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PAPERS

AMC backed circularly polarized dual band antenna for Wi-Fi and WLAN applications

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In this article the design and implementation of dual band circularly polarized antenna which is backed with AMC is presented. The proposed antenna consists of a novel heart shaped concentric ringshaped patch attached to meander line. The dimension of the antenna without AMC is $0.24\,\lambda_0 \times 0.140\,\lambda_0 \times 0.012\,\lambda_0 \times$ and with AMC $0.43\,\lambda_0 \times 0.43\,\lambda_0 \times 0.32\,\lambda_0$ and designed on a commercial FR4 substrate. The antenna gets worked at dual band applications such as 2.4 GHz (wi-fi) operates from 2.3 GHz to 2.5 GHz and 5.2 GHz (WLAN) operates from 4.7 GHz to 5.9 GHz and also gets circular polarization from 2.3 GHz to 2.5 GHz (200 MHz) and 4.95 GHz to 5.40 GHz (450 MHz) is achieved. In this article the proposed model is investigated towards circular polarization, radiation patterns and current distributions by varying parametric analysis is carried to analyze overall performance of antenna with and without AMC.

Keywords: dual band, AMC, circular polarization

1 Introduction

Nowadays, in the fields of electromagnetics and wireless communication system, circular polarized techniques are used extensively. Circularly polarized (CP) antennas can reduce orientation issues between transmitting antenna and receiving antenna, can reduce the interference due to multipath reflections and mitigate the losses due to polarization mismatching. Because of the advantages such as simple structure, low profile, ease of fabrication and integration, and wide achievable axial ratio (AR) bandwidth, the printed slot antenna has been widely utilized to generate CP property. To achieve the circular polarization phenomenon, the antenna must excite two degenerated modes and the phase difference between these two modes should be 90°. In [1] a rectangular antenna having Split Ring Resonator (SRR) in the form of concentric circles in ground surface for achieving Circular Polarization. A fractalbased loop antenna with two rectangular shaped portions are etched on the either sides of the SRR in the ground plane for enhancing bandwidth and CP is designed by the author in [2] In [3] the author designed a wideband circular polarization antenna by replacing thin dipole in a conventional dipole with a wide strip to achieve two orthogonal modes. An annular ring slot antenna is designed for dual band dual sense circular polarization [4]. Here the annular rings are arranged in concentric structure and two distributed capacitances are introduced with the T-shaped arcs to achieve the circular polarization. In [5] a dual band dual sense circular polarized asymmetric H-shaped antenna fed with two port coplanar waveguide is designed. The higher band is achieved with the help of asymmetry feed lines. In [6] a triple band CP antenna the circular polarization at the middle band, middle band and higher band are achieved U-shaped patch, an I-shaped stub and inserting an inverted L-shaped stub at the end of I-shaped stub. In [7] a triple band hexagonal slot antenna having three L-shaped slots are attached to the hexagonal slot for achieving the triple band circular polarization. M. L. Abdelghani proposed a conformal Artificial Magnetic Conductor to enhance the gain and beam shaping for wireless communication applications [8]. Here AMC contains an array of square unit cells arranged in row and column set. A T shaped antenna is placed at the center of the conformal AMC to enhance the gain and beam shaping of the antenna. S. X. Ta proposed a dual band circular polarized antenna with the help of Artificial Magnetic Conductor [9]. Here the proposed antenna consists of an arrow shaped patches directed towards two adjacent sides of the square shaped substrate and the ground has the same shape directed towards remaining two edges of the square substrate. The AMC consists of 6×6 square patches as array with T shaped slots etched on its four sides. K. Agarwal proposed a circularly polarized wideband antenna backed with AMC reflector for wireless communication applications [10]. Here the proposed antenna consists of reversed L shaped patch as radiating element and the ground has octagonal shaped slot etched in it. The AMC consists of a square patch as 6×6 array in the upper layer and the square patch as 7×7 array in the bottom layer. J. Lin proposed a dual band dual polarized antenna with the help of AMC for wireless communication applications [11]. Here the proposed antenna consists of four sectors

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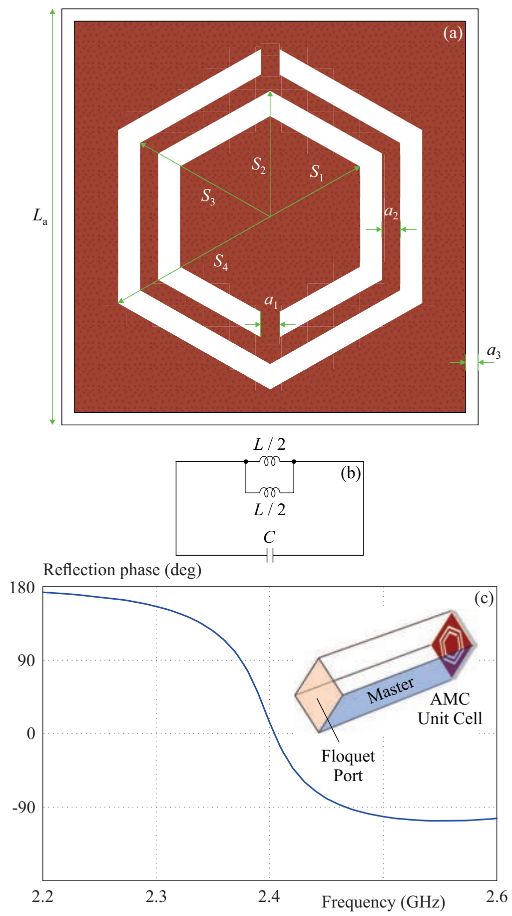

Fig. 1. (a) – unit cell with dimensions, (b) – equivalent circuit of unit cell, and (c) – reflection phase of unit cell

placed orthogonal to each other and the AMC consists of a square patch with a square slot in it as unit cell and arranged as 5×5 array. The proposed antenna is placed at height of 6.5 mm from the AMC to achieve dual band operation. D. Feng proposed a broadband circular polarized antenna fed with power divider along with Artificial Magnetic Conductor for wireless communication applications [12]. Here the proposed antenna consists of four patches placed orthogonal to each other and feed with power divider. The AMC consists of a square patch as unit cell and placed as 6×6 array. The proposed antenna is laced at the center of the AMC to achieve dual band and dual polarization. K. N. Paracha proposed a dual band dual polarized antenna backed with AMC and fed with micro strip feed line for wearable applications [13]. Here the proposed antenna consists of Y shaped patch as driven patch and a square patch along with inverted triangle as parasitic patch. The parasitic patch consists of circular complementary split ring resonator in it. the AMC consists of a square patch with circular slot in it along with rectangular slot patches in four sides. J. Li proposed a circular polarized antenna with Artificial Magnetic conductor and fed with microstrip feed line for wireless communication applications [14]. Here the proposed antenna consists of a rectangular patch as radiating element. The AMC consists of rectangular meander line patch as unit cell and placed as 6×6 array. The proposed antenna resonates at 2.71 GHz and having an impedance bandwidth of 15.9%. R. P. Dwivedi proposed a new technique to improve the gain of the antenna with the help of Artificial Magnetic Conductor [15]. Here the proposed antenna consists of a rectangular patch as radiating element. The antenna has fractal based rectangular slots in its geometry. The AMC consists of a pair of rectangular loops along with circular ring in its geometry as unit cell and placed as $2\times\times2$ array. The proposed antenna is placed over the AMC to enhance the gain and other antenna parameters. H. H. Elzuwawi proposed a RFID microstrip patch antenna with Artificial Magnetic Conductor for wireless communication applications [16]. Here the proposed antenna consists of a rectangular patch along with octagonal ring and octagonal patch as radiating element. The AMC consists of meander line on both the sides of a rectangular patch as unit cell and placed as an array. The proposed antenna is placed over the AMC to enhance the antenna parameters. A. Sharma proposed a circular polarized Artificial Magnetic Conductor for gain enhancement and Radar Cross Section reduction [17]. Here the proposed AMC consists of three rectangular patches placed horizontal to each other and are connected by a rectangular patch from their center and is placed an array. A circular polarized antenna consists of rectangular patch as radiating element and a pair of split ring resonators on either side of the radiating element is placed as parasitic patches.

In this work a dual sensed AMC backed circularly polarized antenna is designed and analyzed. The proposed antenna works in the bands of modern commercial Wi-Fi and WLAN bands, the antenna is designed using ANSYS HFSS 18 and fabricated on FR4 substrate. The antenna characteristics with and without AMC is observed and discussed in detailed in this article. The simulated and measured parameters show a good matching correlation.

2 Antenna design and implementation

2.1 Unit cell analysis

Figure 1 shows the AMC unit cell which is constructed on a dielectric layer of $\epsilon_r = 4.4$ FR4 material with a dielectric loss tangent $\tan\delta = 0.025$ with a thickness of 1.6 mm . the upper part of the metallic layer comprises of copper ($\sigma = 5.8\times10^7$ s/m) having a layer thickness of 0.035 mm. The geometry of the unit cell like hexagonal metamaterial inspired complimentary split ring resonator. This structure is analyzed using floquent mode of analysis. Here the AMC unit cell is excited incident wave propagate in Z-direction and periodic boundary in both orthogonal directions (X and Y directions).

Table 1. Parameters of AMC unit cell

Parameters	(mm)	(λ_0)
La	18	0.144
a1	0.5	0.004
a2	0.8	0.006
a3	0.5	0.004
S1	4.5	0.036
S2	5.5	0.044
S3	6.5	0.052
S4	7.5	0.060

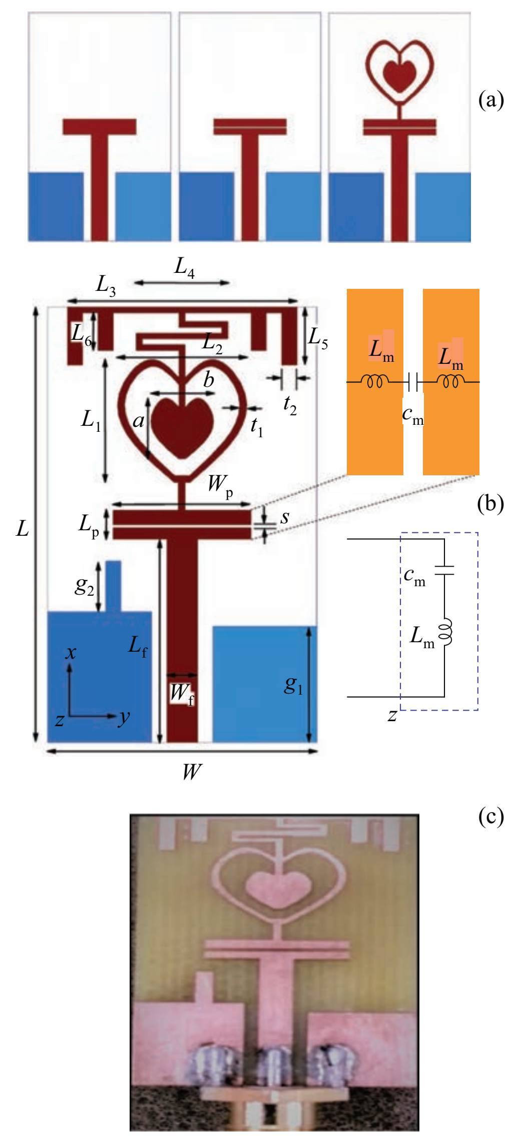

Fig. 2. Proposed: (a) – antenna iterations, (b) – circular polarized antenna, and (c) – fabricated antenna

The proposed Hexagonal CSRR acts as an AMC cell in which it is clearly seen in Fig. 1 phase *vs*frequency at targeted frequency at 2.4 GHz. Here, the reflection phase is calculated using (2). A frame of 3×3 array of unit cell is arranged to achieve desired enhancement in the antenna parameters. The dimensions of the proposed AMC unit cell are explained in Tab. 1. The PEC surface acts as the reference and periodic surface is known for its reflection equation.

$$\phi = \phi_{\text{AMC}} - \phi_{\text{PEC}} + \pi. \tag{1}$$

2.2 Antenna design

The dimensions of the proposed antenna with respect to lowest resonant frequency (2.4 GHz) is presented in Tab. 2. The antenna is designed on commercially available FR4 substrate, the proposed antenna is obtained by iterative type of analysis. In the iteration one the antenna is attached with rectangular patch in which it does not get radiated at required band. Later in the second iteration rectangular patch is separated by a gap of 0.0016 λ_0 which further creates that patch into two parts, one is driven patch and another one is parasitic patch. This iteration does not show much improvement in antenna characteristics but still it has effects on antenna parameters. In the third iteration a novel heart shaped concentric ring is attached to parasitic patch. In this iteration the antenna gets starts working at single band below sub 6 GHz modern communication band. The first three iterations of the antenna are shown in Fig. 2(a).

Table 2. Parameters of AMC unit cellparameters of heart shaped circularly polarized antenna

Parameter	(mm)	(λ_0)	Parameter	(mm)	(λ_0)
L	30	0.240	b	4.1	0.032
W	17.58	0.140	t1	0.5	0.004
Lf	14	0.112	t2	1	0.008
Wf	2	0.016	L1	8.5	0.068
LP	2	0.016	L2	8.5	0.068
WP	9	0.072	L3	15	0.120
g1	8	0.064	L4	6	0.048
g2	3.5	0.028	L5	4	0.032
S	0.2	0.002	L6	3	0.024
a	4.16	0.033	- -	- -	- -

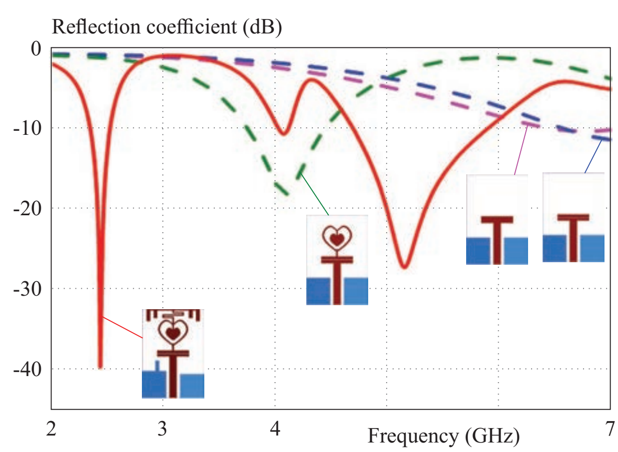

Fig. 3. Reflection coefficient of proposed antenna iterations

Table 3. Reference comparison without AMC

Ref No	Overall antenna size (mm^3)	Electrical size with respect to (λ_{03})	Resonance frequency (GHz)	Imp. BW %	A.R BW %	No. of axial ratio bands covered
3	$158 \times 81.5 \times 1.6$	$0.948 \times 0.489 \times$	1.8	119	51	Single
4	$66 \times 55 \times 1.6$	$0.352 \times 0.293 \times 0.008$	1.6 2.7	22.7 22.3	3.6 5.6	Dual
5	$70 \times 70 \times 1.6$	$0.373 \times 0.373 \times 0.008$	1.6 3.5	96.2 9	16.72 4.7	Dual
6	$55 \times 52 \times 1.6$	$0.471 \times 0.445 \times 0.013$	2.57 5.35	17.4 76.6	12 10 4.4	Triple
7	$60 \times 60 \times 1.6$	$0.772 \times 0.772 \times 0.020$	3.86 5.37	33.1 22.1	1.7 3.8 5.2	Triple
Without AMC	$30 \times 7.58 \times 1.6$	$0.24 \times 0.140 \times 0.012$	2.4 5.2	12.5 23.52	12.5 23.52	Dual

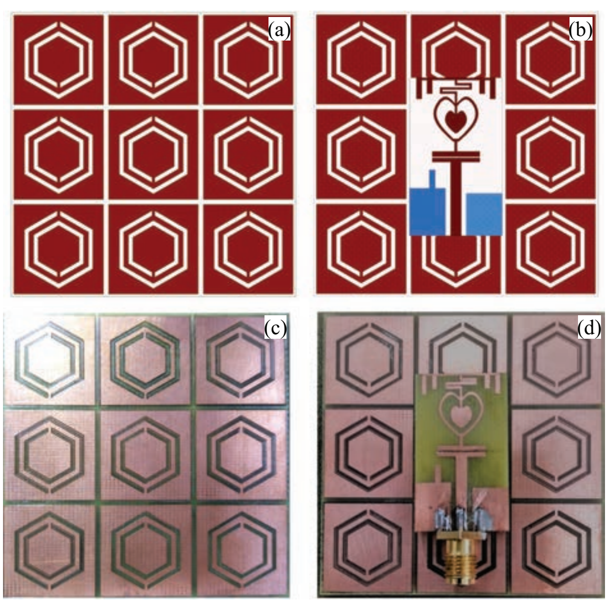

Fig. 4. (a) – 3×3 AMC array, (b) – AMC backed circularly polarized antenna, (c) – 3×3 AMC prototype, and (d) – AMC backed antenna placement

The fourth and final iteration is the proposed antenna in which the parasitic patch is attached with combination of meander line along with a pair of rectangular stubs on each side of the antenna. The fourth iteration of the antenna is shown in Fig. 2(b). The circular polarization of the antenna is an added advantage in which it mainly happens due to a rectangular stub added to one side of the ground stub. Fig 2(c) shows the fabricated antenna prototype on FR4 substrate. The reflection coefficient of proposed antenna iterations and final Circular polarized antenna are shown in Fig. 3.

A novel heart shaped circularly polarized dual band antenna is designed analyzed using HFSS-18. The antenna works in the modern communication bands such as 2.4 GHZ (Wi-Fi) and 5.2 GHz (WLAN). The principle of the antenna can be explained by considering the gap capacitance between the feed line and the parasitic patch. Here resonance frequency of the antenna is depending upon the gap S of the antenna. The antenna characteristics like resonance frequency, impedance bandwidth, gain and etc are incorporated in Tab. 3.

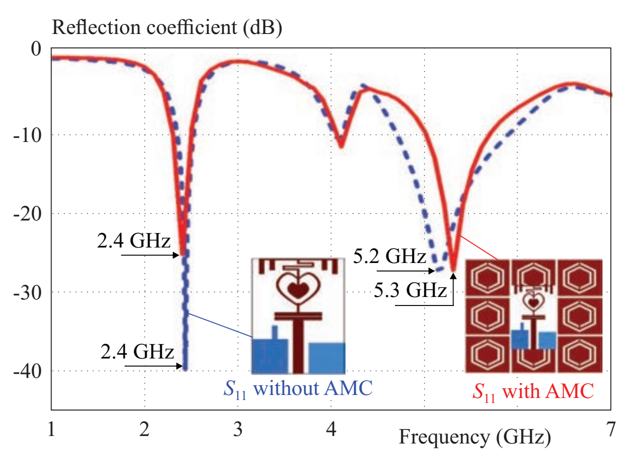

Fig. 5. $|S_{11}|$ simulated *vs*frequency plot with and without AMC reflector

2.3 Antenna with AMC

This section describes the implementation of 3×3 AMC surface structure. The Fig. 4 represents 3×3 AMC array and AMC backed on a circularly polarized antenna designed model in HFSS and the prototype of AMC and antenna placement.

Figure 5 represents the simulated reflection characteristics of the proposed antenna in presence and absence of AMC. Fig. 6 represents the measured reflection characteristics of the proposed antenna with and without AMC

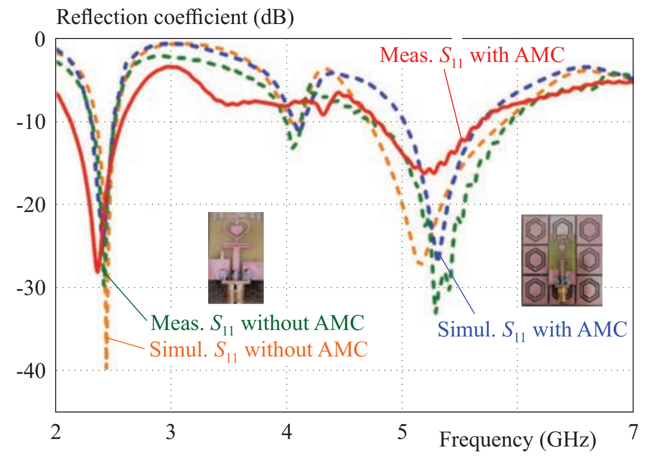

Fig. 6. Simulated and measured: (a) – $|S_{11}|$ *vs*frequency plot, (b) – $|S_{11}|$ with and without AMC reflector

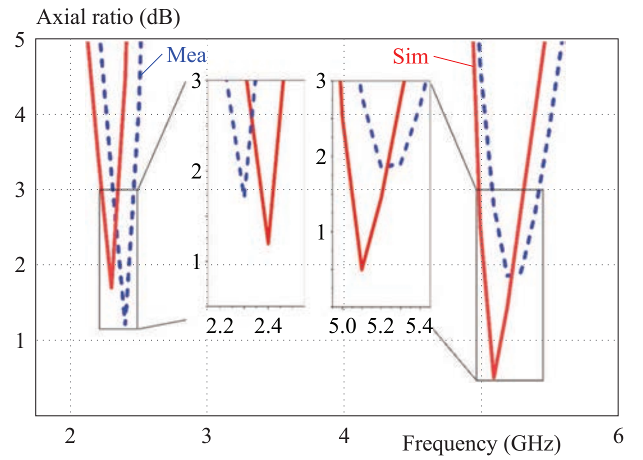

Fig. 7. Axial ratio of heart shaped antenna

Table 4. Reference comparison with AMC

Ref No	Size (mm^3)/(λ_{03})	Resonance (GHz)	ImpBW (%)	Polarization	ARBW (%)	Gain (dBi)
8	$121\times279\times41$ $1\times2.3\times0.33$	2.47	6.06	LP	-	7.5
9	$72\times72\times11$ $0.57\times0.57\times0.08$	2.40 5.20	16.7 11.5	CP CP	8.3 5.77	5.1 6.2
10	$36\times30\times9.5$ $0.72\times0.60\times0.19$	6.00	-	CP	33.2	6.97
11	$115\times115\times6.5$ $0.53\times0.53\times0.03$	1.38 1.57	2 1	LP CP	- 1.27	2 7
12	$252\times252\times20$ $1.5\times1.5\times0.12$	1.78	66.3	CP	44.7	6
13	$130\times130\times10$ $0.68\times0.68\times0.05$	1.57 2.44	1.84 0.75	CP LP	0.83	5.1 5.03
14	$60\times60\times9$ $0.54\times0.54\times0.08$	2.71	15.9	CP	4.1	5.5
15	$40\times40\times10.5$ $1.06\times1.06\times0.28$	8.00	98.7	LP	-	7.7
16	$130\times130\times60$ $0.37\times0.37\times0.17$	0.86	-	LP	-	6.7
17	$80\times80\times$ - $3.1\times3.1\times$ -	11.8	13.5	CP	1.7	6.5
with AMC	$54\times54\times40.2$ $0.43\times0.43\times0.32$	2.4 5.3	12.5 13.2	CP CP	12.5 23.52	5.16 7.60

and the connection to combinational analyzer. The proposed antenna in absence of AMC is giving -25 dB of resonance depth whereas when the antenna is enclosed with AMC cells it is getting around -30 dB in the range 5.0 GHz to 5.7 GHz. From Fig. 6 we have notice that the antenna gets resonance depth in upper cutoff frequency (5.2 GHz). The presence of AMC due to its reflector capabilities, enhances the performance of the antenna and leads to the increase of band coverage with in-depth resonance. The enhancement in the antenna characteristics like resonance frequency, impedance bandwidth, gain and *etc*are incorporated in Tab. 4.

3 Generation of axial ratio for proposed model

The proposed antenna gets worked in dual bands *ie* at 2.4 GHz (Wi-Fi) and 5.2 GHz (WLAN). In addition to that the antenna also attains circular polarization at these bands as shown in Fig. 7. The realization of circular polarization is explained via current distribution,

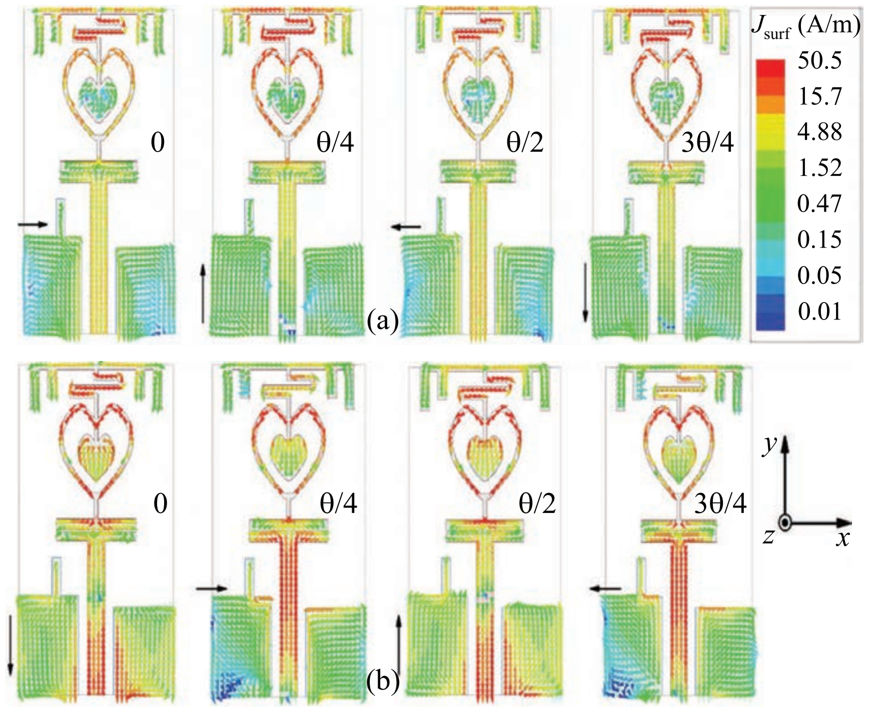

Fig. 8. Field current distributions of the circularly polarized antenna without AMC (a) – @2.4GHz, and (b) – 5.2GHz

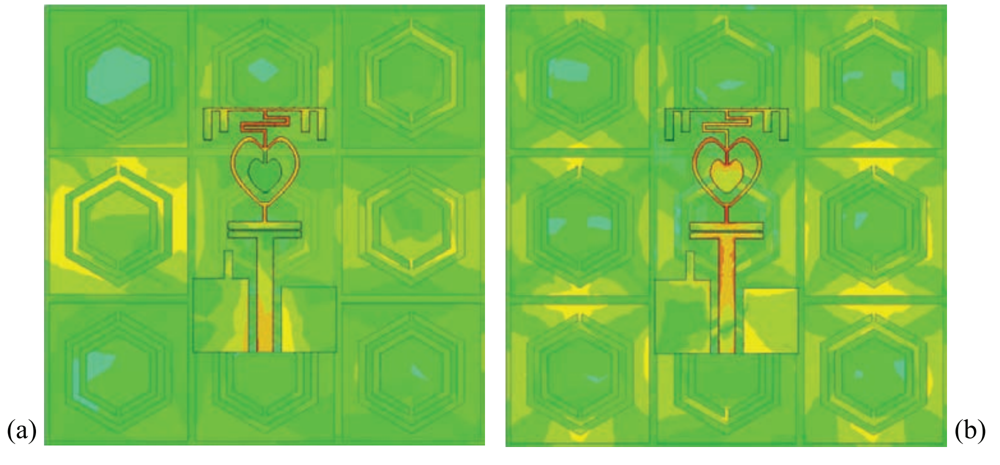

Fig. 9. Field current density of the circularly polarized antenna without AMC (a) – @2.4GHz, and (b) – 5.2GHz

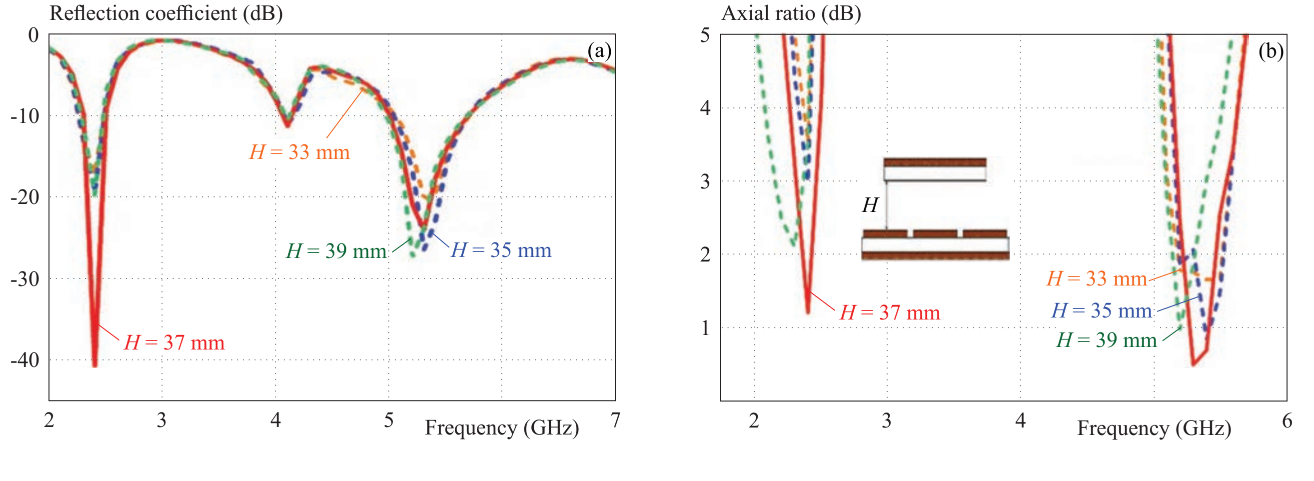

Fig. 10. Effects of H variation on reflection coefficient & axial ratio

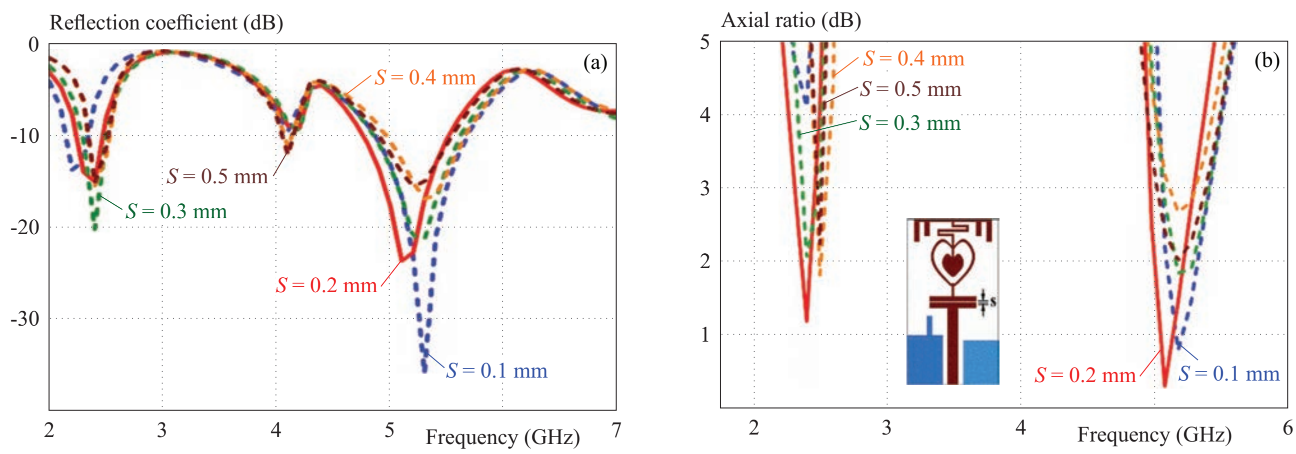

Fig. 11. Effects of S variation on reflection coefficient and axial ratio

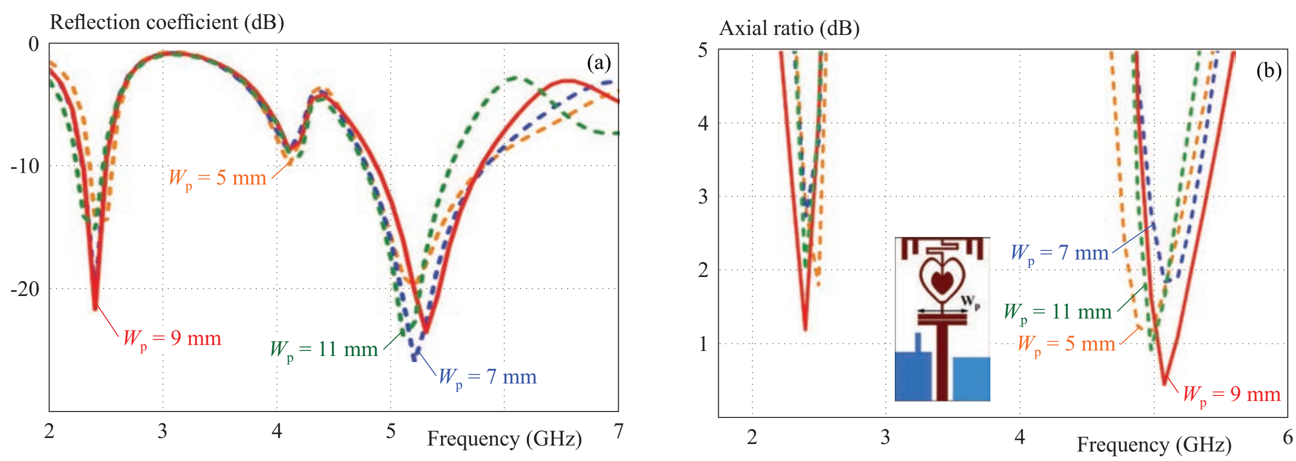

Fig. 12. Effects of wp variation on reflection coefficient and axial ratio

RHCP/LHCP radiation patterns. By observing the current vector distribution over 2.4 GHz and 5.1 GHz.

In Fig. 8 the proposed antenna working band current distribution has been observed. At time instants *ie* at 0°, 90°, 180° and 270° at 2.4 GHz and 5.2 GHz the current vectors observed. It is observed that the strong current occurs by the combination of length of the feed line in combination of diameter of heart shaped ring and meander line gives predominant current fields at 2.4 GHz. Similarly, for second resonance band the combination of feed line and diameter of heart shaped concentric ring have strong replicated currents which gives 5.2 GHz resonance frequency. By looking strong surface currents at two resonant bands a mathematical equation is developed individually by measuring the individual element current concentration. *ie* each element in the antenna geometry acts as half wavelength resonator which causes the obtained bands

$$L_{r1} = 0.96(L_f + \pi(L_1/2) + 2L_4)), \tag{2}$$

$$L_{r2} = 0.65(L_f + \pi(L_1/2)). \tag{3}$$

The electric current concentration and its circular polarized behavior can be noted after calculating from bellow formulae

$$f_{ri} = c/(2L_{ri}\sqrt{\varepsilon_r}), \tag{4}$$

where C is the velocity of light (3×10^8 m/s). The above expression is used to calculate the resonant bands (2.4 GHz & 5.2 GHz). From below diagrams and equation, we can clearly understand the polarization at frequency bands.

The proposed antenna axial ratio is noticed with and without AMC. It is observed that the proposed antenna gets circular polarization at 2.3-2.5 GHz (almost 200 MHz) and it gets right hand circular polarization. Whereas the second band gets 4.95-5.4 GHz (almost 450 MHz) and it gets left hand circular polarization. The surface current density of the proposed antenna with AMC at working bands can be seen in Fig. 9.

4 Parametric study

4.1 Height H

In antenna design reflection coefficient depth plays a major role for efficient radiation. Here the gap H between the antenna and the AMC array is varied from 33 mm to 39 mm and is shown in Fig. 10. For the first two iterations the antenna reflection coefficient maintains around -20 dB at 2.4 GHz while for the iteration $H = 37$ mm the reflection coefficient reaches to -40 dB. The axial ratio of

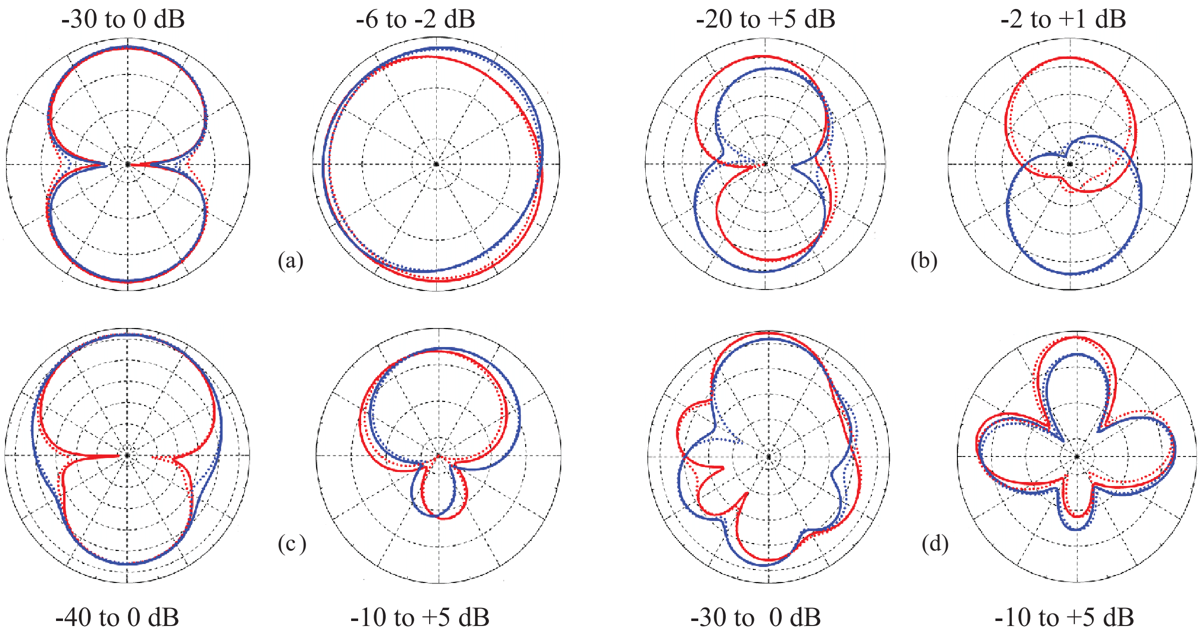

Fig. 13. LHCP(red)/RHCP(blue), simulation(solid-line)/measured(dot-line),for annenas: (a) – without AMC @ 2.4 GHz XZ & YZ, (b) – without AMC @ 5.2 GHz XZ & YZ, (c) – AMC @ 2.4 GHz XZ & YZ, (d) – with AMC @ 5.2 GHz XZ & YZ plane

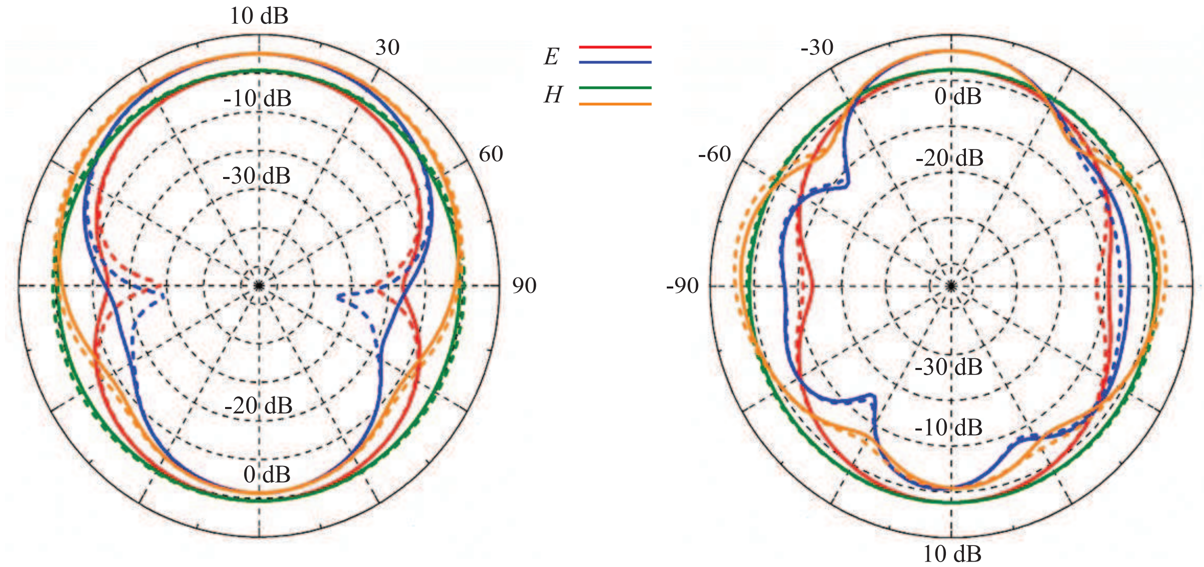

Fig. 14. E-plane and H-plane simulated(dash-lime)/measured(solid-line) at 2.4 GHz (left) and 5.2 GHz (right), without AMC (red & green) and with AMC (blue & orange)

the antenna also fine-tuned in accordance with H variations. For the first two iterations the antenna axial ratio maintains up to 3 dB at 2.4 GHz while for the iteration $H = 37$ mm the axial ratio reaches below 3 dB.

4.2 Gap S

Here the gap S is varied to find how its effects reflection coefficient and axial ratio. Interestingly, while varying the gap S it effects the axial ratio at lower resonance frequency 2.4 GHz and alters towards lower frequency. There is no such change in reflection coefficient as observed in Fig. 11. Here the gap S between the driven patch and parasitic patch is varied to achieve the better axial ratio values at desired resonance frequencies. The parameter S is varied from 0.1 mm to 0.5 mm. For the iteration S = 0.2 mm the antenna gives better reflection coefficient and axial ratio at 2.4 GHz and 5.2 GHz resonance frequencies. For the remaining values of S the axial ratio of the antenna at 2.4 GHz is shifted towards higher frequencies.

4.3 Width W_p

By varying the width of the rectangular patch W we observe that the axial ratio of the antenna at higher

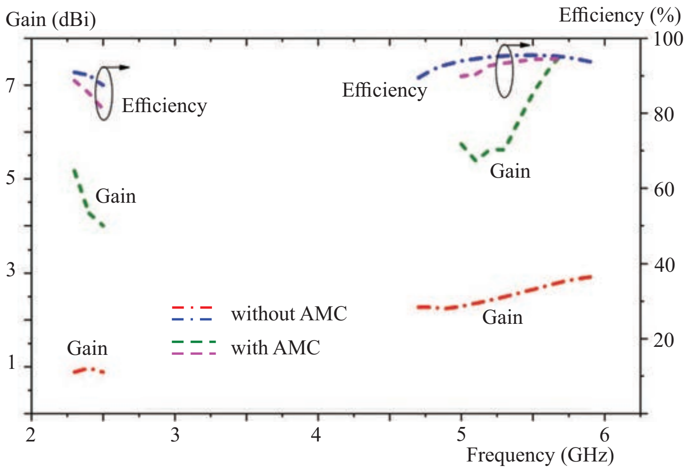

Fig. 15. Simulated gain and efficiency of the antenna with and without AMC

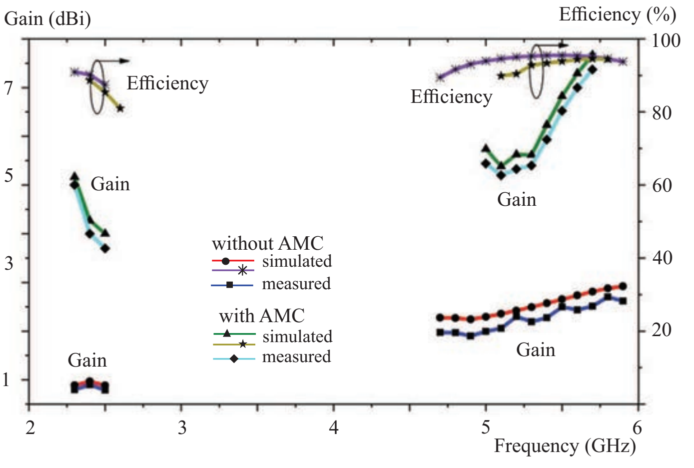

Fig. 16. Simulated and measured gain and efficiency of the antenna with and without AMC

resonance frequency 5.2 GHz and alters towards higher frequencies and there is no such noticeable change in axial ratio at lower resonance frequency 2.4 GHz. the reflection coefficient is also fine-tuned by varying parameter W to 9 mm. The variation of reflection coefficient and axial ratio are shown in Fig. 12.

5 Radiation patterns

The radiation patterns of the proposed antenna with and without AMC are observed in Fig. 13. At 2.4 GHz pattern (both XY-plane $\phi = 0$ and YZ -plane $\phi = 90°$) the propagation of radiation wave is a right-handed wave in the positive Z direction and left-handed wave in negative Z direction. From Fig. 13 at 2.4 GHz with and without AMC the boresight direction is evident of right-handed polarization at 2.4 GHz, coming to 5.2 GHz the propagation of radiation wave gives left-handed wave in positive Z direction and right-handed in negative Z direction. At 5.2 GHz patterns (both with AMC and without AMC) we can clearly say that this resonant frequency can be called as cross-polarization discrimination (XPD). That means when the difference between RHCP and LHCP or LHCP and RHCP patterns are below 20 dB which can be indeed called as excellent circular polarization characteristics. In respect to all these patterns the resonant frequencies at E-plane and H-plane with and without AMC patterns are observed in Fig. 14, which are almost dipole type of patterns at E-plane (2.4 GHz and 5.2 GHz) and omnidirectional patterns at H-plane (2.4GHz and 5.2GHz).

The simulated gain and efficiency of the proposed antenna with and without AMC are shown in Fig. 15. From figure we can observe that the proposed antenna attains around 3 dBi gain at the lower band frequencies (2.4 GHz) and around 7.6 dBi gain at higher band frequencies (5.2 GHz) after introducing AMC in the antenna geometry. The measured gain and efficiency of the proposed antenna with and without AMC are shown in Fig. 16.

6 Conclusion

In this article design and experimental demonstration of a novel heart shaped concentric ring attached with a fork shape meander line is analyzed in presence of AMC and without AMC. A CPW ground attached with a stub is influenced to get circular polarization characteristics. The measured reflection coefficient under the influence of AMC and without AMC are verified and it shows good agreement after validating. Considering advantage of compact modal without AMC is 0.24 λ_0 $\times 0.140\lambda_0$ $\times 0.012\lambda_0$ and with AMC $0.43\lambda_0 \times 0.43\lambda_0 \times 0.32\lambda_0$ having circular polarization. the proposed heart shaped antenna is suitable in various wireless communication application bands such as 2.4 GHz (Wi-Fi) and 5.2 GHz (WLAN) bands. The current distribution and owing towards validation patterns (both LHCP/RHCP) show that it is good candidate for wireless communication in both the bands.

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