Progress In Electromagnetics Research M, Vol. 74, 33–40, 2018

An Arrow Headed Modified Cross Slot Array Antenna with Dual Band Characteristics and Circular Polarisation

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Abstract—Design and development of a novel arrow headed modified cross slot array antenna with dual band characteristics and circular polarisation is reported. The proposed array configuration consists of an array of four arrow headed modified cross slot elements which are electromagnetically coupled by using a 1 : 4 corporate feed network. The slot elements are etched on the ground plane of the dielectric substrate with a feeding network on the other side. The proposed slot array shows dual band behaviour and enhanced gain characteristics compared to a single element arrow headed modified cross slot antenna. The slot array antenna shows resonance at two frequencies of 1.72 GHz (1.6912 GHz–1.7656 GHz) and 2.45 (2.3656 GHz–2.5568 GHz) GHz with circular polarisation in the upper band. This novel slot array configuration has a measured gain of 6.23 dBi at the lower resonant frequency and 7.01 dBi at the upper resonant frequency. The proposed slot array antenna exhibits bidirectional radiation patterns with improved gains. The simulated results are in good agreement with the experimental ones.

1. INTRODUCTION

With the tremendous advances in wireless technology, most of the wireless communication systems including satellite and mobile communication systems use circularly polarized (CP) microstrip antennas as it can fairly communicate with randomly oriented linearly polarised antennas and reduce the polarization mismatch and losses between the transmitting and the receiving antenna [1]. Also, reception of orthogonal signals is an advantage of circularly polarized antennas. A typical method of producing circularly polarised radiation in an antenna is by electromagnetically exciting the two orthogonal degenerated modes in phase quadrature [2].

Microstrip antennas are generally classified into microstrip patch antennas and microstrip slot antennas [3]. Single-feed microstrip patch antennas with different patch shapes viz. square, circle, annular-ring, etc., have been reported in various literatures [4–6]. Such types of antennas can easily produce circularly polarised radiation by creating two orthogonal degenerate modes at the resonant frequency by using perturbation cut or slots on the patch. But the usage of microstrip CP patch antenna in many applications is limited by its inherent narrow axial ratio bandwidth.

The idea of microstrip-line fed slot antenna, otherwise called the printed slot antenna, was proposed by Yoshimura in 1972 [7]. Since then, the microstrip slot antenna gained much attention as they provide wide impedance bandwidth and 3-dB axial ratio bandwidth while maintaining its low-profile. Kahrizi and Sarkar [8] theoretically analysed the radiation from a wide slot excited by a microstrip line feed. Since the microstrip slot antenna is the complement of the microstrip patch antenna, it is highly probable to produce CP radiation by introducing some asymmetric perturbations to the ground plane of the antenna.

Received 12 August 2018, Accepted 22 September 2018, Scheduled 3 October 2018
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The microstrip slot antenna can be fed either by a coplanar waveguide feed (CPW) or by a microstrip feedline. Many CPW fed and microstrip fed slot antennas have been stated in many works [9–11]. Circularly polarised coplanar waveguide fed slot antennas achieve great attention with the advantages of low radiation loss, less dispersion, wide impedance and axial ratio bandwidth when compared to the microstrip-fed type. But the microstrip line-fed slot antenna can easily excite the fundamental mode and can avoid the higher resonant modes as generated in the CPW feeding [12]. As a result, the microstrip-fed slot antennas have comparatively lesser bandwidth than the coplanar waveguide fed slot antenna.

Circularly polarised microstrip antenna arrays have become an excellent candidate due to their light weight, low profile planar configuration and ease of fabrication and integration with other circuitries. Printed CP slot array antenna achieves considerable attention as they provide better impedance bandwidth and axial ratio bandwidth while maintaining low profile [13–15]. Also, the recent demand of compact wireless devices points to the development of antennas operating with multiple operating frequencies with polarization diversity within a single antenna excited by a single feed.

In this paper, a printed slot array antenna for dual band operation is developed which is an extension of the work reported in [16], where a single arrow headed modified cross slot antenna is fed electromagnetically by a microstrip line printed on the other side of the substrate. The slot array antenna proposed in this literature is a 1×4 slot array with a highly efficient corporate feeding technique to feed the arrow headed modified cross shaped slot arrays. The slot array elements are etched on the ground plane and are electromagnetically coupled using the microstrip corporate feeding network. The two operating frequencies are 1.72 GHz and 2.45 GHz with circular polarization on the upper band is achieved. The proposed slot array antenna structure shows appreciable gain enhancement in addition to the dual band behaviour as compared to [16].

2. ANTENNA ELEMENT CONFIGURATION AND DESIGN

The geometrical layout of the proposed antenna structure is shown in Fig. 1. The antenna is simulated and fabricated on a 1.6 mm thick, low-cost FR-4 substrate with dielectric constant of 4.4 and loss tangent of 0.025. The antenna prototype consists of a 1×4 arrow headed modified cross shaped slot arrays etched on the ground plane of the substrate. A corporate feed is designed and etched on the other side of the substrate to feed the slot arrays. The corporate feed type microstrip feedline is having a line width of 3 mm which is matched and connected to a 50 Ω SMA connector. The length and width of the proposed antenna is L and W respectively. The top view and bottom view of the proposed design are shown in Figs. 1(a) and 1(b). The array geometry is designed, simulated and optimised using the CST Microwave studio suite software. The optimised parameters of the antenna are as follows: $L = 75$, $W = 130$, $L_1 = 9.5$, $L_2 = 8$, $L_3 = 23$, $d = 32.5$, $w_g = 3$, $w_e = 28.5$, $c = 2.12$ (units: mm).

The slot array antenna is composed of four arrow headed modified cross slot elements etched on the ground plane of the FR-4 substrate. Each element resonates at a frequency of 2.45 GHz. The slot array antenna utilises the corporate feed configuration, in which the slot elements are fed by a 1 : 4 power divider network with identical path lengths from the feed point to each slot element. The corporate feed configuration is preferred to other feeding techniques due to its design simplicity, broader bandwidth and flexibility in the choice of element spacing. The arrow headed modified cross slot elements are separated by a $\lambda/4$ (λ corresponding to 2.45 GHz) distance from the centre of the slot element as shown in Fig. 1. The spacing of the slot elements from both of the non-radiating edges is approximately $\lambda/7$ which is represented as w_e. The corporate feeding technique having width w_g incorporated in the design electromagnetically couples the energy to each of the slot array elements simultaneously. A small cut of length 'c' is made at the edges of the feed in order to improve the current flow through the feed network.

The single element of the proposed slot array antenna is shown in Figs. 2(a) and (b). The two arrow headed slots, having lengths P_1 and P_2 with width 2 mm are placed in a manner such that it makes an angle of θ ($\theta = 60°$) degrees between the slots. The term 'modified cross slot' is used in this literature since the angle θ between a regular cross slot is modified from 90° to 60° in the proposed design. This modification is introduced in order to improve the axial ratio of the slot antenna. The microstrip feedline which is extended beyond the centre of the slot, denoted by 's' in Fig. 2(b) acts as a tuning stub and enhances the impedance matching of the array antenna. The selection of the

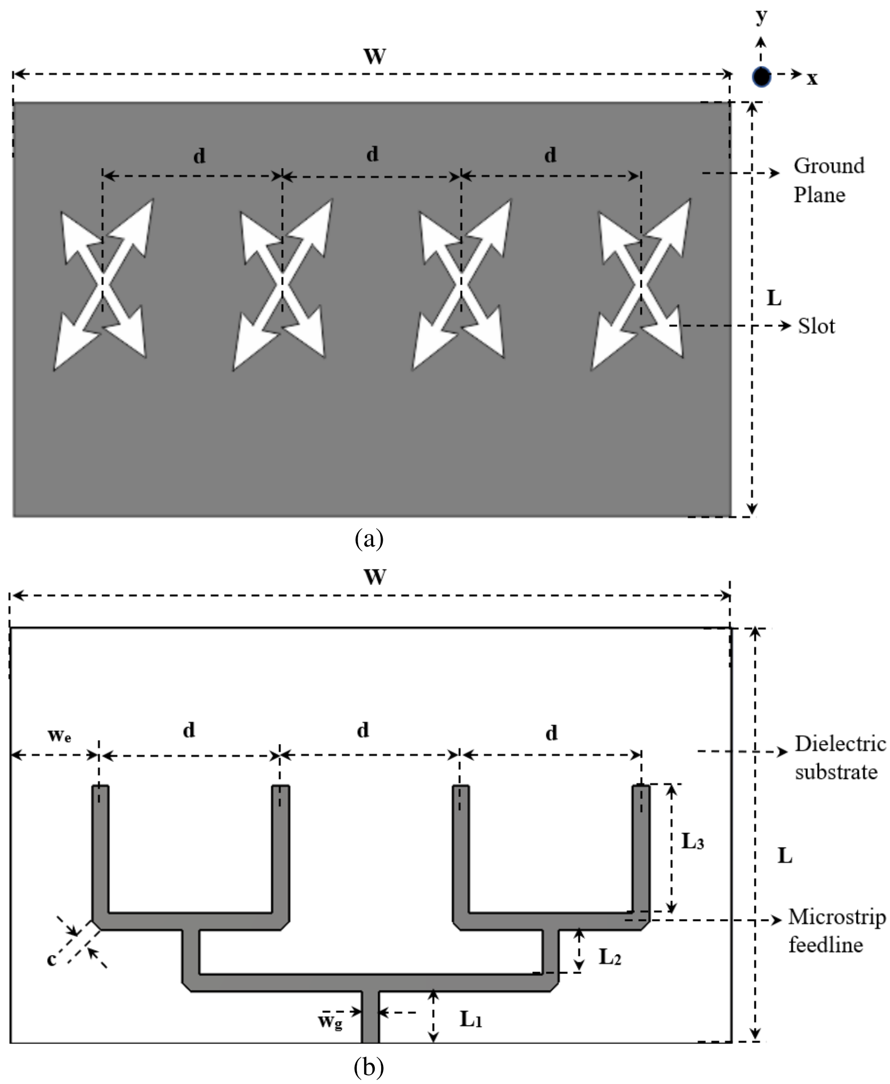

Figure 1. Configuration of the proposed arrow headed modified cross slot array geometry (a) top view (b) bottom view.

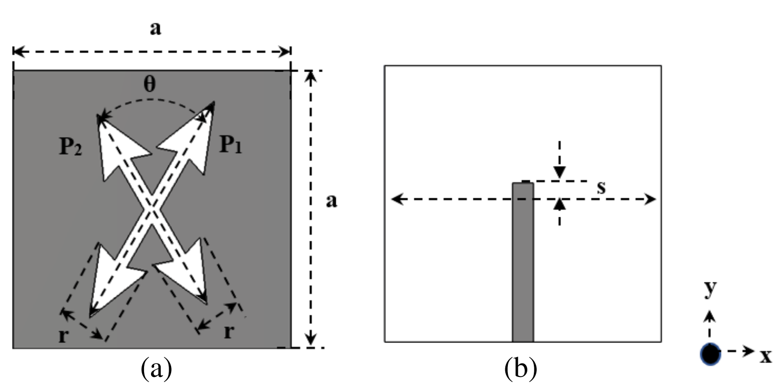

Figure 2. Geometry of the single element of the slot array (a) top view (b) bottom view. ($a = 40\,\mathrm{mm}$, $P_1 = 36\,\mathrm{mm}$, $P_2 = 31.6\,\mathrm{mm}$, $r = 8\,\mathrm{mm}$, $\theta = 60^\circ$, $s = 3\,\mathrm{mm}$).

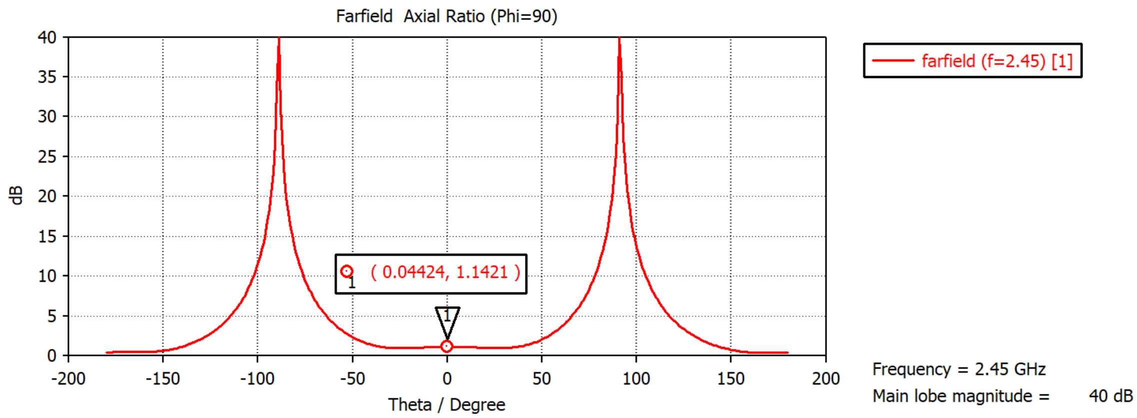

Figure 3. Simulated axial ratio (AR) of the proposed slot array antenna at $f_r = 2.45$ GHz.

lengths P_1 and P_2 is such that their ratio contributes to the axial ratio (AR) at the resonant frequency ($f_r = 2.45$ GHz).

$$AR = P_1/P_2 = 36/31.6 = 1.14$$

As shown in Fig. 3, it is observed that the simulated axial ratio at the resonant frequency ($f_r = 2.45$ GHz) is 1.14. By introducing this geometrical asymmetry, the fundamental resonant mode gets split into two orthogonal degenerated modes with equal amplitude and a 90° phase difference. Also, from the simulation results it is noticed that the single element slot antenna resonates only at 2.45 GHz with a gain of 3.52 dBi in the boresight direction with bidirectional radiation pattern and having an impedance bandwidth of 14.4% (2.25 GHz–2.6 GHz). By modifying the single element slot antenna to a 4-element slot array antenna, the gain is enhanced to 7.01 dBi at 2.45 GHz, and the antenna exhibits a dual band behaviour, at 1.72 GHz and at 2.45 GHz, having bidirectional radiation pattern at two resonant frequencies with both maxima in the boresight direction.

For better understanding the excitation mechanism properly, simulated surface current distributions of both the resonant frequencies of the optimised modified cross slot array were studied. Fig. 4 shows the surface current distributions on the slot array surface for both the lower and upper resonant frequencies. In the case of lower resonant frequency, the surface current is mainly confined to the slots uniformly as shown in Fig. 4(a). It is evident from the surface current distributions of the upper resonant frequency, as shown in Figs. 4(b)–(e), that the surface current distributions at phase $\theta = 0°$ are equal in magnitude and opposite in direction to that at $\theta = 180°$. Similarly, the surface current distributions at phase $\theta = 90°$ are equal in magnitude and opposite in direction to that at $\theta = 270°$, thereby satisfying the condition for producing a circularly polarised radiation.

3. RESULTS AND DISCUSSIONS

The optimised antenna is fabricated and tested using Agilent Network Analyzer E5071C in an anechoic chamber. The measured and simulated variations of S_{11} with frequency of the proposed modified slot array antenna are shown in Fig. 5. The simulated −10 dB impedance bandwidth of the proposed slot array for lower band is 74.4 MHz (1.6912 GHz–1.7656 GHz) or 4.325% with a peak resonance of 1.72 GHz, and for the upper band is 191.2 MHz (2.3656 GHz–2.5568 GHz) or 7.804% with a peak resonance of 2.45 GHz. The measured values for the lower band are 72.8 MHz (1.6768 GHz–1.7496 GHz) or 4.257% with a peak resonance of 1.71 GHz, and for the upper band is 177.2 MHz (2.3656 GHz–2.5428 GHz) or 7.292% with a peak resonance of 2.43 GHz. The slight discrepancies in the simulated and measured results may be due to the fabrication tolerances. The lower resonant frequency covers the Meteorological Aids and Fixed Services frequency band (1.700–1.710 GHz) and the upper resonant frequency covers the WLAN (2.4–2.497 GHz), Bluetooth, Zigbee, DECT (2.4–2.4835 GHz) and the 2.45 GHz ISM band (2.4–2.485 GHz) and the Microwave RFID band. The proposed slot antenna array shows circular polarisation in the upper frequency band. The variations of axial ratio with frequency for the upper frequency band

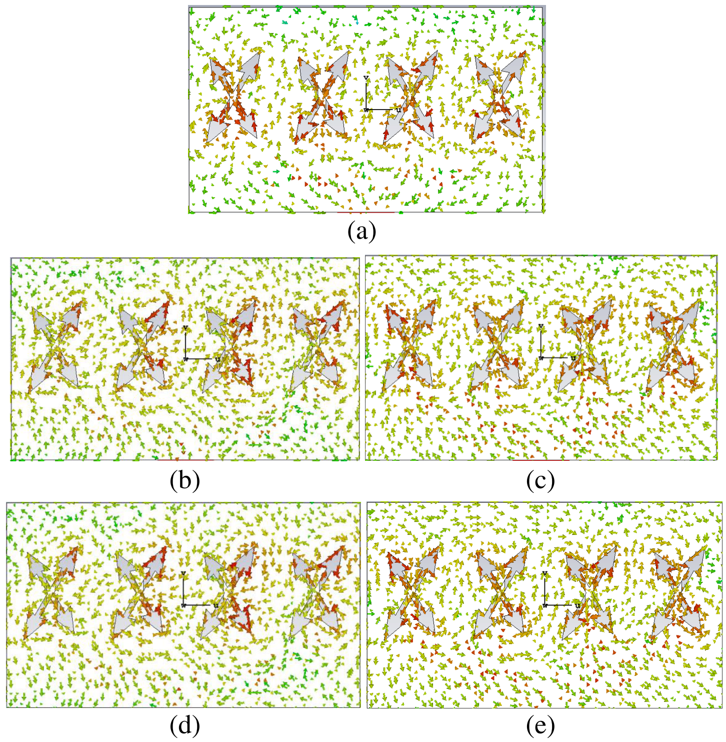

Figure 4. Surface current distributions of the proposed modified cross slot array antenna at (a) 1.72 GHz and at 2.45 GHz for (b) $\theta = 0°$ (c) $\theta = 90°$ (d) $\theta = 180°$ (e) $\theta = 270°$.

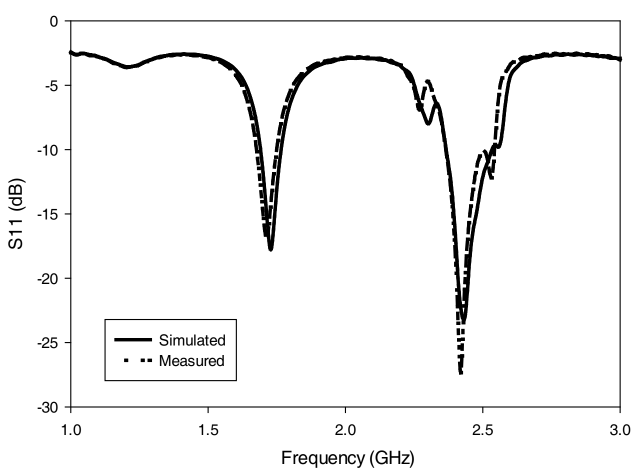

Figure 5. Simulated and measured variations of S_{11} with frequency for the proposed modified slot array antenna.

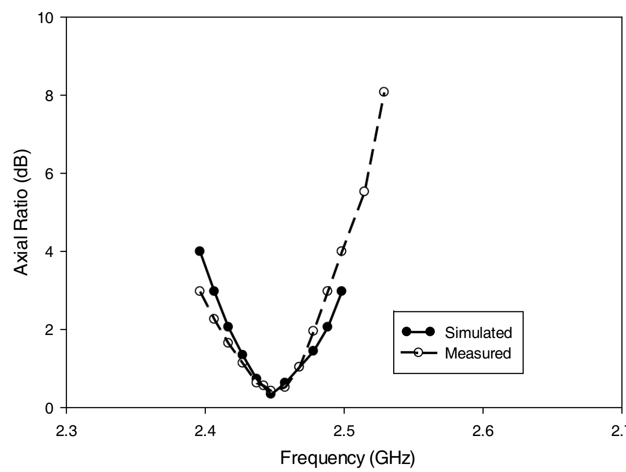

Figure 6. Simulated and measured variations of axial ratio with frequency for the upper band of the proposed modified slot array antenna.

of the proposed array antenna are plotted in Fig. 6. The simulated 3 dB axial ratio bandwidth is 90.12 MHz (2.411 GHz–2.5011 GHz) with a fractional bandwidth of 3.677%, and that of measurement is 88.8 MHz (2.402 GHz–2.4908 GHz) with a fractional bandwidth of 3.654%.

Figure 7 shows the top and bottom views of the fabricated structure of the proposed modified slot array antenna. The simulated and measured radiation patterns of the proposed slot antenna array in the x-z and y-z plane for 1.72 GHz and 2.45 GHz are plotted in Figs. 8 and 9. The antenna exhibits a bidirectional radiation pattern for both the lower and upper frequencies. The circular polarisations of

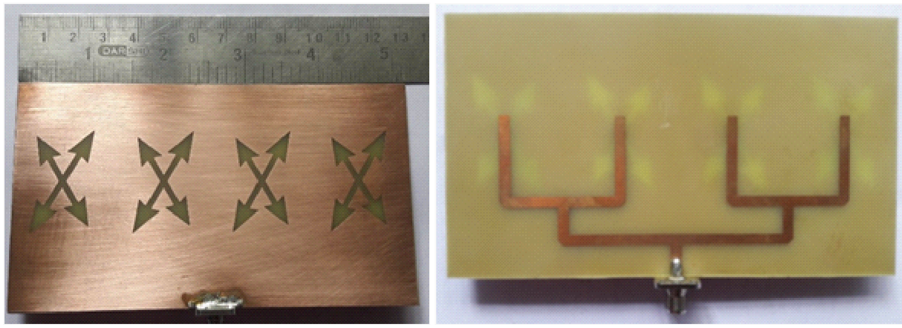

Figure 7. Fabricated structure of the proposed modified slot array antenna (a) top view (b) bottom view.

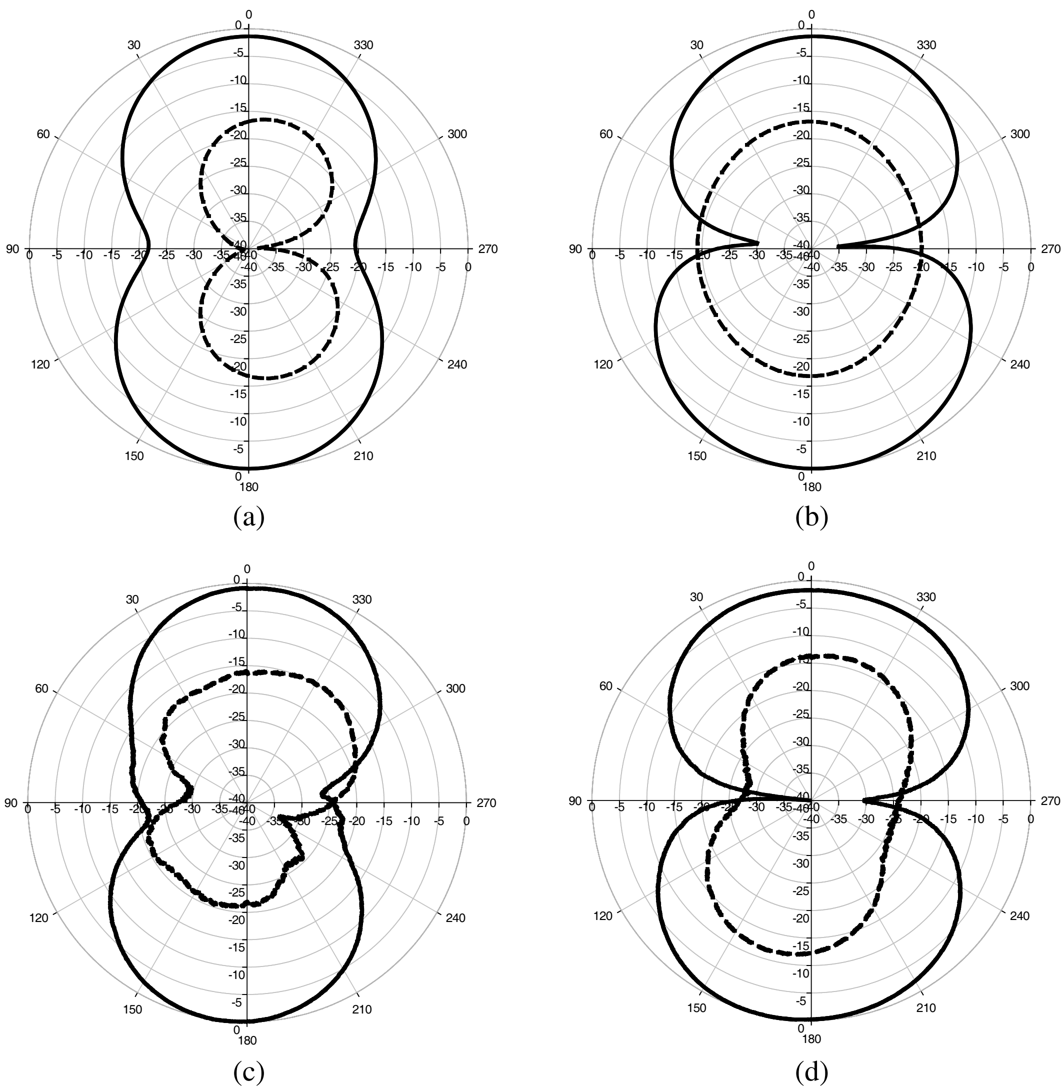

Figure 8. Simulated and measured radiation patterns of the proposed modified slot antenna array at 1.72 GHz (a) simulated x-z plane, (b) simulated y-z plane, (c) measured x-z plane, (d) measured y-z plane. (co-polarised__ solid line and cross polarised . . . dashed line).

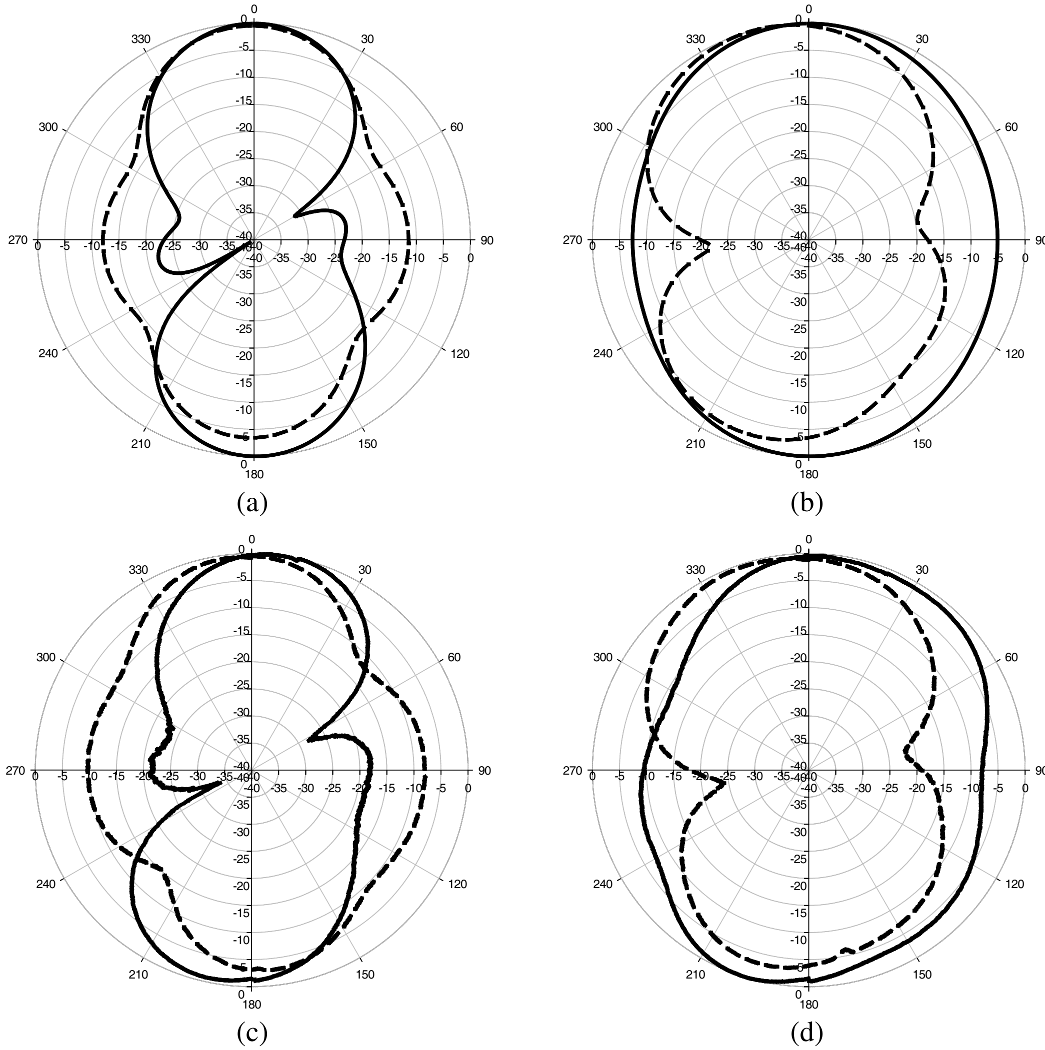

Figure 9. Simulated and measured radiation patterns of the proposed modified slot antenna array at 2.45 GHz (a) simulated x-z plane, (b) simulated y-z plane, (c) measured x-z plane, (d) measured y-z plane. (co-polarised__ solid line and cross polarised . . . dashed line).

the antenna at $+z$ and $-z$ directions are in the opposite directions. The radiation pattern is left-hand circular polarisation (LHCP) for $z > 0$ region and right-hand circular polarisation (RHCP) for $z < 0$ region. The measured gain of the proposed antenna is 6.23 dBi at the lower resonant frequency and 7.01 dBi at the upper resonant frequency. Compared to the single element slot antenna, the proposed modified slot array antenna exhibits a dual band behaviour with an enhancement in gain from 3.52 dBi to 7.01 dBi at 2.45 GHz.

4. CONCLUSIONS

A novel arrow headed modified cross slot array antenna with dual band behaviour and circular polarisation with enhanced gain characteristics is proposed. A corporate feeding network is employed to efficiently couple the electromagnetic energy to the slot array elements. The proposed slot array antenna exhibits dual band behaviour with resonances at 1.72 GHz and 2.45 GHz with circular polarisation in the upper frequency band. The measured resonant frequencies are 1.71 GHz and 2.43 GHz. The measured axial ratio bandwidth is 88.8 MHz. The measured results are in good agreement with the simulated readings. The proposed slot array antenna exhibits bidirectional radiation pattern at both resonant frequencies with improved gains. The antenna may find applications in Meteorological Aids and Fixed Services frequency devices at the lower frequency and in WLAN, Bluetooth, Zigbee, DECT, ISM and Microwave RFID band in the upper frequency band. As the antenna exhibits circular polarisation with appreciably good gain characteristics in the upper frequency band, it can also be used as an RFID reader antenna.

ACKNOWLEDGMENT

One of the authors, A. R. Parvathy, would like to acknowledge University Grants Commission, Govt. of India, for providing a research fellowship.

Authors would like to sincerely express the gratitude to Dr. C. K. Aananadan, Professor, Dept. of Electronics, Cochin University of Science & Technology for his valuable suggestions throughout the work.

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