Circularly Polarized Split Ring Resonator Loaded Slot Antenna for RFID Readers and WLAN Applications

Parvathy A. R.[1], Ajay V. G.[2], Thomaskutty Mathew[3]

[1,2,3]School of Technology and Applied Sciences, M. G. University Regional Centre, Edappally
[1]Corresponding author, E-mail: arpinmvk@gmail.com

Abstract

The design of a compact circularly polarized printed slot antenna operating at 2.45 GHz is reported. The antenna consists of a pair of rotated square split ring resonators (SRR) inside a rectangular slot etched on the ground plane of an FR-4 dielectric substrate. A square shaped microstrip open-loop feeding mechanism is etched on the backside of the dielectric substrate to feed the split ring resonators (SRR) loaded slot. The overall size of the antenna is 60x42x1.6 mm^3. The measured -10dB impedance bandwidth is 10.48% (2.38-2.64 GHz) and the measured 3dB axial ratio (AR) bandwidth covers the entire impedance bandwidth.

1. Introduction

Rapid progress in wireless communication technology has demanded the need for developments in antenna designs. Many wireless communication systems such as mobile telephony, cognitive radio, radio frequency identification (RFID), wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX) and various remote-sensing devices require miniaturized antennas. Slot antenna is a best choice for such type of applications due to its low profile planar structure with simple and low-cost fabrication [1]. The concept of printed slot antenna was first introduced by Y. Yoshimura in 1972 [2]. Printed slot antenna consists of a slot etched on the ground plane of the substrate fed by a microstrip feedline. The ground plane is an essential part of the slot antenna which defines the total size of the antenna and is used to support the feed lines to the slot [3,4]. A printed slot antenna can be used to enhance the operating bandwidth, without increasing the size of the antenna [5-6]. The main advantages of the radiating slots are a wide operating bandwidth with good isolation and negligible radiation from the feed network. Many researchers have focused on the design and development of different types of slots such as circular, tapered, folded, fractal and miniaturized spiral slots. [7,8].

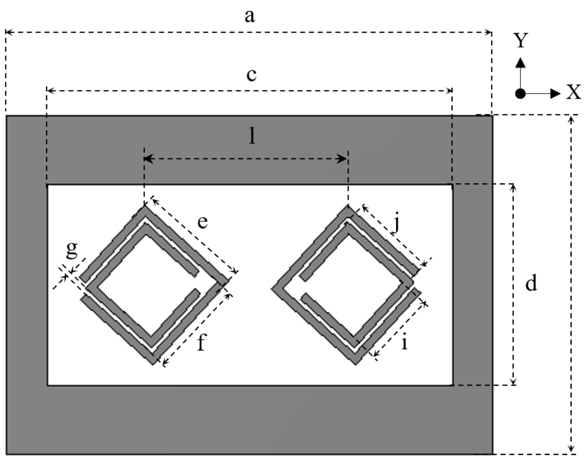
In an RFID system, the reader antenna sends a radio frequency communication signal to the tag attached to the object to be identified and receives the backscattered signal from the tag. Different frequency ranges used in RFID are Low Frequency (LF;125 kHz), High Frequency (HF;13.56 MHz), Ultra High Frequency (UHF;433 MHz, 860-960 MHz) and Microwave Frequency (2.45 GHz, 5.8 GHz) [9]. The reader antenna is one of the most important component in an RFID system which is designed for circular polarization (CP) operation, because circularly polarized antennas can fairly communicate with linearly polarized antennas with random orientations and also avoid the polarization losses and mismatches caused by multipath effects. The CP antenna, with its low profile, small size, and light weight, is ideal for portable RFID readers [10,11]. Antennas for WLAN [12] and rectenna applications [13] operates at a frequency band of 2.4-2.484 GHz (specified by IEEE 802.11b/g). In WLAN systems, various slot antennas have been proposed such as a narrow rectangular slot-ring antenna, stair-shaped slot antenna [14] or parasitic element [15]. But these have larger dimension and are not suitable for WLAN applications that require miniaturized antennas. Circularly polarized antennas are preferred in WLAN systems as it offer better mobility and enhanced system performance than a linearly polarized antenna [16].

A typical method of generating the circularly polarized radiation is by exciting two orthogonal degenerated resonant modes, with phase quadrature. Since the printed slot antenna is a dual form of the microstrip antenna, it is possible to produce circularly polarized (CP) radiation by introducing some symmetrical or asymmetrical perturbation elements to the slot antenna. The introduction of such symmetrical or asymmetrical perturbation elements into a single-feed slot antenna produces greater bandwidth than that of a conventional circularly polarized microstrip antenna operated in the fundamental mode [17,18]. Single-feed circularly polarized square, circular and annular-ring patch antennas, with perturbation elements, have all been reported in many papers. [19-21]. The antenna can easily radiate a CP wave by generating two orthogonal degenerated modes using perturbation cuts or strips. But these antennas exhibit small impedance and narrow axial ratio (AR) bandwidths. In order to produce a circularly polarized radiation, either the geometrical topology of the slot can be adjusted or the length of the microstrip line can be optimized resulting in frequency tuning and good impedance matching of the antenna respectively [22].

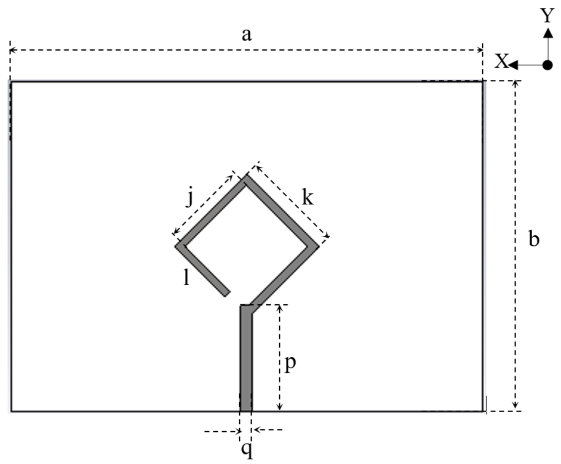
A microstrip slot antenna loaded with square split ring resonators fed by a microstrip open-loop feed is proposed in [23]. But the axial ratio bandwidth does not cover the entire impedance bandwidth. A solution to this problem is introduced in the proposed paper where the split ring resonators inside the slot antenna are rotated and fed by a microstrip open-loop feed. The antenna is designed to operate at 2.45GHz which can be used as RFID reader antennas and in WLAN systems. This new design offers enhancement in the axial ratio bandwidth which covers the entire impedance bandwidth.

2. Antenna Structure

The configuration of the proposed slot antenna with a pair of rotated square split ring resonators is shown in Figure 1. A rectangular slot of 50 x 25 mm^2 dimension is etched on a 1.6mm thick low-cost FR-4 substrate with dielectric constant of 4.4 having a dimension of 60 x 42 mm^2. A pair of rotates square split ring resonators are embedded within the rectangular slot antenna. A microstrip line open loop feed is used for feeding both the slot and the split ring resonators. The dimensions of the split ring resonators are e, f, i, j and g, where g is the gap between the split ring resonators. The antenna shape and dimensions were simulated and optimized using the software CST Microwave Studio Suite.



(a)



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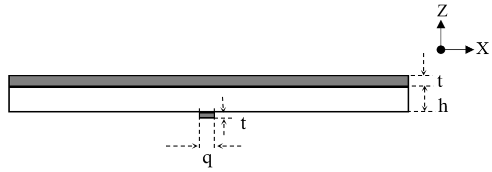
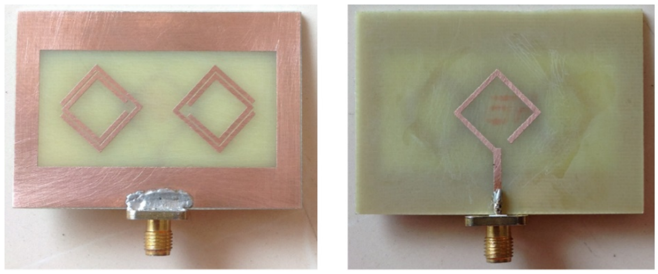


(c)

Figure 1: Configuration of the proposed slot antenna loaded with a pair of rotated square split ring resonators (a=60mm, b=42mm, c=50mm, d=25mm, e=14mm, f=12mm, g=1mm, h=1.6mm, i=9mm, j=11 mm, k=13mm, l=9mm p=13.5mm, q=1.5mm, t=0.03mm) (a) Front view (b) Back view (c) Side view

3. Results and Analysis

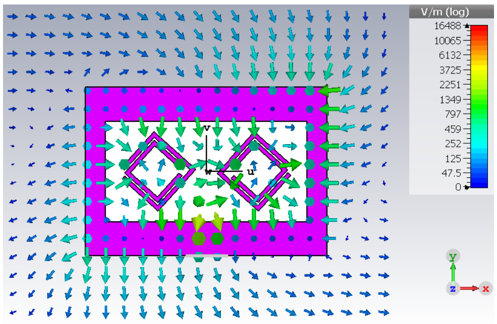
The prototype of the proposed slot antenna with optimal geometrical parameters was fabricated and the radiation characteristics were measured in an anechoic chamber. The photograph of the fabricated structure is shown in Figure 2. The measurements were carried out by using Agilent network analyser E5071C.



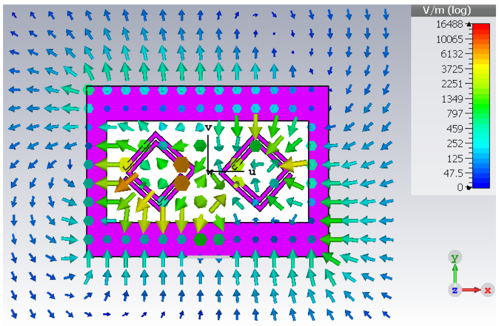
(a) (b)

Figure 2: Photograph of the fabricated structure of the proposed slot antenna loaded with rotated square SRR fed by microstrip open loop feed (a) Front view (b) Back view

For introducing a phase quadrature, the two split ring resonators (SRR) are fed by a particular type of open loop feeding mechanism. By the introduction of this feeding mechanism, the two SRR are excited with 90^0 phase differences which satisfies the condition for circular polarization. In order to confirm this, the electric field distributions on the antenna at the operating frequency is to be analyzed. Figure 3 (a) - (d) illustrates the simulated electric field distributions on the antenna at the operating frequency of 2.45GHz. The figure explains that the electric field is concentrated mainly on the split ring resonators. It is observed that the electric field distributions of the proposed slot antenna at $\phi = 0^0$ and $\phi = 180^0$ are equal in magnitude and opposite in direction. Likewise, the electric field distributions at $\phi = 90^0$ and $\phi = 270^0$ are equal in magnitude and opposite in direction. Therefore, the electric field distributions on the proposed slot antenna clearly satisfies the condition for circularly polarized radiation. Also, the direction of rotation of electric field vector is anti-clockwise while looking into +z direction and is clockwise while looking into -z direction which clearly confirms that the sense of polarization is left handed along +z direction and right handed along -z direction.



(a)



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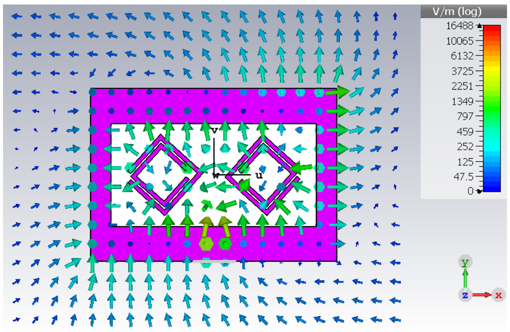

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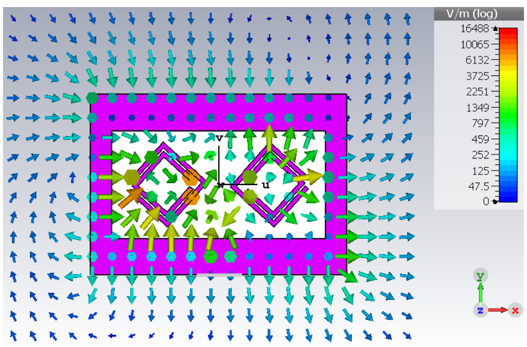

(d)

Figure 3: Simulated electric field distributions of the proposed slot antenna loaded with rotated square SRR at 2.45 GHz for different phase angles (a) $\phi = 0^0$ (b) $\phi = 90^0$ (c) $\phi = 180^0$ (d) $\phi = 270^0$

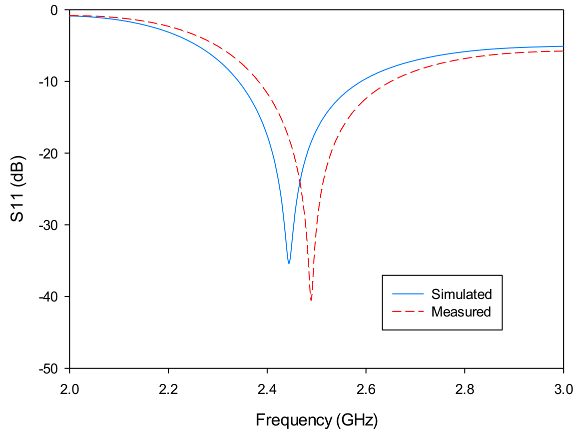

Figure 4: Simulated and measured variations of return loss with frequency of the proposed slot antenna loaded with rotated square SRR

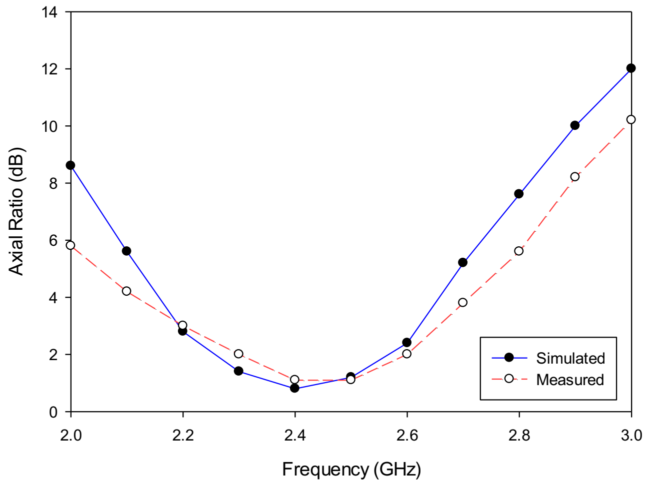

Figure 5: Simulated and measured variations of axial ratio with frequency for the proposed slot antenna loaded with rotated square SRR

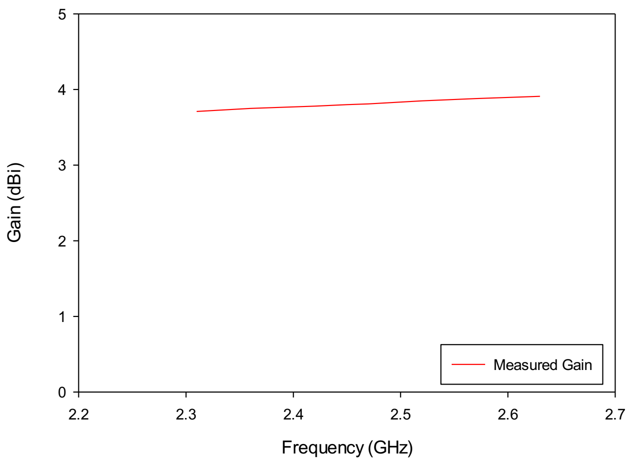

Figure 6: Gain of the proposed slot antenna loaded with rotated square SRR with frequency

Figure 4 shows the simulated and measured return loss variations with frequency of the proposed slot antenna. The antenna achieves a simulated impedance bandwidth of 10.2% (2.34 - 2.59 GHz) and a measured impedance bandwidth of 10.48% (2.38 - 2.64 GHz) which cover the IEEE 802.11b/g WLAN standard and the Microwave RFID frequency band. Reasonable agreement is achieved between the measured and simulated results and the slight discrepancy is due to the fabrication tolerance. Figure 5 shows the simulated and measured variations of axial ratio with frequency for the proposed slot antenna. The antenna exhibits a simulated and measured 3dB axial ratio bandwidth of 420 MHz (2.19 GHz to 2.61 GHz) and 450 MHz (2.2 GHz to 2.65 GHz) respectively. It is evident that the 3dB axial ratio bandwidth covers the entire impedance bandwidth. The variations of gain of the proposed slot antenna with the frequency is plotted in Figure 6.

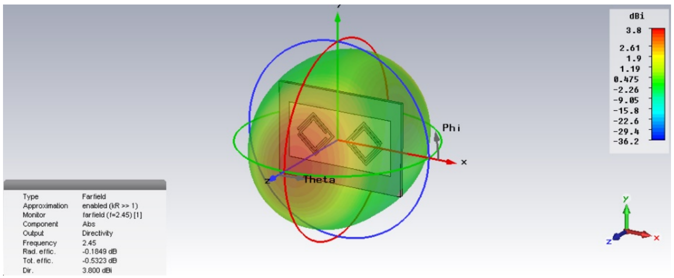

Figure 7: Simulated three-dimensional radiation pattern of the proposed slot antenna at 2.45 GHz.

The co-polar and cross polar radiation patterns have been measured at 2.45 GHz for both X-Z and Y-Z plane. The simulated three-dimensional radiation pattern of the proposed slot antenna at 2.45 GHz is shown in Figure 7. The simulated and measured normalized far field radiation patterns in the X-Z plane and Y-Z plane at 2.45GHz are shown in Figure 8 & 9. From the figures it is clear that the proposed slot antenna achieves a bidirectional radiation pattern. The difference between the co-polar and cross-polar components of the radiation pattern in both directions at the boresight is below 3 dB, which visibly demonstrates the presence of circularly polarized radiation. The 3-dB axial ratio beamwidth is 107^0 for +z direction and 94^0 for -z direction for both planes.

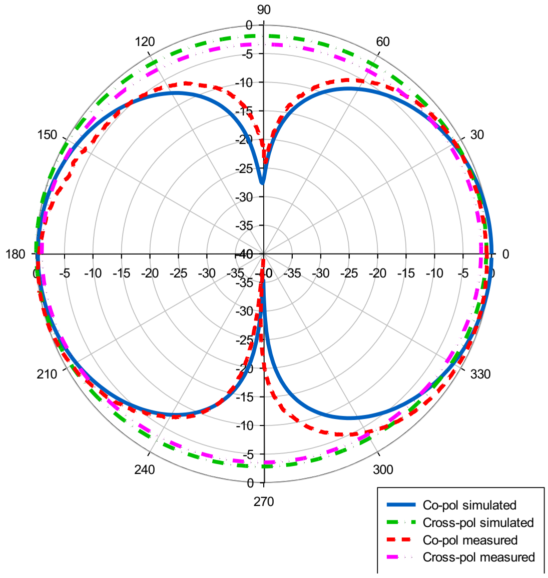

Figure 8: Simulated and measured normalized radiation patterns in the X-Z plane of the proposed slot antenna loaded with rotated square SRR.

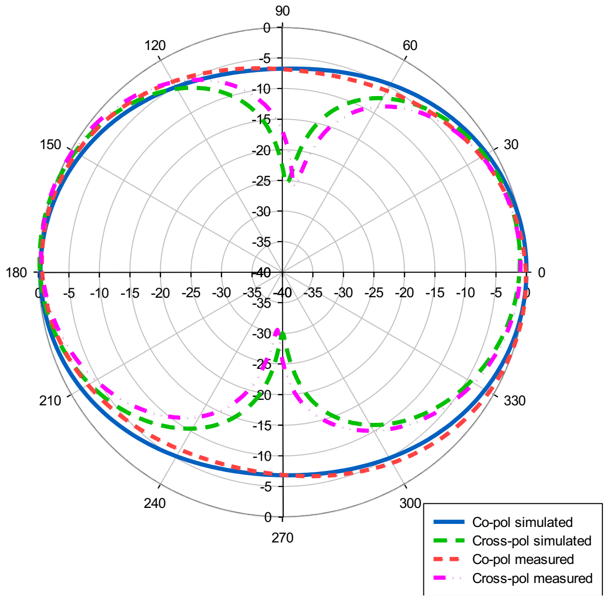

Figure 9: Simulated and measured normalized radiation patterns in the Y-Z plane of the proposed slot antenna loaded with rotated square SRR.

4. Comparison

Table 1 shows the comparison between the proposed slot antenna and the antenna in Ref [23]. It can be observed that the proposed antenna exhibits better performance such as impedance bandwidth and axial ratio bandwidth than the antenna in Ref [23].

Table 1: Comparison between proposed slot antenna and the antenna in Ref [23].

Parameters	Antenna in Ref [23]	Proposed Slot Antenna
Overall size	$50 \times 42 \times 1.6$ mm^3	$60 \times 42 \times 1.6$ mm^3
Slot size	40×20 mm^2	50×25 mm^2
Impedance BW	180 MHz	260 MHz
Axial Ratio BW	130 MHz	260 MHz
Gain	4.27 dBi @ 3.75 GHz	3.8 dBi @ 2.45 GHz

5. Conclusions

A compact circularly polarized printed slot antenna loaded with a pair of square split ring resonators operating at 2.45 GHz is designed and fabricated. The typical microstrip open loop feed structure contributes for the circular polarization. The overall size of the antenna is 60x42x1.6 mm^3. The measured -10dB impedance bandwidth is 10.48% (2.38-2.64 GHz) and the measured 3dB axial ratio (AR) bandwidth covers the entire impedance bandwidth. The antenna exhibits a bidirectional radiation pattern which can be used for reducing multipath fading in repeater station antennas and in various wireless communication applications such as in RFID reader antennas and in WLAN systems.

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