Slotted Circularly Polarized Microstrip Antenna for RFID Application

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Submitted July 30, 2016 / Accepted June 9, 2017

Abstract. *A single layer coaxial fed rectangular microstrip slotted antenna for circular polarization (CP) is proposed for radio frequency identification (RFID) application. Two triangular shaped slots and one rectangular slot along the diagonal axis of a square patch have been embedded. Due to slotted structure along the diagonal axis and less surface area, good quality of circular polarization has been obtained with the reduction in the size of microstrip antenna by 4.04%. Circular polarization radiation performance has been studied by size and angle variation of diagonally slotted structures. The experimental result found for 10 dB return loss is 44 MHz with 10 MHz of 3 dB Axial Ratio (AR) bandwidth respectively at the resonant frequency 910 MHz. The overall proposed antenna size including the ground plane is $80 \times 80 \times 4.572$ mm^3.*

Keywords

Circularly polarized, microstrip antenna, radio frequency identification

1. Introduction

Recently, the RFID (radio frequency identification) has become very popular which is an electronic identification technology that uses radio EM waves to exchange data between reader and tag antennas i.e. an object basically used in commercial applications. The common examples are UHF band (840-960 MHz) RFID systems becoming more attractive for many applications such as supply chain, tracking, bioengineering, inventory management, large information storage capacity, logistics etc. [1–3]. Generally, the UHF tag antennas are linearly polarized but the orientations of the tag antennas are random, so actual application and requirement of RFID tag antennas are circularly polarized systems [4]. Circularly polarized microstrip antenna reduces the multipath effect generated by misalignment of reader and tag antennas and becomes most effective and efficient RFID system. Therefore recently, RFID antennas are usually circularly polarized [5], [6]. The total frequency range of the UHF band used for RFID system is 840–960 MHz. However, the frequency band for RFID application is different for different countries. In America, operating band is 902–928 MHz, in Europe 865–867 MHz, in India 865–867 MHz, in China 840.5–844.5 MHz and 920.5–924.5 MHz, in Japan 952–955 MHz etc. [7], [8]. In general, circular polarization commonly needs two orthogonal linear polarizations with 90 degree phase shift difference [9]. Generally, circular polarization antenna is divided into two types: single feed and multi feed technique types. A single feed CP antenna is simple and compact with respect to dual or multi-feed CP antenna but these antennas have a disadvantage of narrow bandwidth and AR 1–4% [10],[11]. The major consideration for the CP microstrip antenna design of handheld/ portable RFID reader applications is that it must cover at least one UHF RFID band with a bandwidth of few MHz [12], [13]. A compact, circularly polarized, slotted-slit loaded square patch is used to generate circular polarization by using two unequal sizes of circular slots along the diagonal axis of the patch with slits to reduce the size [14].

Recently, a reduced size CP arrowhead shaped slot is embedded in the first quadrant center of the radiator square patch to achieve 10-dB return loss bandwidth of 35.0 MHz (888.0–923.0 MHz) and 3-dB AR bandwidth (ARBW) of 8 MHz (908.0–916.0 MHz) with overall size $87 \times 87 \times 4.572$ mm^3 [15].

In this paper, a single layer coaxial fed circularly polarized microstrip antenna with two asymmetrical triangular slots embedded in it has been proposed. Due to these two asymmetrical slots entrenched diagonally into the square patch, the circular polarization is being generated. A rectangular slot is cut along the diagonal axis in order to improve the impedance matching. A good quality CP has been achieved by adjusting the size of the slots. The proposed structure gives large bandwidth and large AR bandwidth.

2. Antenna Geometry Design

The theoretical results considered here are based with the assumption that a sinusoidal basis function on patch antenna in a direction of resonance is sufficient to approximate the current distribution. Multi-frequency behavior of patch antenna can be obtained by means of multiple radiating elements, which supports strong currents and radiation at resonance. These types of configurations include multi slot patch antennas fabricated by using circular, annular, rectangular and triangular slots in it. The physics behind the design is to create an asymmetric slot object so as to create two degenerate modes, one in X and the other in Y direction. Since we want to have two orthogonal modes 90° out of phase, the slot/slots in the patch should be not symmetric. In this manner, the length of the currents in the X direction travels a slightly different path than the currents in Y direction. This different length is optimized so as to create the needed 90° out of phase to create the circular polarization. The triangular slot as well as rectangular slot has four components of the current distribution for all the quadrants with 0°, 90°, 180° and 270°. It is clearly visible that the current distribution for all the slots is being polarized towards left hand side from the antenna face. The current distribution for the triangular slot patch reveals that they are approximately similar to those of the rectangular slot patch with the exception that the antenna exhibits a cross polarized component in the E & H plane. However since for the same resonant frequencies, the triangular slot antenna requires less patch area, this property has been exploited to get the application advantage for RFID in this paper.

The double asymmetrical triangular with rectangular shaped slotted microstrip antenna is proposed with a reduction in antenna size (Fig. 1). The radiating square patch has length and width L_p and W_p, respectively. The single layer antenna designed on the FR4 substrate with dielectric constant 4.4 and thickness h 4.572 mm and loss tangent 0.02. Size of the substrate is 80 mm × 80 mm and the overall size is 80 × 80 × 4.572 mm^3. Length and width of the rectangular slot are L_b and L_c. By adjusting the length of the triangle to optimize in x and y direction, $L_a > L_e$ and $H_a > H_e$ where L_a, L_e, H_a and H_e are the base length and height of triangular slots respectively. The location of the two triangular slots is at the first and the third quadrant along the diagonal axes. To achieve CP operation of the antenna the area of triangles should be unequal. All the dimensional parameters of the antenna are shown in Table 1.

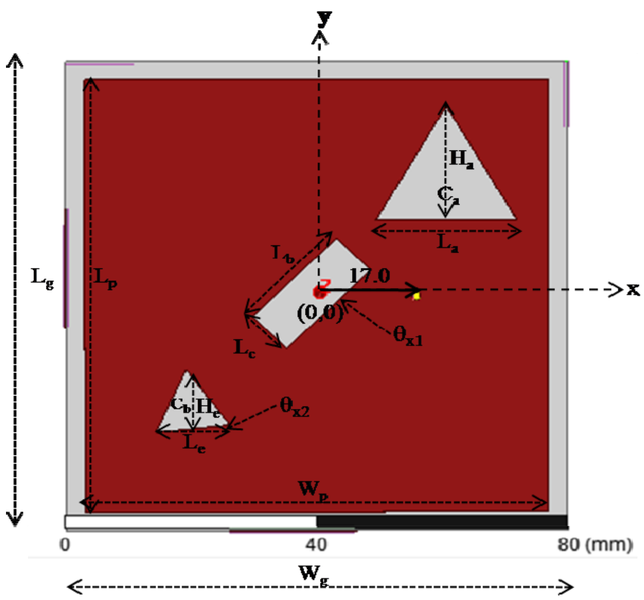


Fig. 1. The proposed antenna geometry.

L_g	W_g	L_p	W_p	L_a
80	80	74	74	22
H_a	L_b	L_c	L_e	H_e
19	19	7.6	11	9

Tab. 1. Dimensions of antenna in millimeter.

3. Parametric Analysis

The proposed antenna has dimensions 74 mm (L_p) × 74 mm (W_p) and substrate size of 80 mm (L_g) × 80 mm (W_g) (Fig. 1). This antenna has been simulated using 3D-Electromagnetic software i.e. Ansoft HFSS, based on finite element method. The critical design parameters are based on length and height of the triangle and the length and width of rectangular slots having a strong influence on characteristics of the antenna. Two unequal triangle slots are located in the first and the third quadrant diagonally on the radiator patch antenna. The coordinate of the first triangle is C_a (20.8, 20.8) and the coordinate of the second triangular is C_b (–19.3, –20.3) with respect to the center of the patch. The probe feed location is on the positive x-axis direction at 17 mm from the center of the ground plane. Slight variations in the dimensions of the triangular slots excited the CP. For the realization of circular polarization radiation, asymmetrical triangular slotted patch antenna must have a 90 degree phase shift between two orthogonal modes of the electric field. These two orthogonal modes are produced by asymmetries along the diagonal axis of the radiator patch using triangular slots and the impedance matching conditions can be obtained by entrenching rectangular slot along the diagonal axis of the radiating patch which has been shown in Fig. 2(a),(b). The proposed antenna has good circular polarization radiation with a reduction in antenna patch size. A slot perturbing the modes is what matters to generate the circular polarization. A triangular slot has been proposed in order to show that an arbitrary shape can be useful to obtain circular polarization: position and size are the important parameters for the design rather than slot shape.

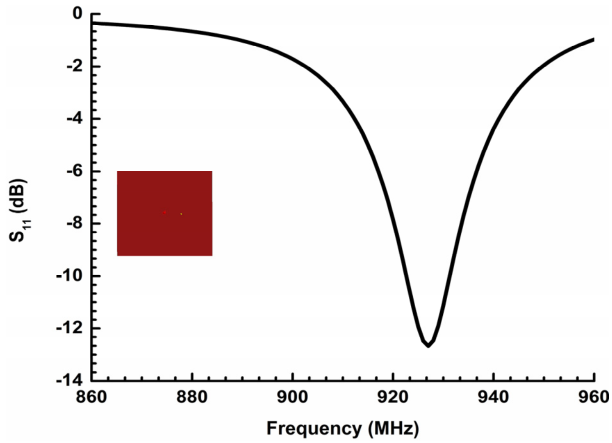
In Fig. 2(a), the simulated result of the basic patch antenna without any slot has been shown and Fig. 2(b) represents the simulated result of the proposed antenna. It is observed that without any slot, the resonance frequency is obtained at 930 MHz with a very low impedance bandwidth. Embedding the two asymmetrical triangular slots with a rectangular slot, resonance frequency shifts towards the lower frequency range with better impedance bandwidth as well as AR bandwidth. It significantly increased in impedance bandwidth shown in Fig. 2(b) at 910 MHz resonance frequency. In this condition, all other parameters are kept with the same values as listed in Tab. 1.

The proposed geometry (area $80 \times 80 \times 4.572$ mm^3 including the ground plane) shown in Fig. 2(b), gives better impedance bandwidth as compared to a simple square patch antenna in shown in Fig. 2(a). To determine the circularly polarized waves of the proposed microstrip antenna, the simulated surface current distributions at 910 MHz are shown in Fig. 3. Figure 3(c)–(f) shows the direction of the distributed current at different time phase from 0 degree to 270 degree with a 90 degree interval. It shows that the surface current of the patch radiator is in the clockwise direction which results in exciting a left handed circular polarization (LHCP) radiation.

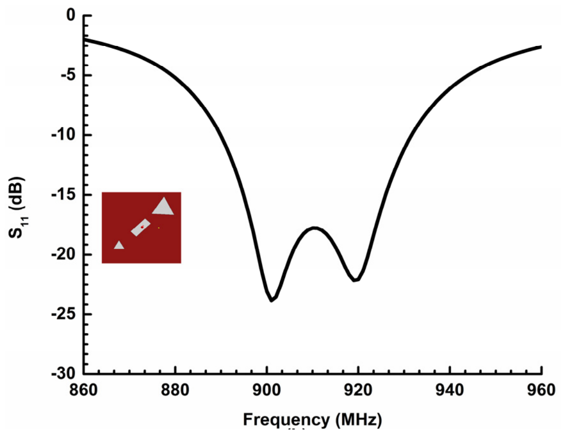
The length of the ground plane has been optimized from 76 mm to 84 mm to obtain the best result at 80 mm. Therefore, the ground plane size of 80 mm is selected as the optimum size for a better result at 910 MHz resonance frequency. It is known that the resonance frequency shifts towards the lower size band, with an increase in patch size. The reason for this shifting is that the resonance frequency is inversely proportional to the patch size but an improved impedance bandwidth of the radiating patch is obtained at patch size of 74 mm for a resonance frequency around 910 MHz. Figure 4 shows the simulation results of reflection coefficient against the frequency for the single triangular slot, double triangular slot and the proposed asymmetrical triangular slotted antenna geometry. It is found that when the number of the slotted area on the radiating patch increases, the resonance frequency of the antenna is reaching towards the desired frequency, which leads to a reduction in the antenna size. This is due to a longer current path [16]. Figure 5 shows the simulated results of AR against the frequency for a single triangular slot, double triangular slot and the proposed asymmetrical triangular slotted antenna. It is also found that AR frequency decreases with increase in slotted area on the patch radiator. This is due to increases in the electrical size of the antenna with the increased slotted area size on the patch radiator. Other important parameters are width and length of the rectangular slot which gives the impedance matching. Increasing or decreasing the width enhances or weakens the electromagnetic coupling between the feed line and the patch, which affects the impedance bandwidth.

The effect on the reflection coefficient bandwidth with respect to the variation of widths of rectangular slot (L_c) is as shown in Fig. 6. The width and length of rectangle optimizes to 7.6 mm and 19 mm respectively.

The width of the rectangle is varied from 6.8 mm to 8.0 mm with a step size of 0.4 mm while keeping the length 19 mm, patch length 74 mm and the feed location 17 mm. As the width increases, the impedance matching improves and AR frequency decreases at lower frequency side approaching near 50Ω input impedance with the im-



(a)



(b)

Fig. 2. (a) Simulated reflection coefficient of the patch antenna without any slot and (b) Simulated reflection coefficient of the proposed double asymmetrical triangular slotted antenna.

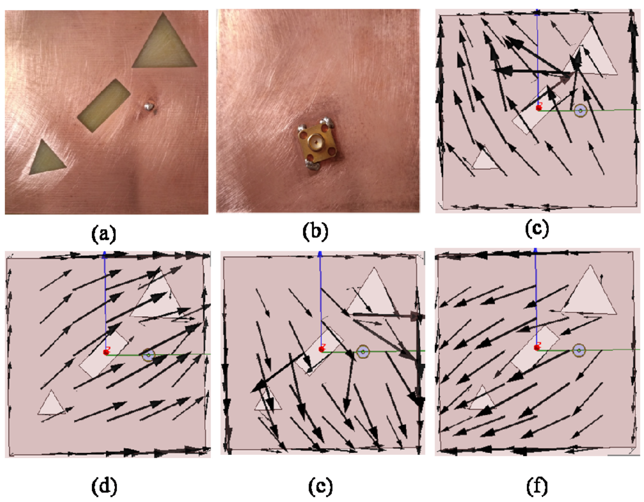


Fig. 3. (a)-(b) Fabricated prototype proposed antenna front view and back view and simulated surface current distribution at 910 MHz: (c) 0°, (d) 90°, (e) 180°, (f) 270°.

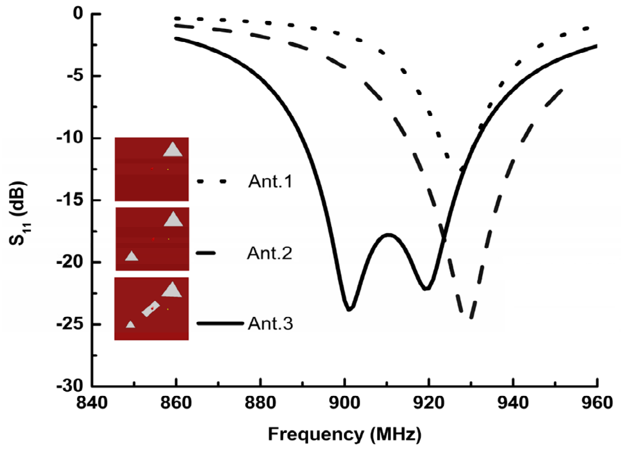


Fig. 4. Simulated reflection coefficient vs. frequency for the single triangular slot (Ant.1), double triangular slot (Ant.2) and the proposed asymmetrical triangular slot (the proposed antenna (Ant.3)).

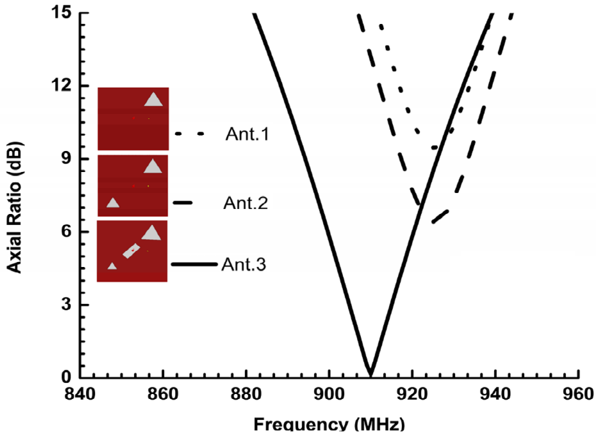


Fig. 5. Simulated AR vs. frequency for the single triangular slot (Ant.1), double triangular slot (Ant.2) and the proposed asymmetrical triangular slot (the proposed antenna (Ant.3)).

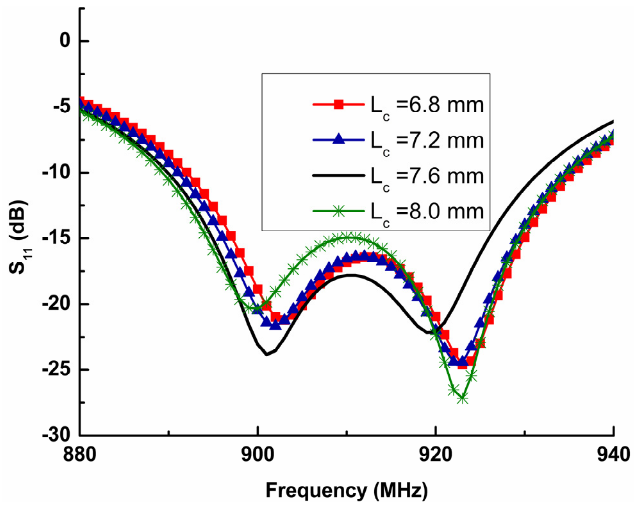


Fig. 6. Simulated reflection coefficient against frequency with various width size of rectangular slot (L_c).

provement found in 10 dB return loss bandwidth. The best minimum AR result obtained at 7.6 mm in the proposed antenna structure. Figure 7 shows the variation of rectangular slot width from 6.8 mm to 8.0 mm with a step size of 0.4 mm and keeping other parameters constant. The first larger triangular slot (Ant.1) gave only the return loss near about the value 13.5 dB at 929 MHz with axial ratio of 9.2 dB around 925 MHz which are not desired and as per

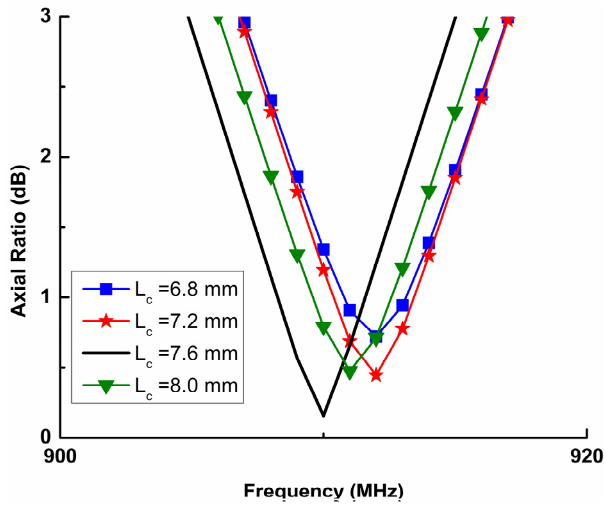


Fig. 7. Simulated AR against frequency with various width size of rectangular slot (L_c).

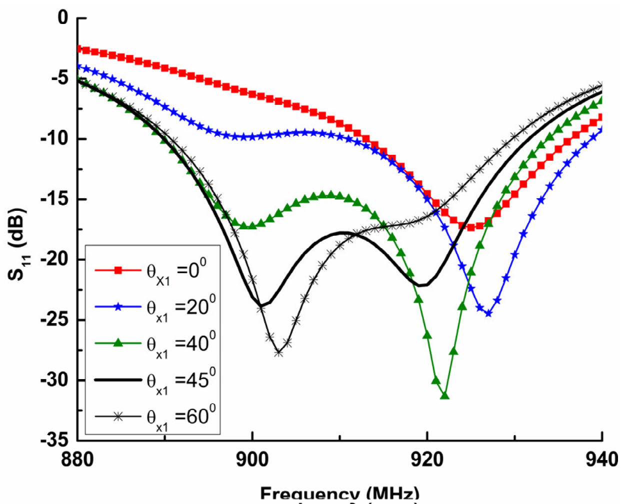


Fig. 8. Simulated reflection coefficient with various inclined angle of θ_{x1}.

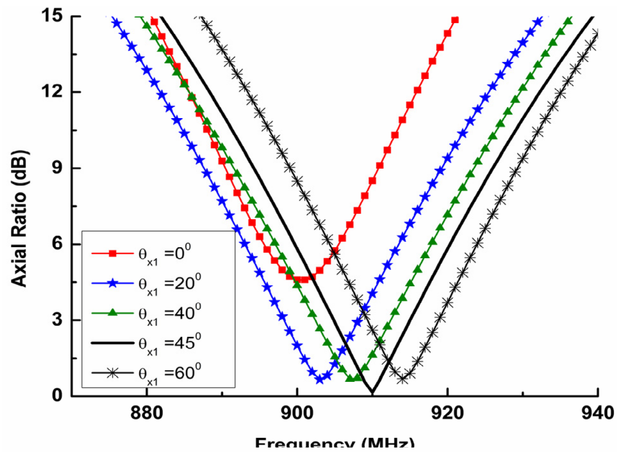


Fig. 9. Simulated axial ratio with various inclined angle of θ_{x1}

the design requirements as shown in Fig. 4 and Fig. 5. To improve this, the second smaller triangular slot (Ant.2) was entrenched diagonally in the patch which makes the current distribution around 45° similar to as shown in Fig. 3(c-f) with respect to the existing distribution of the larger triangular slot patch. This slot makes the result more improved in terms of return loss around 26 dB but at 928 MHz which is again off the required frequency range. Moreover the axial ratio also improved to 5.8 dB with this second triangular slot which is found at 924 dB but again off the required frequency. Hence the third slot i.e. rectangular slot (Ant.3) was entrenched in the patch by angle θ_{x1} with respect to X-axis so as to get the desired return loss and axial ratio at 910 MHz including the circularly polarization with increase in electrical length and reduced patch area i.e. antenna size. This rotation of θ_{x1} has been experimented for different values i.e. 0°, 20°, 40°, 45° and 60° to further improve the return loss and axial ratio as shown in Fig. 8 and Fig. 9 which concludes that the best possible result for θ_{x1} was found at an angle of 45°. Though all the slots are showing the behavior of circular polarization for them but the impact of rectangular slot current distribution is the most contributing part in the circular polarization of this antenna design. At this stage, there is a loss of coupling between the resonances developed by the triangular slots due a dimension difference. Such a decoupling is reduced by the small rotation of the axis of smaller triangular slot. This is clearly seen, where experimenting with and increasing the inclination angle θ_{x2} to 3.28° has only resulted in some shifts in the desired resonant frequencies with the best possible improvement in return loss. Now the improved result with the total bandwidth of 44 MHz at the 10 dB return loss is found on the desired frequency range for the RFID applications.

4. Result and Discussion

The proposed slotted circularly polarized microstrip antenna for RFID application has been optimized at around 910 MHz UHF band using a rectangular slot length L_b of 19 mm and width L_c of 7.6 mm. The antenna of parameters listed in Tab. 1 has been fabricated and measured to compare the simulated results. The return loss for manufactured antenna was found as 17.9 dB as shown in Fig. 10 which was measured with a vector network analyzer at an operating frequency of 910 MHz. The measured result is quite comparable with the simulated results and concluded that the bandwidth of 44 MHz has been found with 10 dB return loss.

The measured 3 dB axial plot points out that minimum AR value of 0.19 dB is achieved at the center frequency as shown in Fig. 11. To measure the AR first the co- and cross- radiation patterns for the XZ have been measured, then the ratio of co- and cross- is taken to calculate the AR taking the consideration the phase. The 3 dB AR bandwidth has been found as 10 MHz. To measure the gain of a CP antenna the co- and cross-radiation patterns in both the planes (XZ and YZ) are measured and then combined to get the CP gain. Figure 12 shows the maximum gain of 3.12 dBic for the proposed antenna structure. Reasonably good agreement between the simulated and measured results is being observed as shown in the respective figures. The small difference between the simulated and measured results may be due the effect of SMA connector soldering and tolerance levels during the fabrication process of the antenna. Overall the proposed result is found better than the results shown for the structures proposed in [7], [11], [13] and [15].

Table 2 shows the comparison of the proposed antenna results with the related published compact CP microstrip antenna structures. The proposed asymmetrical double triangular slotted circularly polarized microstrip antenna is compact in size and gives better results as compared to others listed in Tab. 2. The presented antenna generates wide 3 dB bandwidth and provides minimum AR value at the center frequency. Figure 13 shows the measured and simulated radiation pattern of the proposed MSA. It is observed that the maximum gain (simulated) is 3.12 dBic at 910 MHz and measured gain is 3.07 dBic covering the entire operating band.

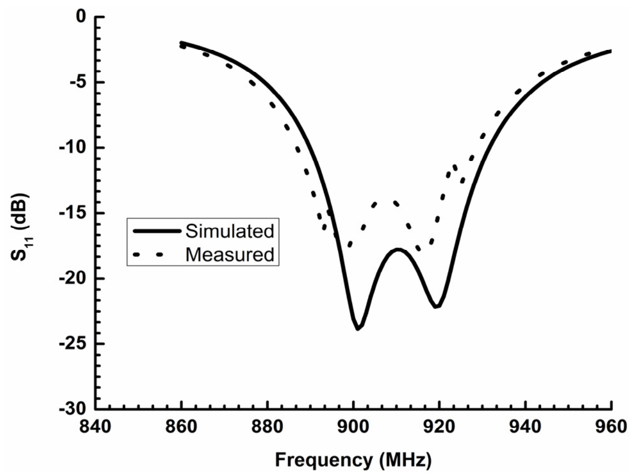


Fig. 10. Impedance bandwidth of antenna.

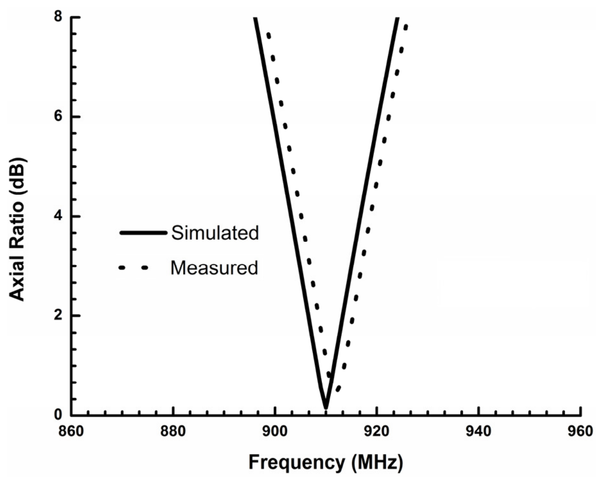


Fig. 11. Axial ratio for the proposed antenna.

Antenna	Description	10-dB return loss bandwidth (MHz)	3-dB axial ratio bandwidth (MHz)	Overall antenna size (mm^3)	Operating frequency of CP (MHz)	Gain (dBic)
Ref.[7]	Asymmetrical circular slotted	17	6	$90 \times 90 \times 4.566$	900	3.70
Ref.[11]	CP cross shaped slotted	18	6	$90 \times 90 \times 4.286$	910	3.80
Ref.[13]	Compact CPMA for RFID	19	4	$90 \times 90 \times 4.572$	920	3.40
Ref.[15]	Arrowhead shaped slotted	35	8	$87 \times 87 \times 4.572$	911	4.50
Proposed	**Slotted CPMA for RFID**	**44**	**10**	**$80 \times 80 \times 4.572$**	**910**	**3.07**

Tab. 2. Comparison of compact CP microstrip antenna.

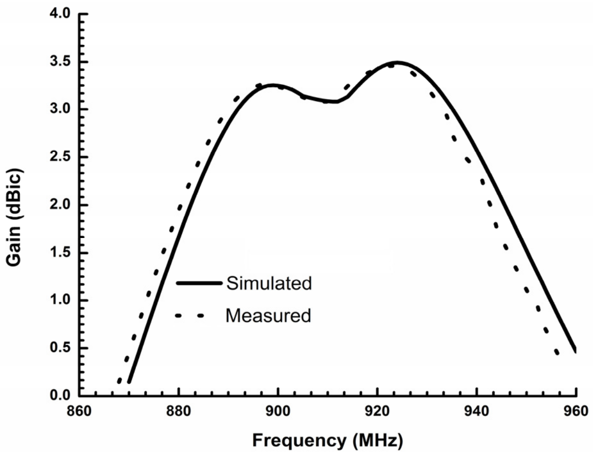


Fig. 12. Gain of antenna measure in the normal direction to the patch.

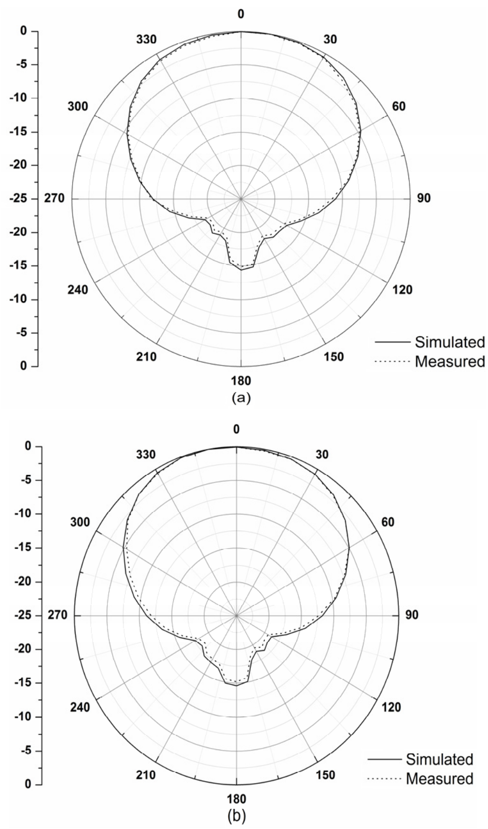


Fig. 13. Radiation pattern of proposed antenna at 910 MHz: (a) $\varphi = 0^o$, (b) $\varphi = 90^o$.

5. Conclusion

A circular polarized slotted microstrip patch antenna has been successfully simulated and manufactured. The prototype with an overall size of $80 \times 80 \times 4.57$ mm^3 achieved a 10 dB return loss bandwidth of 44.0 MHz (889.0–933.0 MHz) and 3 dB AR band width of 10.0 MHz (904.0–914.0 MHz). The smaller sized proposed antenna design can be easily manufactured for portable UHF RFID reader applications. The antenna has been compared with other schemes showing a better bandwidth both in terms of return loss and AR.

Acknowledgment

The authors would like to thank Dr. B. K. Kanaujia, ECE department, AIACTR, Delhi for proving fabrication, measurement and valuable guidance.

References

[1] WANT, R. An introduction to RFID technology. *IEEE Pervasive Computing*, 2006, vol. 5, no. 1, p. 25–33. DOI: 10.1109/MPRV.2006.2

[2] CHUNG, H. L., QING, X., CHEN, Z. N. A broadband circularly polarized stacked probe fed patch antenna for UHF RFID application. *International Journal of Antenna and Propagation*, 2007, p. 1–9. DOI: 10.1155/2007/76793

[3] KWA, H. W., QING, X., CHEN, Z. N. Broadband single fed single patch polarized antenna for UHF RFID applications. In *IEEE Antenna and Propagation Society International Symposium*. San Diego (CA, USA), 2008, p. 1–4. DOI: 10.1109/APS.2008.4619871

[4] XIAO, Y., YU, S., WU, K., et al. Radio frequency identification: technologies, applications and research issues. *Wireless Communication and Mobile Computing*, 2007, vol. 7, no. 4, p. 457–472. DOI: 10.1002/wcm.365

[5] JUNG, Y. K., LEE, B. Dual band circularly polarized microstrip RFID reader antenna using metamaterial branch line coupler. *IEEE Transactions on Antennas and Propagation*, 2012, vol. 60, no. 2, p. 786–791. DOI: 10.1109/TAP.2011.2167943

[6] CHEN, Z. N., QING, X., CHUNG, H. L. A universal UHF RFID reader antenna. *IEEE Transactions on Microwave Theory and*

Techniques, 2009, vol. 57, no. 5, p. 1275–1282. DOI: 10.1109/TMTT.2009.2017290

[7] NASIMUDDIN, CHEN, Z. N., QING, X. Asymmetrical circular shaped slotted microstrip antenna for circular polarization and RFID applications. *IEEE Transactions on Antennas and Propagation*, 2010, vol. 58, no. 12, p. 3821–3828. DOI: 10.1109/TAP.2010.2078476

[8] TONG, K. F., WONG, T. P. Circularly polarized U slot antenna. *IEEE Transactions on Antennas and Propagation*, 2007, vol. 55, no. 8, p. 2382–2385. DOI: 10.1109/TAP.2007.901930

[9] BALANIS, C. A. *Antenna Theory: Analysis and Design*. 3rd ed. New Delhi (India): Wiley India Pvt. Ltd., 2011. ISBN: 978-81-265-2422-8

[10] TSAI, C. L. A coplanar strip dipole antenna for broadband circular polarization operation. *Progress in Electromagnetic Research*, 2011, vol. 121, p. 141–157. DOI: 10.2528/PIER11082407

[11] NASIMUDDIN, CHEN, Z. N., QING, X. A compact circularly polarized cross shaped slotted microstrip antenna. *IEEE Transactions on Antennas and Propagation,* 2012, vol. 60, no. 3, p. 1584–1588. DOI: 10.1109/TAP.2011.2180334

[12] POZAR, D. M., DUFFY, S. M. A dual band circularly polarized aperture coupled stacked microstrip antenna for global positioning satellite. *IEEE Transactions on Antennas and Propagation*, 1997, vol. 45, no. 11, p. 1618–1625. DOI: 10.1109/8.650073

[13] NASIMUDDIN, QING, X., CHEN, Z. N. Compact circularly polarized microstrip antenna for RFID handheld reader applications. In *Asia Pacific Microwave Conference*. Singapore, Dec. 2009, p. 1950–1953. DOI: 10.1109/APMC.2009.5385294

[14] NASIMUDDIN, CHEN, Z. N., QING, X. A compact circularly polarized slotted slit microstrip patch antenna. In *Proceeding of the Asia-Pacific Microwave Conference*. Dec. 2011, p. 582–585. INSPEC Accession number: 15655685

[15] GAUTAM, A. K., KUNWAR, A., KANAUJIA, B. K. Circularly polarized arrowhead shape slotted microstrip antenna. *IEEE Antennas and Wireless Ppropagation Letters*, 2014, vol. 13, p. 471–474. DOI: 10.1109/LAWP.2014.2309719

[16] ANGUERA, J., BOADA, L., PUENTE, C., et al. Stacked H-shaped microstrip patch antenna. *IEEE Transactions on Antennas and Propagation*, 2004, vol. 52, no. 4, p. 983–993. DOI: 10.1109/TAP.2004.825812

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