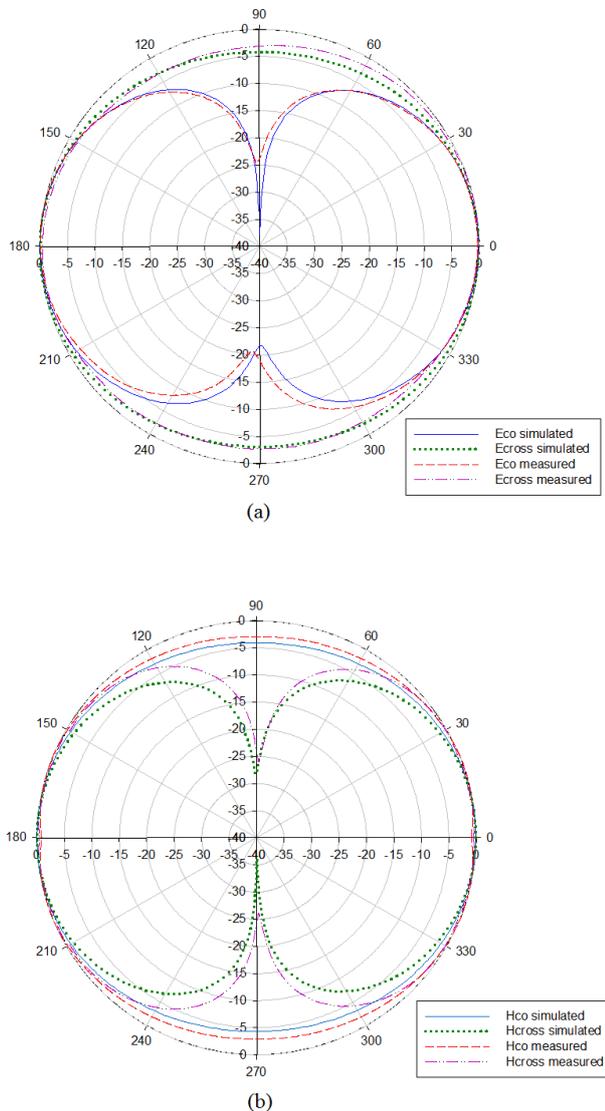


Fig. 7. Radiation patterns of the proposed arrow headed modified cross slot antenna at 2.45 GHz
(a) E-plane (b) H-plane

4. Conclusions

A compact circularly polarised slot antenna operating at 2.45 GHz frequency has been designed, fabricated and tested. By employing an arrow headed modified cross slot, the proposed slot antenna exhibits a measured -10dB impedance bandwidth of 14.4% and circular polarisation with a 3dB axial ratio bandwidth of 8.23%. Both simulated and experimental results are appreciably in good agreement with each other. This novel slot antenna may find applications in rectenna design, RFID and wireless energy harvesting systems.

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References

- [1] C. A. Balanis, "Antenna Theory analysis and design", Wiley, New York, 1997.
- [2] Y. Yoshimura, IEEE Trans. Microwave Theory Tech. **20**(11), 760 (1972).
- [3] B. N. Das, K. K. Joshi, IEEE Trans. Antennas Propagat. **30**(5), 922 (1982).
- [4] P. L. Sullivan, D. H. Schaubert, IEEE Trans. Antennas Propagat. **AP-34**(8), 977 (1986).
- [5] D. M. Pozar, IEEE Trans. Antennas Propagat. **34**(12), 1439 (1986).
- [6] Masoud Kahrizi, Tapan K. Sarkar, IEEE Trans. Microwave Theory & Tech. **41**(1), 29 (1993).
- [7] Mario Leib, Michael Frei, Wolfgang Menzel, Antennas and Propagation Society International Symposium 10.1109/APS.2009.5172336 (2009).
- [8] J. J. Xie, X. S. Ren, Y. Z. Yin, S. L. Zuo, Microwave Opt. Technol. Lett. **54**(6), 1466 (2012).
- [9] Hisamatsu Nakano, Junji Yamauchi, Proceedings of the IEEE, **100**(7), 2158 (2012).
- [10] Chien Yuan Pan, Jen-Yea Jan, Radio Engineering **22**(3), 694 (2013).
- [11] Muhammad Umar Khan, Mohammed S. Sharawi, Microwave Opt. Technol. Lett. **57**(2), 360 (2015).
- [12] Shu-An Yeh, Yi-Fang Lin, Hua-Ming Chen, Jin-Sen Chen, Microwave Conference, APMC 618 (2009).
- [13] Hua Ming Chen, Kuo Yung Chiu, Yi Fang Lin, Shu An Yeh, Microwave Opt. Technol. Lett. **54**(9), 2016 (2012).
- [14] Jeen Sheen Row, Yu De Lin, Microwave Opt. Technol. Lett. **56**(7), 1522 (2014).
- [15] Jhieh Ming Chen, Jeen Sheen Row, Microwave Opt. Technol. Lett. **57**(5), 1140 (2015).
- [16] Bo Xu, Shuai Zhang, Yusha Liu, Jun Hu, Sailing He, Electronic Letters **51**(11), 808 (2015).
- [17] Z. Q. T. Lawrence, J. S. Mandeep, Optoelectron. Adv. Mat. **9**(1-2), 298 (2015).

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