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STUDY ON THE PLANAR CIRCULARLY POLARIZED ANTENNAS WITH SWASTIKA SLOT

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Abstract—Two improved circularly polarized microstrip planar antennas operating in 5 GHz–6 GHz are proposed in this paper. The Swastika slot and a circular feeding line are introduced into Ant.2 which exhibits wide impedance bandwidth and AR bandwidth during simulation and measurement than a basic truncated edge CP microstrip antenna. In further studies, a center circular slot is introduced into Ant.3, and the experimental results show a wider impedance bandwidth and AR bandwidth with high gain.

1. INTRODUCTION

In wireless communication system, research and development efforts are aimed at improving performance with smaller size. Microstrip antennas have the potential for making circularly polarized antennas as a result of several attractive features including low profile, lightweight, conformability to various mounting structures and compatibility with integrated circuit technology. Circularly polarized microstrip antenna can receive any linear polarized waves, and be more anti-fading to enhance the wireless system capacity than the linear polarized antenna [1]. Recently, bandwidth enhancements of antenna are also becoming more and more exigent for expanding capacity of wireless communication [10].

Circularly polarized microstrip antennas are classified as single- or dual-feed types, depending on the number of feeding points required to

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generate the circularly polarized waves. The single-feed type has the advantage of not requiring an external polarizer such as a 90° hybrid coupler, and the truncated edge patch is one of the simplest circularly polarized antennas. The relationship between the optimum probe location and frequency of the obtained circularly polarized wave has been clarified, and good experimental results have been reported [2]. The single-feed solutions are simpler but exhibit a limited axial ratio (AR) bandwidth [2]. CP operations can be accomplished by using a single microstrip line to feed a square ring or annular-ring slot antenna at two appropriately selected positions [4–6]. Single layer dual-band CP microstrip antennas have been reported [9], but possess a limited AR bandwidth. The truncated edges antenna exhibits the best axial ratio but has reduced AR bandwidth [3]. Alternative research [11, 12] has produced bent slot and wide slot antennas with parasitic patch. Single-fed wideband circularly polarized slot antennas have also been reported [8, 13, 14], but the acquired gain is only about 3.5 dB. Besides patch antenna, printed slot antenna can also work in a wider bandwidth.

The Swastika slot looks like a rotator, in which the resistance is small enough to rotate in the fluid field. If the Swastika slot is introduced into the patch, some current may be distributed along the curved slot. The rotational symmetry of the Swastika slot may improve the CP performance of the antenna, if the current phase distribution is better. Accordingly, reducing the unrelated linear polarization is another good method to improve the circular polarization, especially in the region near the feeding point.

In this paper, the improved circularly polarized planar microstrip antenna are proposed. The antennas are designed by combining the truncated edges patch, Swastika slot and a center circular slot in the patch, and the antennas exhibit better CP performance than basic truncated edge microstrip antenna and other slot antennas [7]. During further study, it has been realized that the width of Swastika slot directly affects resonant frequency. Increasing the width of the slot increases the bandwidth and vice versa; however, big changes in the width of Swastika slot can affect AR bandwidth. By adding a circular slot in the center of the Swastika slot and patch layer, improved gain has been observed. A single 50 Ω co-axial SMA connector followed by a round microstrip line is used to further improve the −10 dB bandwidth and axial ratio of the proposed antenna. Increasing the width of the circular microstrip feeding line can also increase the impedance bandwidth of the antenna.

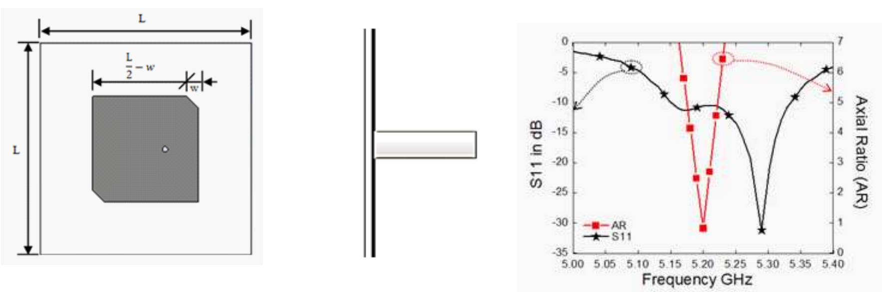
2. ANTENNA STRUCTURE AND DESIGN

2.1. Antenna Structure

The basic structure of the antenna is a truncated edges microstrip patch, called Ant.1. The improved antennas are Ant.2 and Ant.3. Ant.2 is obtained by combining the truncated edges and Swastika slot, and Ant.3 is obtained by combining the truncated edge, Swastika slot and circular slot in the center of the patch.

2.1.1. Ant.1 — Basic Truncated Edges Circularly Polarized Antenna

A basic truncated edges microstrip patch is shown in Fig. 1, which is a narrow band circularly polarized antenna with a patch, substrate and the ground. The substrate used for the design is Arlon AD 250 which has a thickness of 0.76 mm and permittivity of 2.55. The radiating patch with truncated edges was fabricated on the top of the substrate and the ground plane on the bottom. The antenna is fed in the back by a co-axial line.



(a) (b) (c)

Figure 1. A basic truncated edge CP microstrip patch antenna. (a) Front view. (b) Side view. (c) Simulated S_{11} & AR for Ant.1.

This is a basic circularly polarized planar microstrip antenna. Its impedance bandwidth is 5.15 GHz–5.31 GHz, and the circular polarization AR bandwidth is 5.18 GHz–5.20 GHz. The design is shown in Fig. 1(a) and the simulated S_{11} and axial ratio (AR) shown in Fig. 1(c). Since the bandwidth of this antenna is very narrow, further steps were taken to improve the operational -10 dB impedance bandwidth, AR and gain, which are discussed in the following section.

2.1.2. Ant.2 — Combining the Truncated Edges and Swastika Slot

Based upon Ant.1, Swastika slot is added to the patch, and the improved CP antenna is shown in Fig. 2. The radiation patch with Swastika slot is fabricated on the dielectric substrate with a thickness of 0.76 mm and permittivity of 2.55 (Arlon AD 250). The antenna was excited through the circular microstrip line fabricated on the other layer. The circular microstrip line was fed by a co-axial SMA connector from the ground plane as shown in Fig. 2.

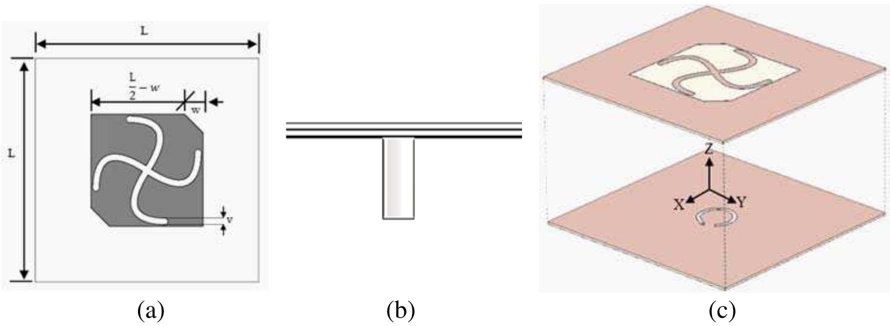


Figure 2. A truncated edge and Swastika slot circularly polarized microstrip patch antenna. (a) Front view. (b) Side view. (c) Perspective view.

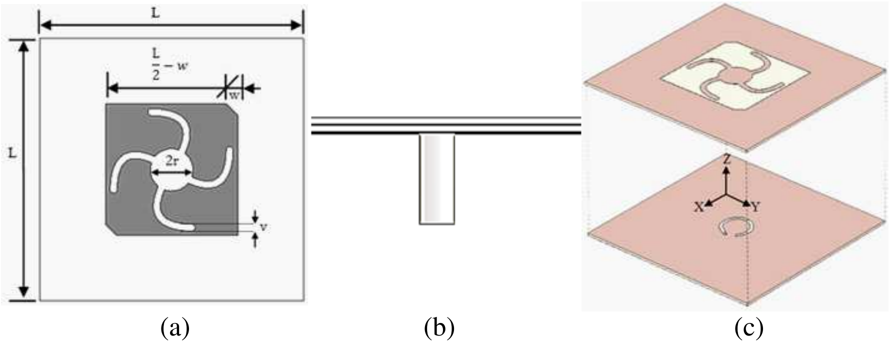


Figure 3. A truncated edge, Swastika slot and center circular slot circularly polarized microstrip patch antenna. (a) Front view. (b) Side view. (c) Perspective view.

2.1.3. Ant.3 — Combining the Truncated Edge, Swastika Slot and Center Circular Slot

Reducing the unrelated linear polarization is a good method to improve the circular polarization, especially in the region near the feeding point. By removing the central part of the metal from the patch, this improvement may be achieved. Based upon Ant.2, center circular slot was introduced into the patch. The radiation patch with Swastika slot and center circular slot fabricated on the upper dielectric substrate was excited through the circular microstrip line fabricated on the other dielectric substrate, fed by a co-axial SMA connector from the ground plane as shown in Fig. 3.

2.2. Design Method and Measurement

Here, the simulation tool is CST, MICROWAVE STUDIO, which is based on Finite Integration in Time Domain and Finite Difference in Time Domain methods.

During the experiment, an Agilent vector network analyzer 8361 was used to measure the impedance band of the antennas. The pattern, axial ratio and gain of the experimental antennas were measured in a half open space on the top of our laboratory building with an Agilent PSG E8267D signal generator, Agilent PSA E4447A spectrum analyzer and the antenna rotator. The gains of the experimental antennas were estimated by comparing the experimental data with the standard horn antennas at the same frequencies.

3. SIMULATED RESULTS ANALYSIS OF THE IMPROVED ANTENNAS, ANT.2 AND ANT.3

3.1. Discussion on Ant.2

Ant.2 is an improved circularly polarized planar microstrip antenna in which the Swastika slot was introduced into the patch in order to improve the $-10\,\mathrm{dB}$ bandwidth, axial ratio (AR) and gain of the antenna. Some simulation results are shown in Fig. 4.

If the slot width v, ($1\,\mathrm{mm} \sim 1.6\,\mathrm{mm}$) is increased, the resonant band moves to higher frequency, and the impedance band becomes wider. The simulated results are shown in Fig. 4(a). Similarly, if the width of the circular microstrip feeding line d_B, ($0.92\,\mathrm{mm} \sim 1.52\,\mathrm{mm}$) is increased, then the impedance band becomes wider to the lower band as shown in Fig. 4(b). As a result of nearly symmetrical geometry, the simulated AR results at Phi $= 0^\circ$ and Phi $= 90^\circ$ are very similar. Here, AR at Phi $= 0^\circ$ is discussed.

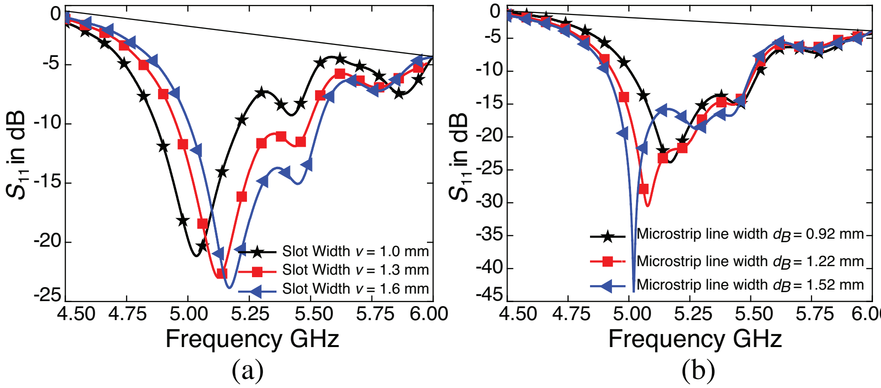


Figure 4. Slot and circular feeding line parameters effect on impedance band. (a) S_{11} with different slot width, when $d_B = 0.92\,\text{mm}$. (b) S_{11} with different circlular feeding line width, when $v = 1.6\,\text{mm}$.

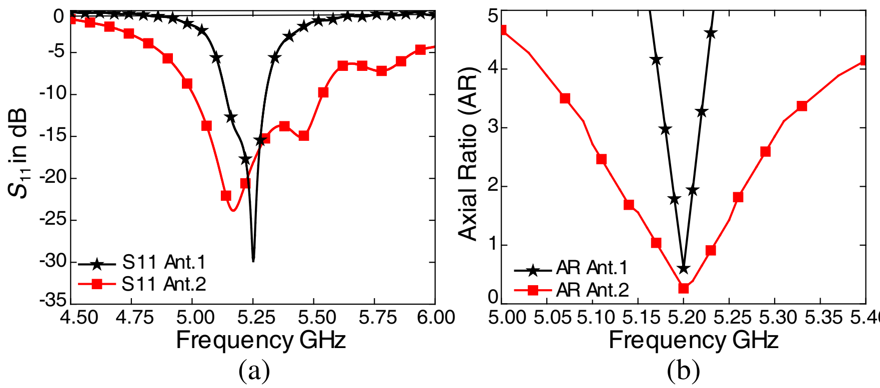


Figure 5. Simulated results of Ant.1 and Ant.2. (a) S_{11} Ant.1 VS Ant.2. (b) AR Ant.1 VS Ant.2.

In Fig. 5, the simulated S_{11} and AR of Ant.1 and Ant.2 are shown. In Fig. 5(a), the impedance band of Ant.2 is 10.05%, which is much wider than Ant.1. This difference is due to their feeding methods, as Ant.1 uses co-axial feeding while Ant.2 uses a co-axial back feeding to the circular microstrip feeding line and then coupling to the patch and Swastika slot. On the other hand, the Swastika slot is rotationally symmetrical, and it has a wider impedance band and CP band structure, which helps to widen the band of the antenna.

3.2. Discussion on Ant.3

Based on Ant.2, a center circular slot is introduced into the patch and the simulated results are shown in Fig. 6. Fig. 6(a) shows that the impedance band of Ant.3 is much wider than Ant.1, but slightly narrower than Ant.2. The 3 dB AR band is similar too. In Fig. 6(c), the gain of the improved Ant.2 and Ant.3 is increased by about 1 dBi compared to Ant.1. The gain of Ant.3 is the highest, about $8.1 \sim 8.4$ dBi in the band (5 GHz–5.4 GHz).

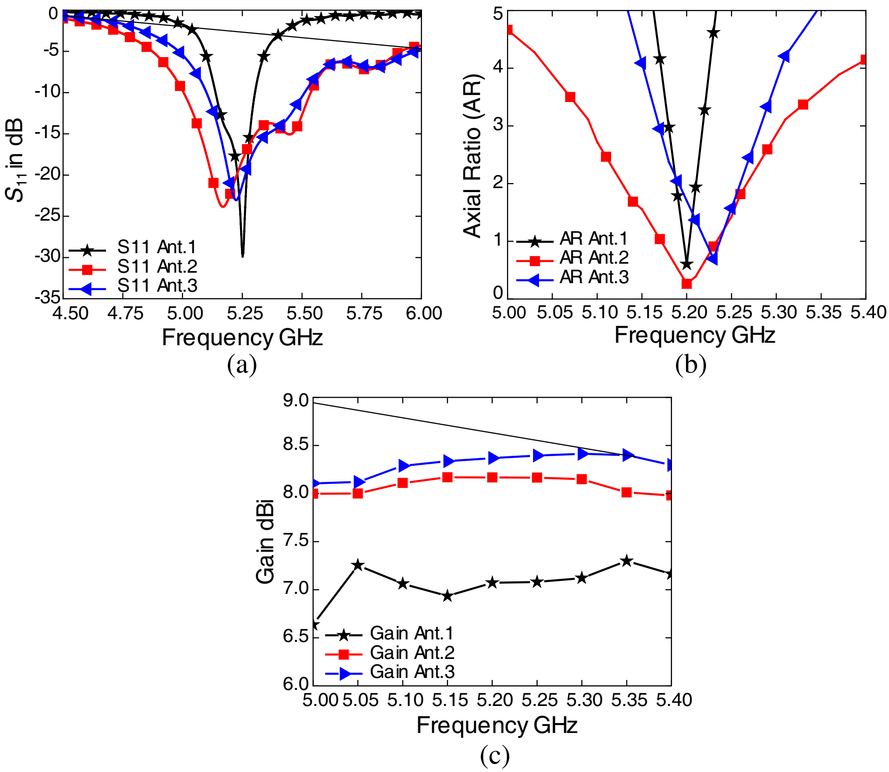


Figure 6. Simulated results comparing Ant.1, Ant.2 and Ant.3. (a) S_{11}. (b) AR. (c) Gain.

Tables 1 and 2 show that by introducing the Swastika slot to Ant.2, the impedance bandwidth and AR bandwidth have been increased by 6.99% and 3.233%, respectively. The gain has been increased by 0.88 dBi. Similarly, by adding the center circular slot to Ant.3, the gain has been increased by 0.23 dBi and 1.11 dBi, compared to Ant.2 and Ant.1, respectively.

Table 1. Simulated impedance bandwidth, AR bandwidth and maximum gain.

Antenna	Impedance matching bandwidth		
Ant.1	5.15 GHz–5.31 GHz	3.06%	
Ant.2	5.01 GHz–5.54 GHz	10.05%	
Ant.3	5.10 GHz–5.51 GHz	7.72%	
Antenna	AR Bandwidth		Maximum Gain
Ant.1	5.18 GHz–5.21 GHz	0.577%	7.29 dBi
Ant.2	5.10 GHz–5.30 GHz	3.84%	8.17 dBi
Ant.3	5.17 GHz–5.28 GHz	2.10 %	8.40 dBi

Table 2. Parameters of the fabricated antennas.

	L (mm)	w (mm)	Swastika Slot	
			Width v (mm)	Length u (mm)
Ant.1	34	2.75		
Ant.2	54	6.08	1.6	14.5
Ant.3	55	4.3	1.6	9.9
	Circular feeding line			
	Radius R (mm)	Width d_L (mm)	Length d_B (mm)	
Ant.1				
Ant.2	2.3	0.92	2.3	
Ant.3	2.3	0.92	2.3	

3.3. The Fabricated Antennas

Following above discussions, the following parameters were chosen for the fabrication of the antennas. The substrate used for fabrication is Arlon AD 250 which has a permittivity of 2.55 and thickness of 0.76 mm.

Similar to Figs. 1, 2, and 3, the three proposed antennas are fabricated with a whole edge length L, truncated edges length w, substrate height h, slot of length u and width v, and central circular slot radius r. Length, width and radius of the circular microstrip

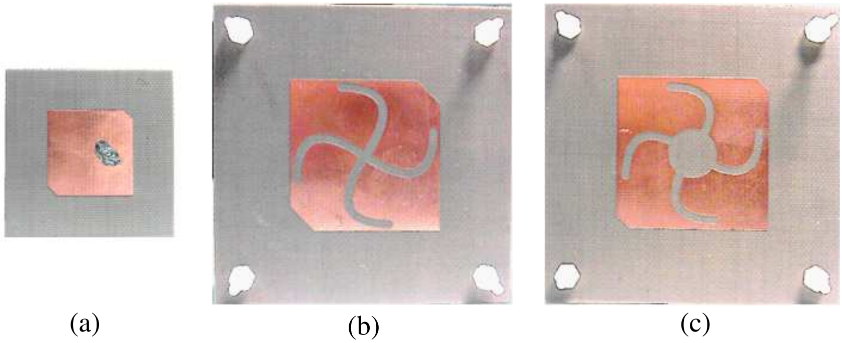


Figure 7. The fabricated antennas. (a) Ant.1. (b) Ant.2. (c) Ant.3.

feeding line are d_L, d_B and R, respectively. The fabricated antennas are shown in Fig. 7. The fabricated antenna shown in Fig. 7(c) has a center circular slot of radius 4.5 mm.

4. RESULTS AND DISCUSSION

The measured S_{11}, AR, far field pattern and gain from the fabricated antennas in Fig. 7 are shown in Fig. 8, Fig. 9, Fig. 10, and Fig. 11, respectively.

4.1. Impedance Matching Bandwidth

In Fig. 8, the return loss of the fabricated antennas is shown, and the measured results are nearly consistent with the simulated ones.

Further, the measured impedance matching bands are from 5.16 GHz–5.33 GHz (3.24%) for Ant.1, from 5.11 GHz–5.89 GHz (14.18%) for Ant.2, and from 5.07 GHz–5.63 GHz (10.47%) for Ant.3. The impedance matching band of Ant.2 and Ant.3 is much wider than Ant.1, as discussed in section 3.1. The coupling feeding structures of Ant.2 and Ant.3 help to widen the impedance band. Fig. 8 (b) shows that the impedance bandwidths of Ant.2 and Ant.3 have been widened. The measured S_{11} of Ant.2 is 4.13% wider than simulation S_{11}; similarly, the measured S_{11} of Ant.3 is 2.75% wider than simulated S_{11}.

4.2. Axial Ratio and CP Bandwidth

In Fig. 9, the simulated and measured axial ratios are shown. Measured results are nearly consistent with the simulated ones.

Furthermore, the measured AR matching band is from 5.18 GHz–5.22 GHz (0.77%) for Ant.1, from 5.11 GHz–5.30 GHz (3.65%) for Ant.2, and from 5.20 GHz–5.33 GHz (2.47%) for Ant.3. The AR matching band of Ant.2 and Ant.3 is much wider than Ant.1. That the Swastika slot is rotationally symmetric and has a wider impedance band and CP structure mainly improves the circular polarization while widening the band of the antenna. The truncated edges and ring feeding strip line also aid in the circular polarization. Comparing Ant.1 with Ant.2 and Ant.3, AR bandwidth has been increased by 2.88% and 1.7%, respectively.

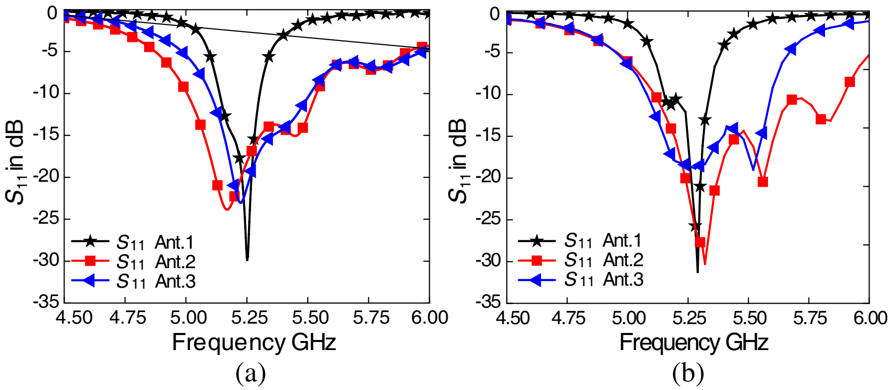


Figure 8. Simulated and measured return loss of fabricated antennas. (a) Simulated S_{11} for these 3 antennas. (b) Measured S_{11} compared among the three fabricated antennas.

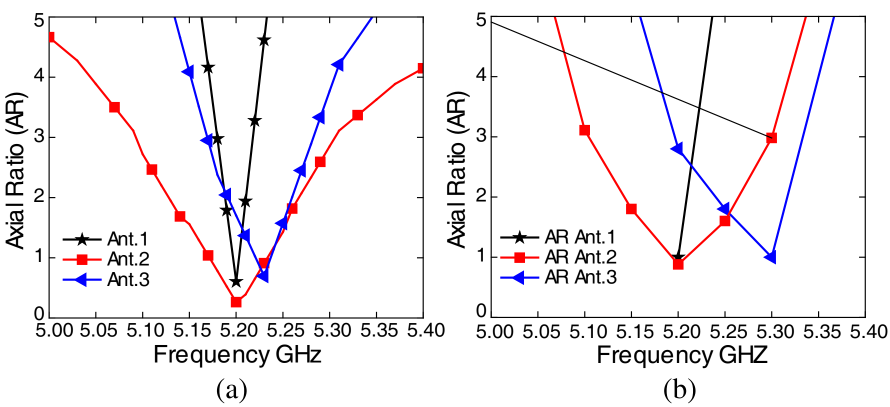


Figure 9. Axial ratio. (a) Simulated AR for fabricated antennas. (b) Measured axial ratio.

4.3. Far Field Pattern

The simulated and measured radiation patterns at Phi = 0° of Ant.1, Ant.2 and Ant.3 at 5.20 GHz are shown below in Figs. 10(a), (b), and (c), respectively. The measured patterns are in LHCP wave and nearly consistent with the simulated ones. The simulated RHCP field is a cross polarization component, which is very small. The measured results also show that the far field patterns of Ant.2 and Ant.3 are almost on the same direction as Ant.1.

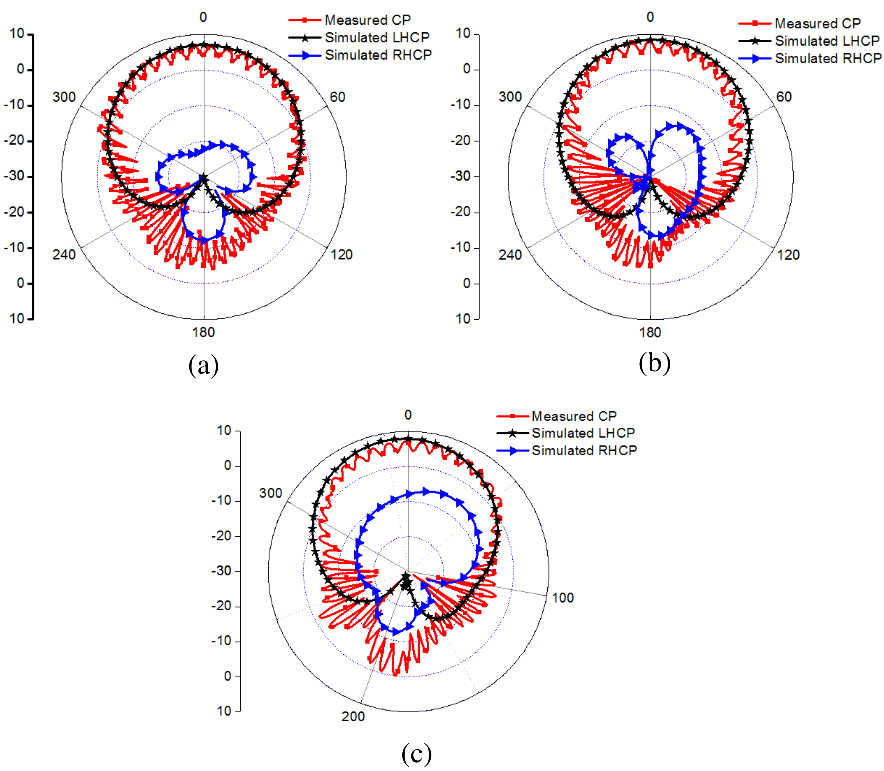


Figure 10. Radiation pattern at 5.20 GHz. (a) Ant.1 Simulated RHCP, LHCP & Measured at Phi = 0°. (b) Ant.2 Simulated RHCP, LHCP & measured at Phi = 0°. (c) Ant.3 Simulated RHCP, LHCP & Measured at Phi = 0°.

4.4. Gain

The comparison of the simulated and measured gains of the antenna is shown in Fig. 11. Measured results are nearly consistent with the simulated ones. The maximum measured gains for Ant.1, Ant.2 and Ant.3 are 7.28 dBi, 8.26 dBi and 8.41 dBi, respectively, while the maximum simulated gains for Ant.1, Ant.2 and Ant.3 are 7.29 dBi, 8.17 dBi and 8.40 dBi, respectively. The simulated and measured gains of Ant.3 are comparatively higher than the other two antennas in all the points measured, which verifies that reducing the unrelated linear polarization, especially from the center of the circularly polarized patch, is a good method to improve the performance of circularly polarized antenna.

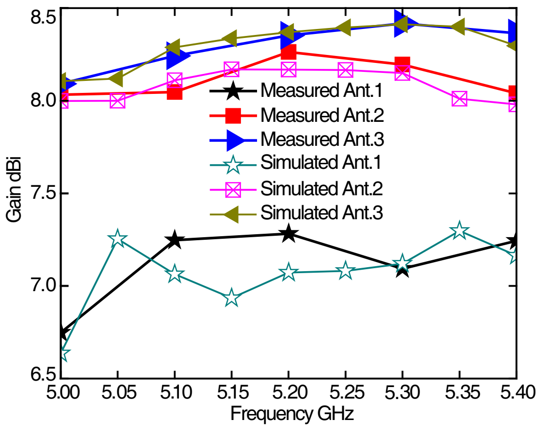


Figure 11. Simulated and measured gain to fabricated antennas.

5. CONCLUSION

In this paper, the improved planar circularly polarized microstrip antenna operations in the 5 GHz-6 GHz band are presented. The rotationally symmetrical Swastika slot and circular feeding line are introduced into Ant.2 which exhibits wider impedance bandwidth and AR bandwidth in simulation and measurement than the basic truncated edge CP microstrip antenna. A center circular slot is introduced into Ant.3 which exhibits better current distribution and improved gain. The measured -10 dB impedance bandwidths of Ant.2 & Ant.3 are 14.18% and 10.47%, respectively, while the measured AR bandwidths of Ant.2 & Ant.3 are 3.65% and 2.47%, respectively.

Furthermore, the S parameters among different slot widths and microstrip line feeding widths are compared. Later, using the best simulated results, the three antennas were fabricated. Results show that Ant.2 & Ant.3 have wider impedance and AR bandwidth than Ant.1. The maximum gain of Ant.1 is about 7.28 dBi, whereas the other two antennas have maximum gains of 8.17 dBi and 8.40 dBi, respectively.

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REFERENCES

1. Gilbert, B., "The MICROMIXER: A highly linear variant of the Gilbert mixer using a bisymmetric Class-AB input stage," *IEEE Journal of Solid-State Circuits*, Vol. 32, 1412–1423, Sep. 1997.
2. Naderi, F., W. J. Weber, and G. H. Knouse, *NASA'S Mobile Satellite Communications Program: Ground and Space Segment Technologies*, Los Angeles, CA, Oct. 1984.
3. Sharma, P. and K. Gupta, "Analysis and optimized design of single feed circularly polarized microstrip antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 31, 949–955, Nov. 1983
4. Qing, X. M. and Y. W. M. Chia, "A novel single-feed circular polarized slotted loop antenna," *International Symposium on Antennas and Propagation Society*, Vol. 1, 248–251, Aug. 1999.
5. Row, J. S., "The design of a squarer-ring slot antenna for circular polarization," *IEEE Transactions on Antennas and Propagation*, Vol. 53, 1967–1972, Jun. 2005.
6. Minard, P. and A. Louzir, "A new wide frequency band feeding technique of annular slot antenna," *International Symposium on Antennas and Propagation,* 406–409, 2002.
7. Iwasaki, H., "A circularly polarized small-size microstrip antenna with a cross slot," *International Symposium on Antennas and Propagation*, Vol. 44, Oct. 1996.

8. Tong, K.-F. and G. Lacotte, "Novel single-feed proximity coupled wideband circularly polarized slot antenna," *Asia-Pacific Microwave Conference,* 1–4, Dec. 2008.
9. Sim, C.-Y.-D. and B. H. Yang, "A single layer dual-band CP microstrip antenna for GPS and DSRC applications," *Journal of Electromagnetic Waves and Applications*, Vol. 22, No. 4, 529–539, 2008.
10. Chen, Y., H. Sun, and X. Lv, "Design of a broadband wide-angle circularly polarized microstrip patch antenna with small phase deviation," *International Conference on Microwave and Millimeter Wave Technology,* Vol. 3, 1089–1091, Apr. 2008.
11. Shi, S., K. Hirasawa, and Z. Chen, "Circularly polarized rectangularly bent slot antennas backed by a rectangular cavity," *IEEE Transactions on Antennas and Propagation,* Vol. 49, 1517–1524, Nov. 2001.
12. Row, J.-S. and S.-W. Wu, "Circularly-polarized wide slot antenna loaded with a parasitic patch," *IEEE Transactions on Antennas and Propagation*, Vol. 56, 2826–2832, Sep. 2008.
13. Trinh-Van, S., H. B. Kim, G. Kwon, and K. C. Hwang, "Circularly polarized spidron fractal slot antenna arrays for broadband satellite communications in Ku-band," *Progress In Electromagnetics Research*, Vol. 137, 203–218, 2013.
14. Deng, J.-Y., L.-X. Guo, T.-Q. Fan, Z.-S. Wu, Y.-J. Hu, and J. H. Yang, "Wideband circularly polarized suspended patch antenna with indented edge and gap-coupled feed," *Progress In Electromagnetics Research*, Vol. 135, 151–159, 2013.