CHAPTER 5: MEANDERED CROSS-SHAPED SLOT CIRCULARLY POLARISED ANTENNA FOR HANDHELD UHF RFID READER

5.1 Introduction

Passive ultra high frequency RFID system works on the backscatter modulation mechanism, in which an RFID reader transmits an interrogatory electromagnetic signal to a tag. The passive RFID tag wakes-up by converting the interrogatory signal energy to DC voltage as it does not consist of any internal power source. Subsequently, the tag IC switches its input impedance between the shorted state and the matched state with the tag antenna. When the impedance is matched, the interrogatory signal is absorbed by the tag chip, and when it is shorted, the interrogatory signal is backscattered towards the reader. Generally, RFID tag antennas are linearly polarised and have arbitrary orientations in practical applications. Therefore, circularly polarised antennas are used for UHF RFID readers for reliable communication between the reader and tag [172]. This ensures tag detection with a 3 dB loss regardless of the orientation of the receiving antenna. Circularly polarised radiation can be obtained by exciting two orthogonal modes of equal amplitude with 90^0 phase difference. Various circularly polarised reader antennas have been reported for UHF RFID systems. CP antennas can be divided into multi-feed [173], [174] and single-feed [175], [176] structures. Multi-feed antennas are bulky in size but have the advantage of wide axial ratio bandwidth for circularly polarised radiation. Thus single-feed antennas are preferred for handheld RFID reader applications due to the advantage of size miniaturization and simplicity, but the two orthogonal modes for circular polarization have to be excited internally in antenna structure. In the single-fed single-patch antenna, these two orthogonal modes are excited by perturbing the antenna structure with a slot or slit at a suitable location with respect to feed point but suffer a narrow AR bandwidth.

In this chapter, a single feed circularly polarized microstrip antenna is designed for handheld radio frequency identification reader in ultra-high frequency band. Circularly polarized radiation has been achieved by etching a slot along the diagonal axis of the square patch. Four different shaped slots (square, circular, cross and meandered cross) are studied and compared for CP radiation. Antenna size miniaturization is realized on increasing the slot perimeter. The meandered cross-shaped slot circularly polarized antenna is the most compact among all the simulated structures. Two and four meandered slot antennas are investigated for further antenna size miniaturization and compared for a fixed antenna volume. The gain and the 3 dB AR bandwidth of the designed four slot antenna are comparable to the previously reported structures [157]–[159] with the advantage of miniaturized size. One and four meandered cross-shaped slot antennas are fabricated and tested. The measured results are in good agreement with the simulated results obtained from HFSS (High Frequency Structure Simulator).

5.2 Single Slot Circularly Polarized Antenna

Figure 5.1 shows four differently shaped slot antennas with circularly polarised radiation. For circularly polarised radiation, the antenna should generate two equal magnitude orthogonal resonant modes with 90^0 phase difference. Two orthogonal modes are excited by creating perturbation in the form of the slot along one of the diagonal axes of the square patch. The slot perturbation makes the diagonal axes asymmetric. The location of feed is at an angle of 45^0 (on X-axis) to the diagonal axes.

The four differently shaped slots are studied in the context of the generation of circular polarisation and size miniaturisation of the antenna. All the slots are placed at the centre of the first quadrant of the square patch to generate circular polarisation by making diagonal axes asymmetric. Square-, circular-, cross- and meandered cross-shaped slot antennas are studied and compared. Performance of each case is studied with a fixed antenna volume (70×70×1.6 mm^3) and fixed ground plane size. The proposed antenna is designed with 1.6 mm thick low-cost FR4 glass epoxy substrate (ε_r=4.4 and tan δ=0.02).

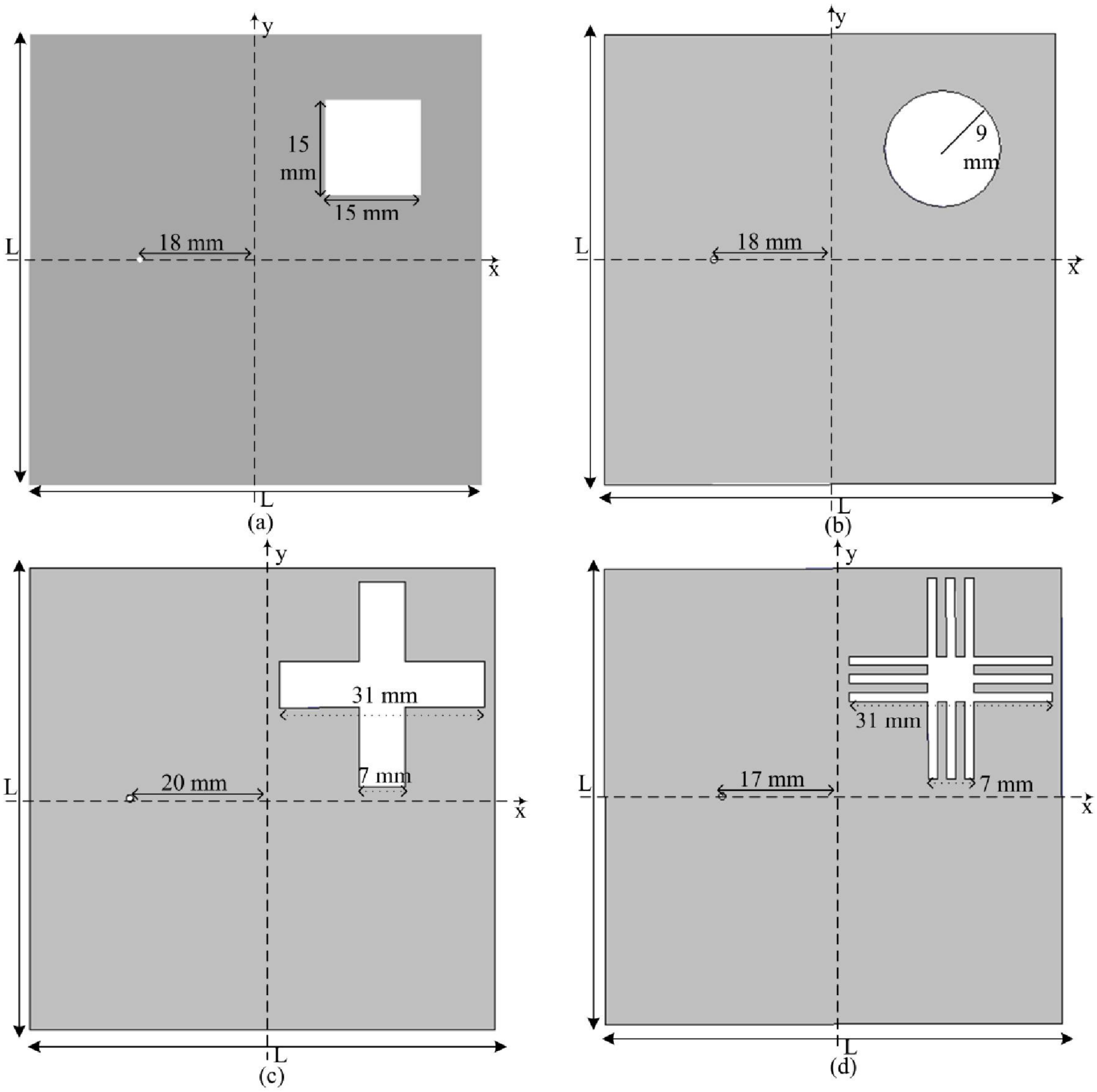


Figure 5.1 One slot based CP antenna (a) Square- shaped slot, (b) Circular- shaped slot, (c) Cross- shaped slot, (d) Meandered cross-shaped slot (L is 70 mm)

During the optimization, first of all, the location of coaxial feed is optimized along the x-axis for good impedance matching of the linearly polarized square patch antenna. Then a slot is inserted in the first quadrant of the square patch along one of the diagonal axis for the circularly polarized radiation. Figure 5.1(a-d) shows Square-, circular-, cross- and meandered cross-shaped slot circularly polarized square patch antennas. The feed location is on the x-axis, the distance from the centre of the antenna to feed position is shown in the respective figures. The perimeters of Square-, circular-, cross- and meandered cross-shaped slots are optimized for circularly polarized radiation and are shown in Table 5.1. From figure 5.2 it is observed that the resonant frequency of the antenna is lowered by increasing the perimeter of the slot. The resonant frequency of the meandered cross-shaped slot antenna is minimum as this slot has the maximum slot perimeter in four optimized antennas of different shapes. The 10-dB return loss bandwidth of the meandered cross-shaped slot antenna is 23 MHz (900 - 923 MHz).

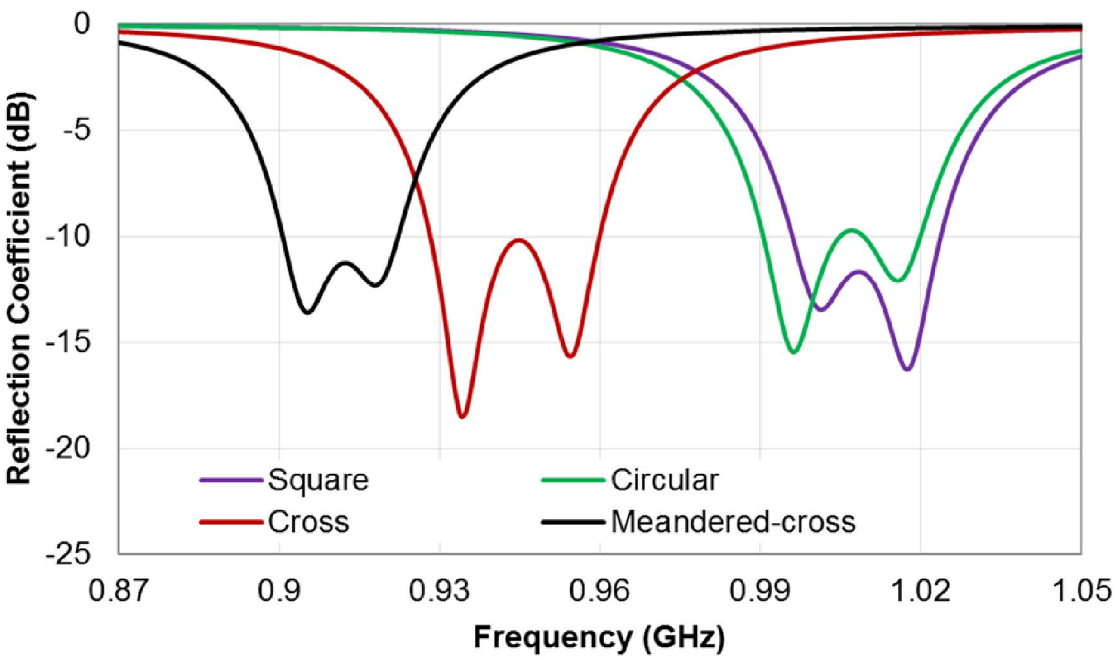


Figure 5.2 Simulated reflection coefficient with frequency of the one slot based CP antenna

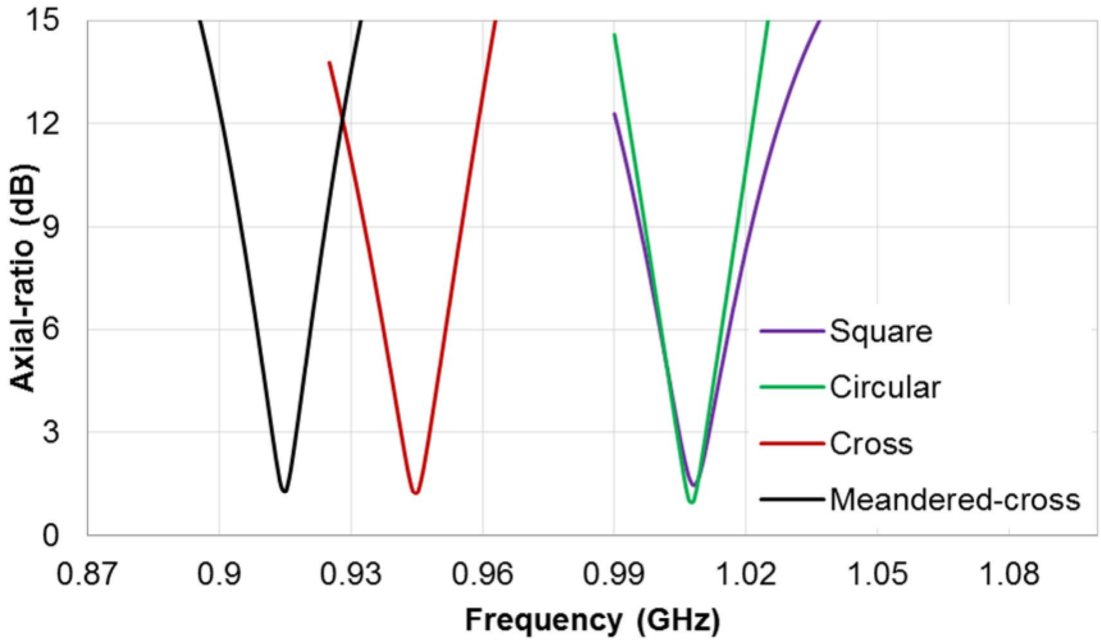


Figure 5.3 Axial-ratio at boresight versus frequency of the one slot based CP antenna

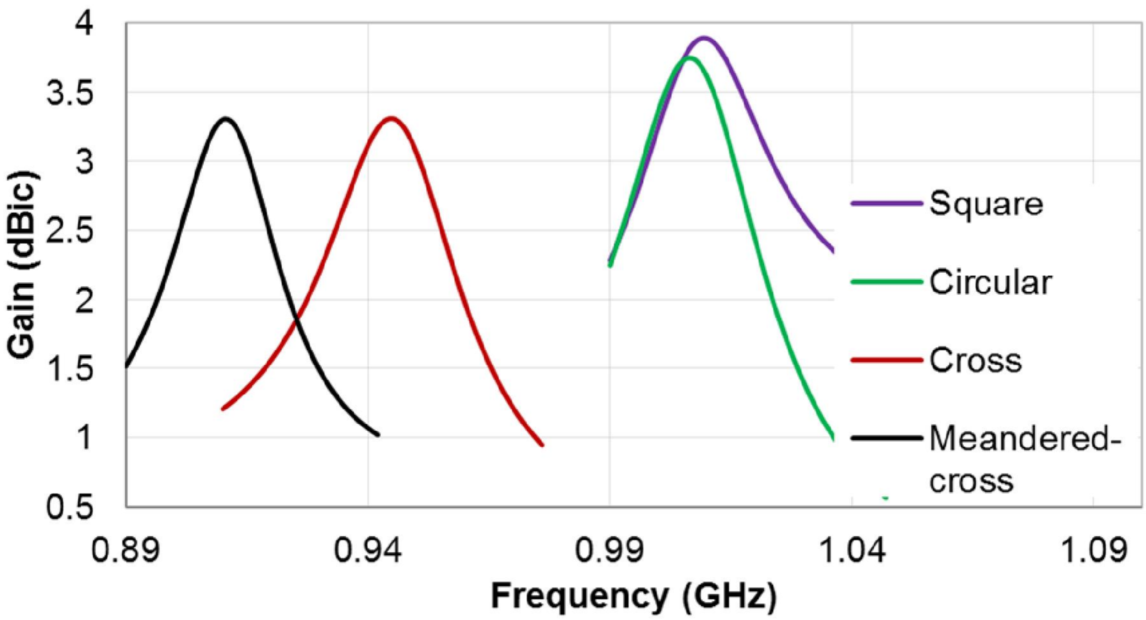


Figure 5.4 Simulated result of gain at boresight versus frequency of the one slot based CP antenna

Axial ratio on the boresight for different antennas is plotted with frequency in figure 5.3. The simulated 3-dB AR bandwidth for meandered cross-shaped slot CP antenna is 7 MHz (911 - 918 MHz). Gain at the boresight of one slot based CP antennas are plotted in figure 5.4. At the lower cut-off frequency, the effective length of the CP antenna decreases, thus, the gain of the antenna also decreases. Meandered cross-shaped slot provides larger perimeter and smaller slot area than cross-shaped slot thus meandered cross-shaped slot antenna provides more size reduction with slightly higher gain at boresight. The simulated results of all the antennas are summarized in table 5.1, from which it is concluded that the proposed meandered cross-shaped slot CP antenna has better performances in terms of size miniaturization and CP radiation compared to the previously reported circular-, square-, and cross-shaped slotted antennas.

Table 5.1 Performance comparison among one slot CP antennas

Slot Shape	Perimeter (mm)	Resonating Frequency (MHz)	10-dB return loss bandwidth (MHz)	3-dB AR bandwidth (MHz)	Maximum Gain at boresight (dBic)
Circular	56.54	1008	30 (990-1020)	7 (1004-1011)	3.74
Square	60	1008	29 (995-1024)	8 (1004-1012)	3.89
Cross	124	946	32 (928-960)	7 (941-948)	3.30
Meandered-cross	316	915	23 (900-923)	7 (911-918)	3.32

5.3 Experimental Results of Meandered Cross-shaped Slot CP Antenna

Meandered cross-shaped slot CP antenna is fabricated and measurement is carried out to authenticate the simulated results, displayed in figure 5.5. Figure 5.6 exhibits the simulated and measured reflection coefficient versus frequency of the antenna. The measured 10-dB return loss bandwidth is 20 MHz (903-923 MHz), and the simulated 10-dB return loss bandwidth is 23 MHz (900-923 MHz). Both simulated and measured axial ratios at the boresight are plotted in figure 5.7. The measured 3-dB axial ratio bandwidth is 5 MHz (915-920 MHz) and it is within the measured 10-dB bandwidth. The simulated reflection coefficient and axial ratio results agree well with that of the measured results. Figure 5.8 presents the measured radiation pattern of the single meandered cross-shaped slot CP antenna at 915 MHz on both XZ and YZ plane. The radiation pattern is almost same in both the planes, at the boresight the antenna radiates right hand circularly polarised wave, and at the backside it radiates left hand circularly polarised wave.

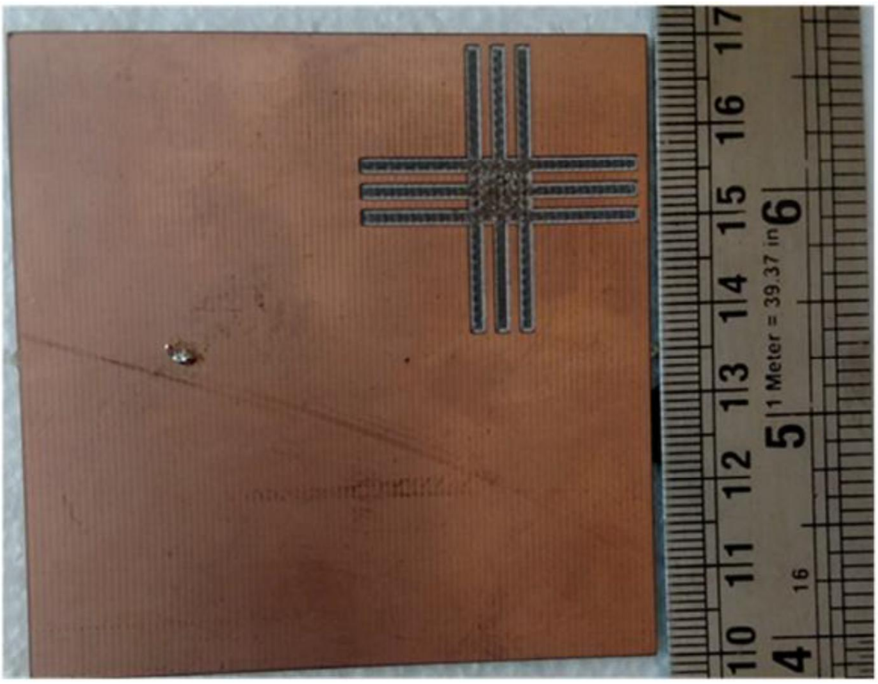


Figure 5.5 A fabricated prototype of the single meandered-cross shaped slot antenna

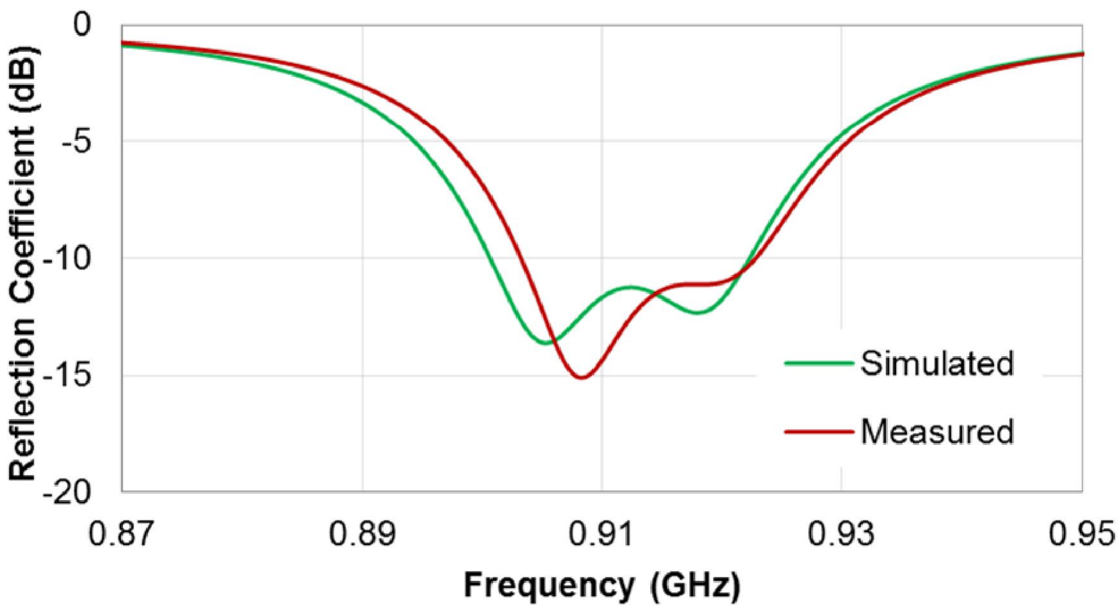


Figure 5.6 Simulated and measured reflection coefficient with frequency of the single Meandered-cross slot CP antenna

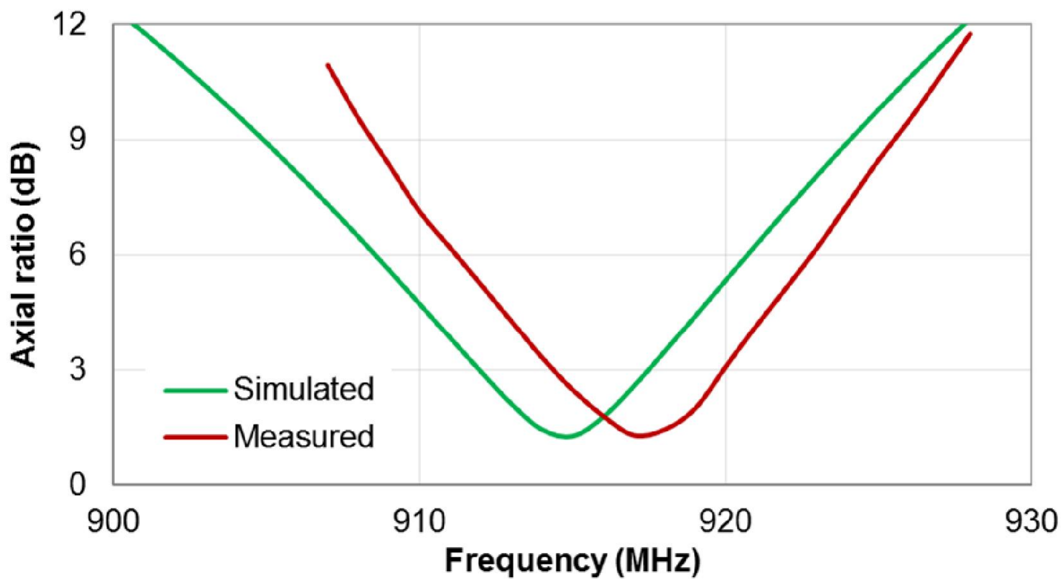


Figure 5.7 Simulated and measured axial-ratio at boresight versus frequency of the single Meandered-cross slot CP antenna

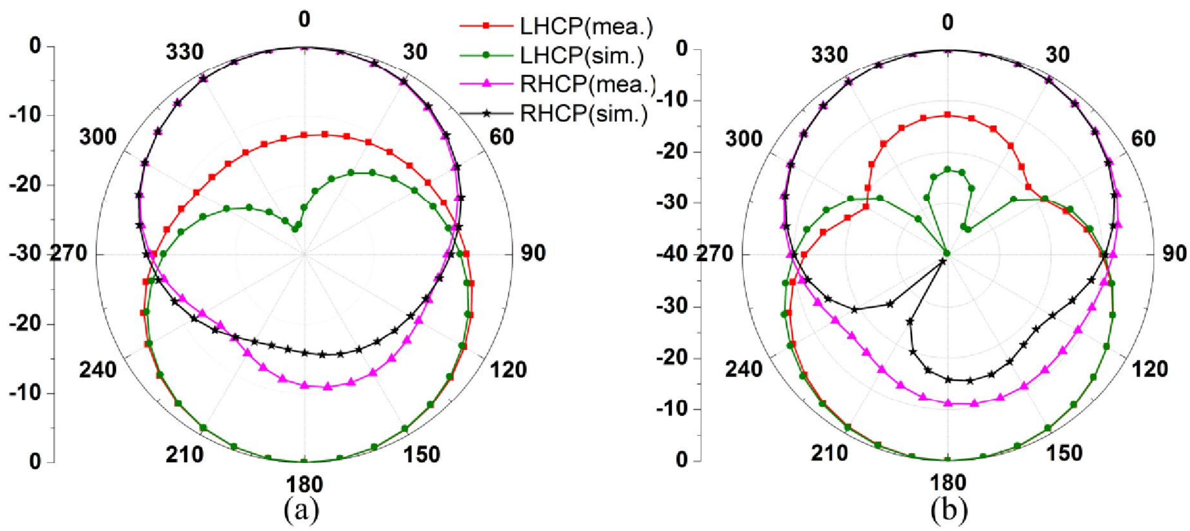


Figure 5.8 Simulated and measured Radiation patterns of the single Meandered-cross slot CP antenna at 915 MHz (a) XZ (b) YZ planes

5.4 Diagonally Symmetric Circularly Polarised Antenna

Figure 5.9 shows the meandered cross-shaped slot CP antenna based on one-, two- and four- slots. Performance of these three antennas, with fixed size patch (W=62 mm), are compared. A single meandered cross-shaped slot antenna is investigated in section 5.3. For circularly polarised radiation, two orthogonal modes are excited with equal magnitude and 90^0 out of phase due to the asymmetries along a diagonal axis of the square patch using two equal perimeter meandered cross-shaped slots at 45^0 to the feed axis, as shown in figure 5.9(b). This diagonally symmetric two-slot antenna produces circularly polarised radiation with antenna size miniaturization. Figure 5.9(c) shows a diagonally symmetric CP antenna with four meandered cross-shaped slots. For circularly polarised radiation, first and third quadrant slot perimeters should be same (S_1=S_3) and second and fourth quadrant slot perimeters should be same (S_2=S_4) to keep the diagonal axes of the square patch asymmetric. Linearly polarised radiation can be obtained by using the equal perimeter slots (S_1=S_2=S_3=S_4).

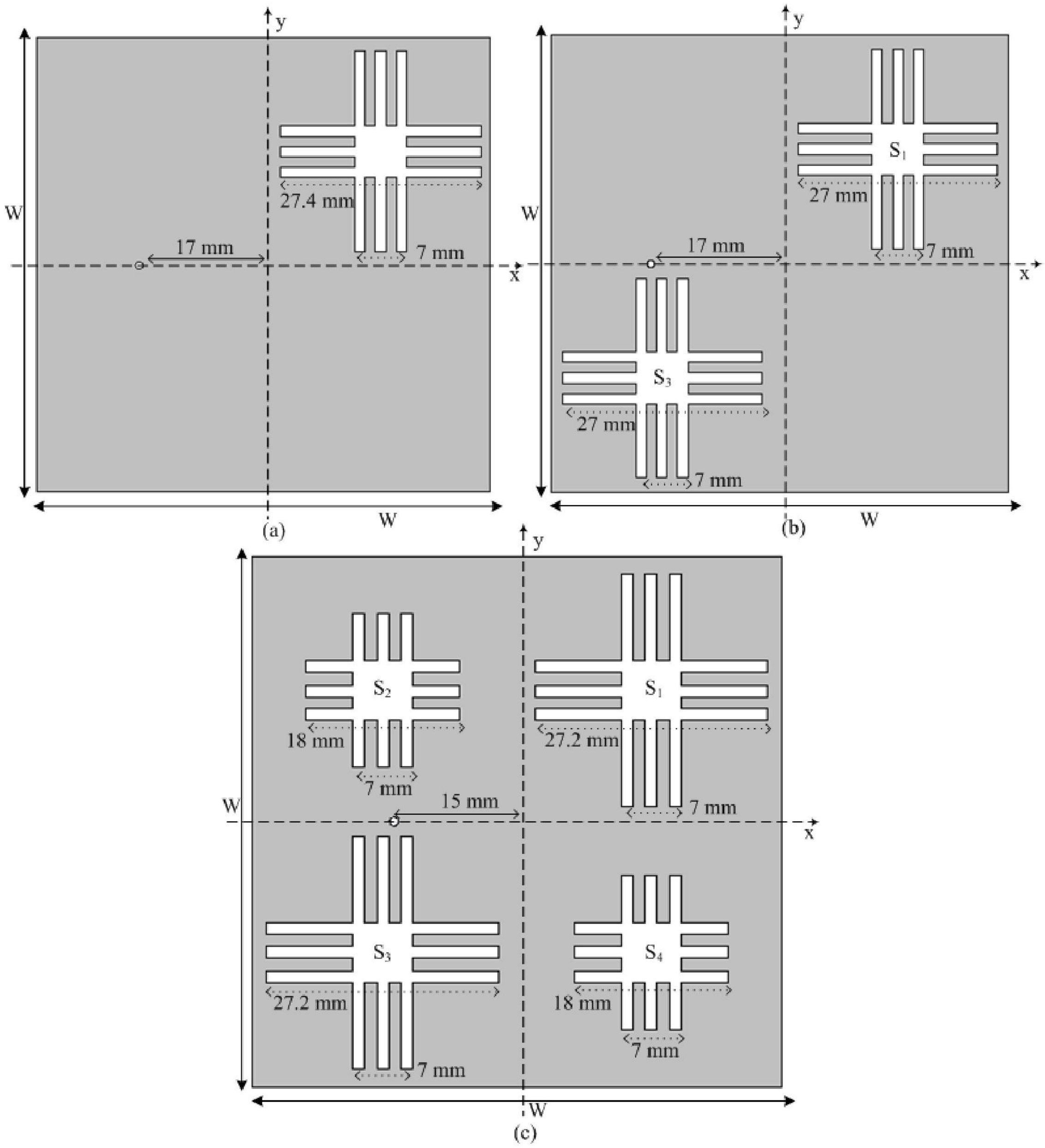


Figure 5.9 Meandered cross-shaped slot based CP antenna (a) One-, (b) Two-, (c) Four-slot (W= 62 mm)

The simulated reflection coefficient and the axial ratio at the boresight of one-, two- and four- meandered cross-shaped slot antennas are plotted in figure 5.10 and 5.11, respectively. The operating frequency of the diagonally symmetric slot antenna is shifted towards the lower frequency with an increase in the number of slots. Figure 5.10 shows that on increasing the slotted perimeter on the square patch, the resonant frequency of the CP antenna reduces. As a result, the size of the antenna is reduced with an increase in the number of slots. The 3-dB axial ratio bandwidth is also shifted towards the lower frequency with an increase in the number of slots and the slotted perimeter on the square patch, as shown in figure 5.11.

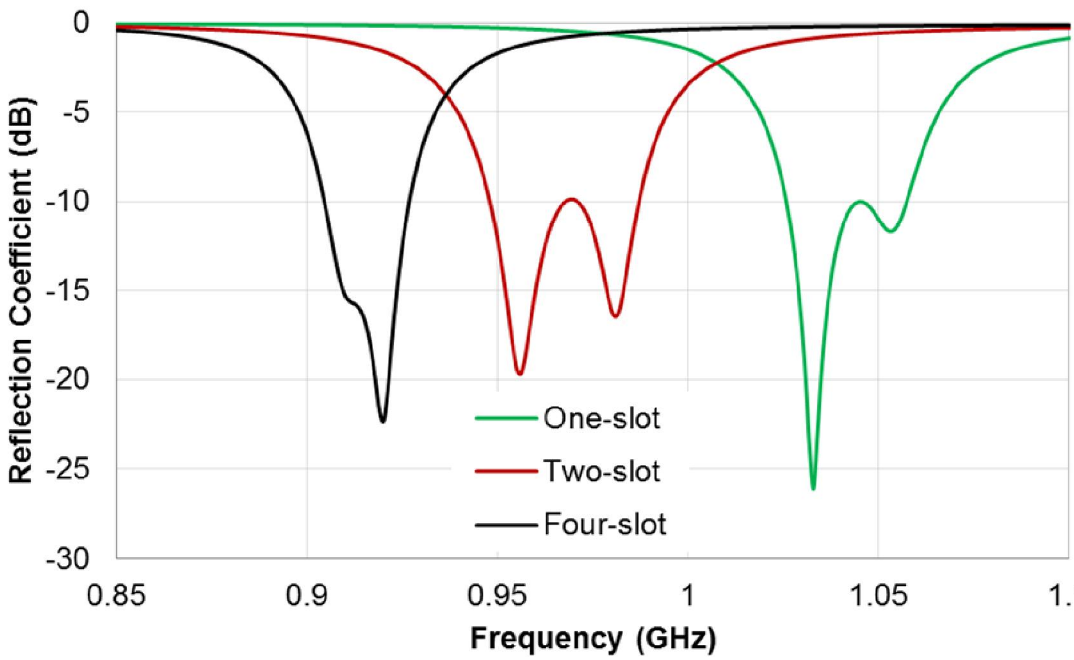


Figure 5.10 Simulated reflection coefficient of one-, two- and four- slot meandered cross-shaped CP antennas

At lower cut-off frequency, the effective antenna size decreases thus the boresight gain of the antenna also decreases. When the slotted area on the patch increases, the phase deviation between the radiated fields increases thus at far field, some fields cancel each other and the gain of the antenna reduces [22]. The simulated gain in boresight for the four-slot antenna is slightly lower than the two- and the one-slot antenna, as shown in figure 5.12. The simulated performances of one-, two- and four- slot meandered cross-shaped CP antennas are compared in table 5.2.

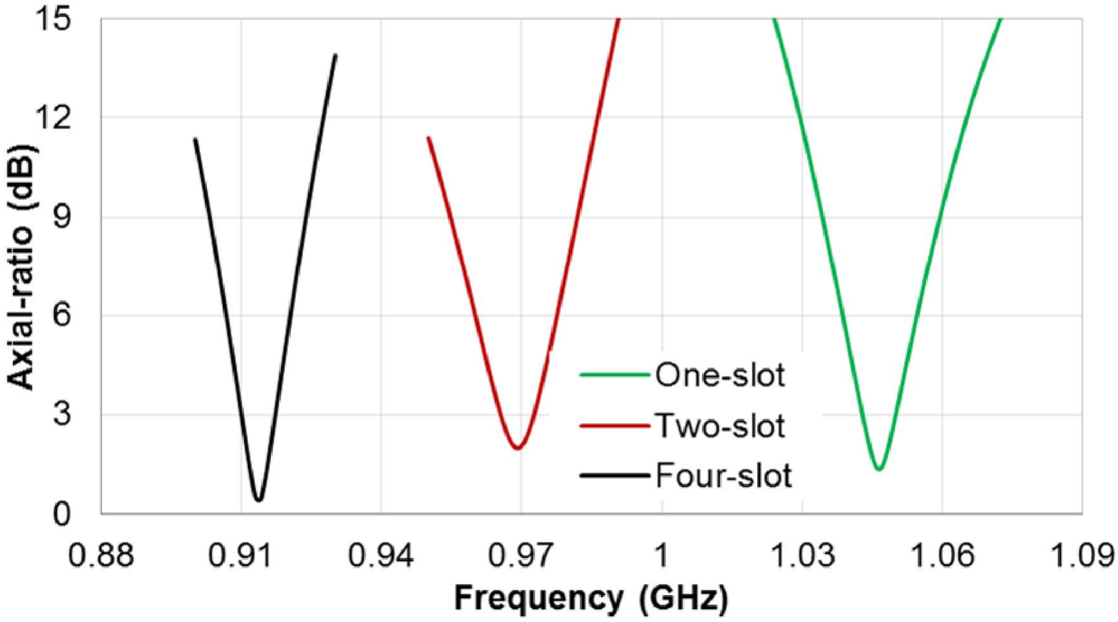


Figure 5.11 Simulated axial ratio at the boresight of one-, two- and four- slot meandered cross-shaped CP antennas

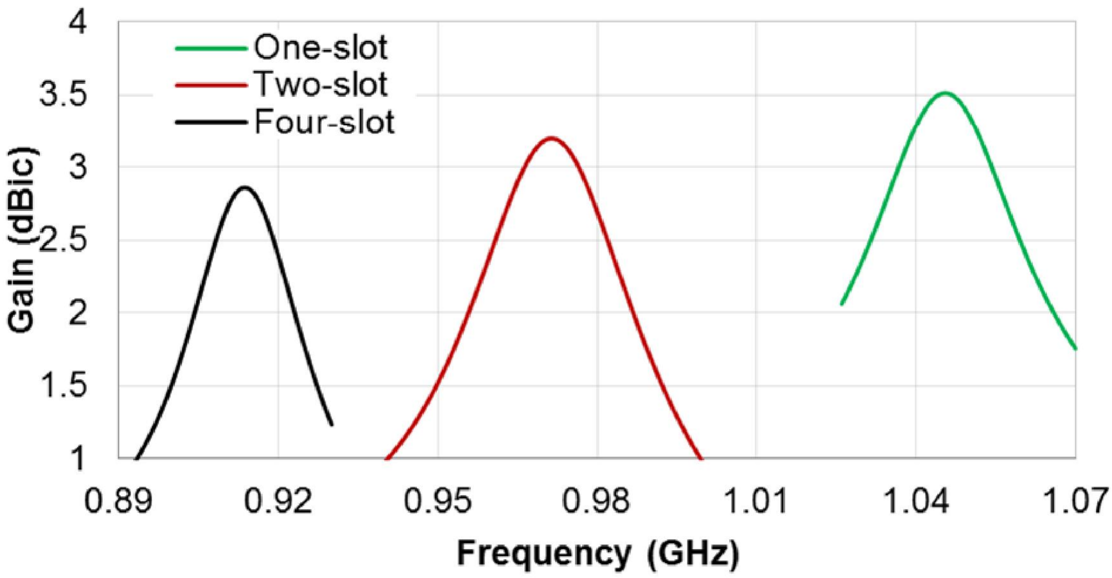


Figure 5.12 Simulated results of gain at the boresight of one-, two- and four- slot meandered cross-shaped CP antennas

The simulated surface current distribution for the designed four slot antenna at 915 MHz with four-time frames t=0(0^0), T/4(90^0), T/2(180^0), 3T/4(270^0) are plotted in figure 5.13(a)-(d). The sense of CP wave is decided by examining the direction of rotation of the surface current. It is shown in figure 5.13 that the tip of current vector rotates in clockwise direction with time which demonstrates an LHCP antenna in boresight direction. The RHCP antenna can be realized either by changing the feed location or by swapping the slots (S_1 to S_2 and S_3 to S_4).

Table 5.2 Performance comparison of one-, two- and four- slot meandered cross-shaped CP antennas

Antenna Description	Resonant Frequency (MHz)	10-dB return loss bandwidth (MHz)	3-dB AR bandwidth (MHz)	Maximum gain at boresight (dBic)
One slot	1033	33 (1025 - 1058)	9 (1042 - 1051)	3.51
Two slots	955	41 (947 - 988)	8 (965 - 973)	3.19
Four slots	915	23 (904 - 927)	9 (909 - 918)	2.86

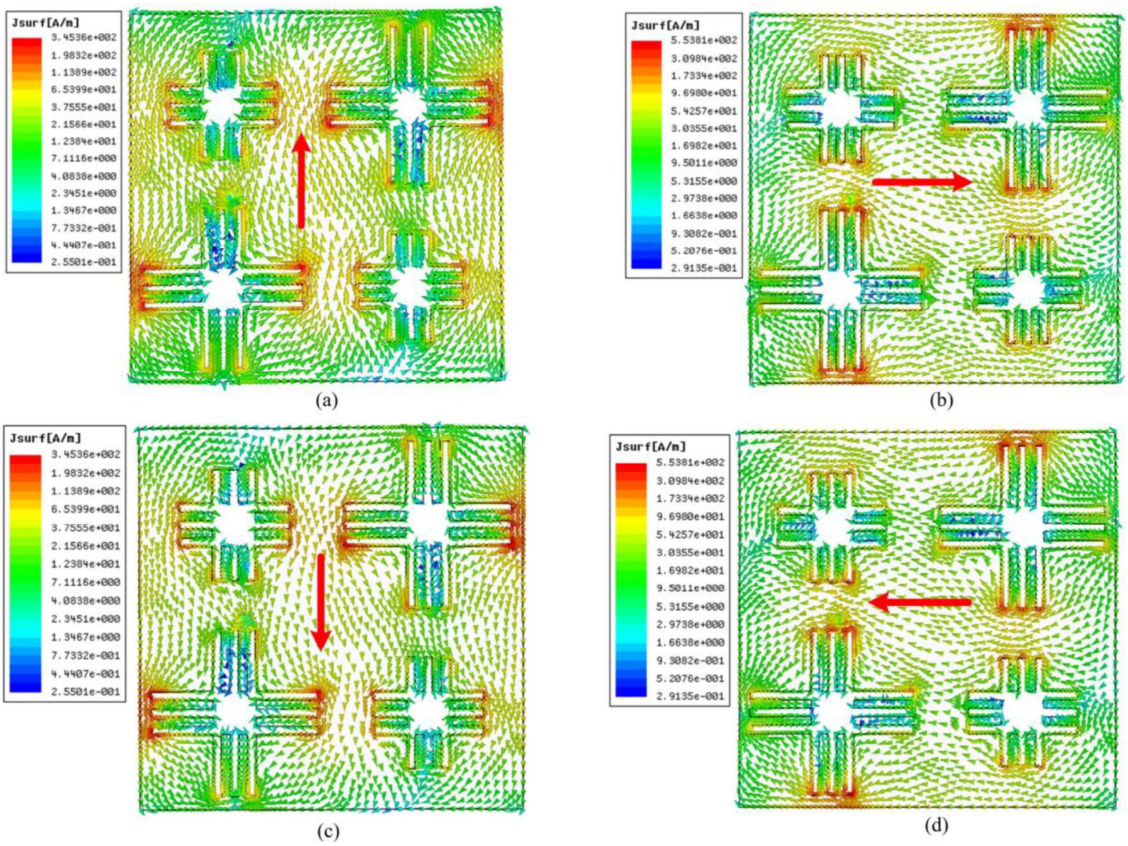
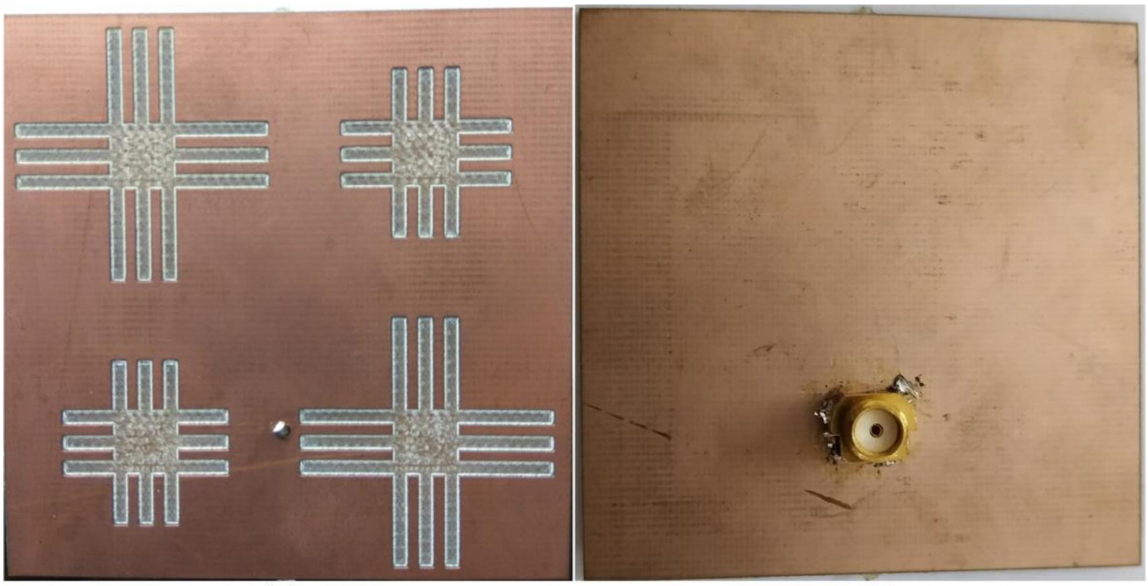


Figure 5.13 Simulated surface current distribution for the meandered cross-shaped four-slot LHCP antenna at 915 MHz in the phase of (a) 0^0, (b) 90^0, (c) 180^0, (d) 270^0

5.5 Experimental Results of Meandered Cross-shaped Four-slot CP Antenna

Figure 5.14 shows the fabricated prototype of the diagonally symmetric antenna based on four slots. The four meandered cross-shaped slot CP antenna is measured to validate the simulated results obtained through HFSS simulator.



(a) (b)

Figure 5.14 A fabricated prototype of the designed four meandered cross-shaped slot antenna (a) Top view, (b) Bottom view

The simulated and measured reflection coefficients are compared in figure 5.15. The simulated and the measured 10 dB return loss bandwidths are 23 MHz (904-927 MHz) and 22 MHz (902-924 MHz), respectively. Figure 5.16 depicts the simulated and measured axial ratio at the boresight of the proposed antenna. The simulated and measured 3 dB AR bandwidths are 9 MHz (909-918 MHz), and 6 MHz (911-917 MHz) respectively, and the 3 dB AR bandwidth is within the 10 dB return loss bandwidth. The simulated and measured gain at the boresight is plotted in figure 5.17. The measured boresight gain is more than 2 dBic over 3 dB AR bandwidth (911-917 MHz). Figure 5.18 shows the simulated and measured radiation pattern of the antenna at 915 MHz in XZ plane and YZ plane. It is obtained that the radiation pattern is bidirectional and almost identical in both planes which is suitable for handheld RFID readers. At the boresight, the antenna radiates left hand circularly polarized wave, and at the back side it radiates right hand circularly polarized wave.

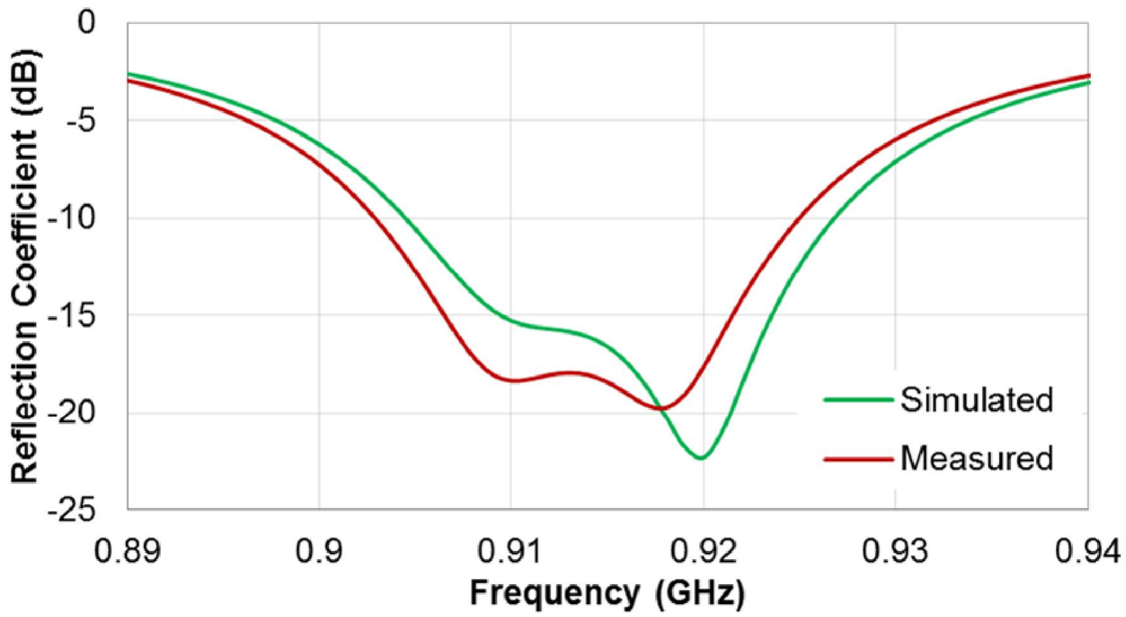


Figure 5.15 Simulated and measured reflection coefficient of four meandered cross-shaped slot antenna

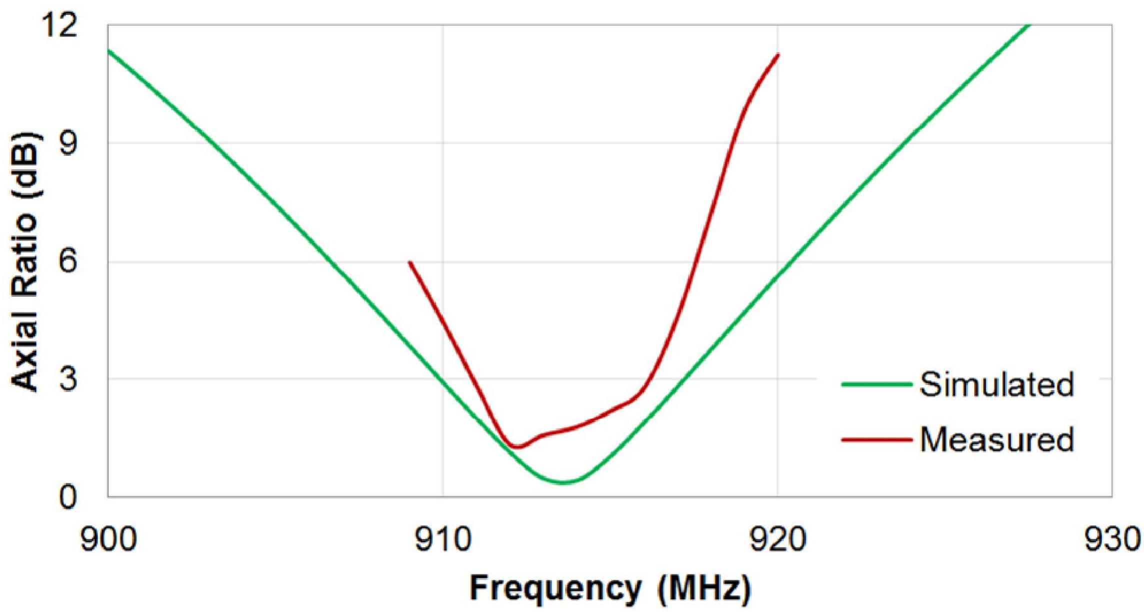


Figure 5.16 Simulated and measured axial ratio at boresight of four meandered cross-shaped slot antenna

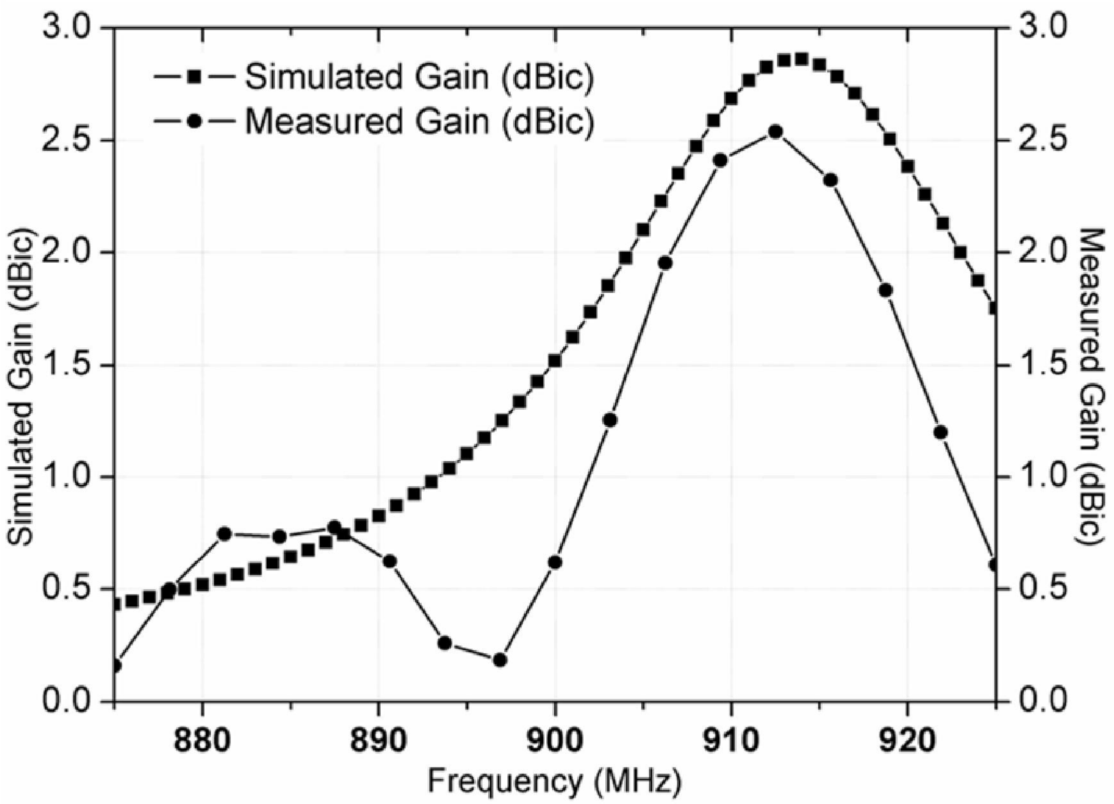


Figure 5.17 Simulated and measured gain of the four meandered cross-shaped slot antenna

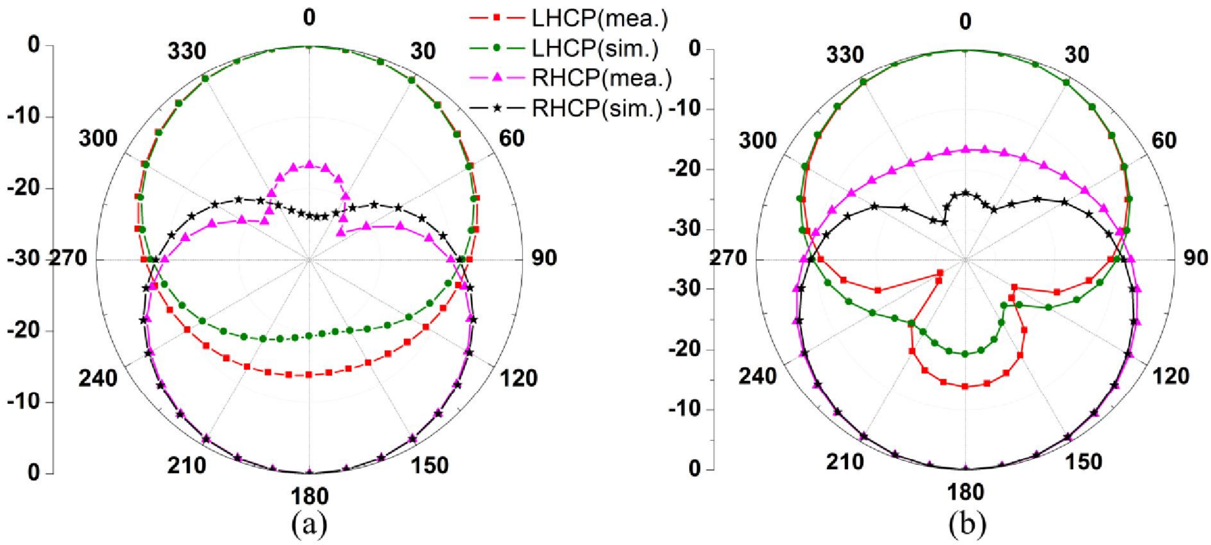


Figure 5.18 Simulated and measured Radiation patterns of the four meandered cross-shaped slot antenna at 915 MHz (a) XZ (b) YZ planes

5.6 Conclusion

A circularly polarised antenna for handheld UHF RFID reader is designed in this chapter. By etching a meandered cross-shaped slot in the first quadrant of the square patch, the antenna generates circularly polarised radiation with compact size. Square-, circular-, cross- and meandered cross-shaped slots have been studied and compared. The compactness of the CP antenna relies on the slot perimeter. The antenna is single feed at 45^0 to the diagonal axes to achieve impedance matching. The overall volume of the antenna is 62×62×1.6 mm^3. The antenna produces a 10-dB return loss bandwidth of 22 MHz (902 - 924 MHz), the fractional bandwidth of 2.4 %, and a 3 dB AR bandwidth of 6 MHz (911 - 917 MHz). The maximum gain at the boresight is 2.86 dBic. The designed antenna has more than 2 dBic boresight gain over 3 dB AR bandwidth. In the upcoming chapter, the major contributions made in the thesis, conclusion drawn during the whole investigation and future scope are summarized.