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Compact dual-band circularly polarized patch antenna with bandwidth enhancement

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This paper introduces a bandwidth enhanced version of dual-band circularly polarized stacked microstrip antenna for ISM Bands (2.45GHz & 5.8GHz) applications. The aim is to reduce the limitation of patch antenna which is narrowband. Implementing two frequencies on a single antenna with circular polarization can be significant because of the presence of mutual coupling and interference effect between the two radiating elements. With the enhanced bandwidth the application area of the proposed antenna is further widened. The stacking antenna with two different corner-truncated square patches, had achieved dual-frequency circular polarization (CP) with 9.1% and 26.2% measured impedance bandwidth at VSWR of 2.5:1. The obtained results show that the proposed dual band CP antenna achieves high antenna efficiency and provides better bandwidths, while still maintaining the structural compact size. The antenna is therefore a promising candidate for smart antenna systems, cognitive radios, and radar applications in the future.

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Keywords: Patch Antenna, Circular Polarized, Dual Bands, ISM Band, Bandwidth enhancement.

1. Introduction

Based on definition of ITU-R (International Telecommunication Union – Radio communication Sector), there are a list of unlicensed spread spectrum bands reserved internationally for other radio frequency (RF) purposes other than communications. These include the use of RF energy for industrial, scientific and medical (ISM) purposes. Since these bands are unlicensed, wireless local area network (WLAN) applications also use these bands as well. A WLAN links two or more devices using some wireless distribution method, typically spread-spectrum or Orthogonal Frequency Division Multiplexing (OFDM) radio. It usually provides a connection through an access point to the wider internet. This provides the mobility for the users to roam within a local coverage area without losing network connectivity.

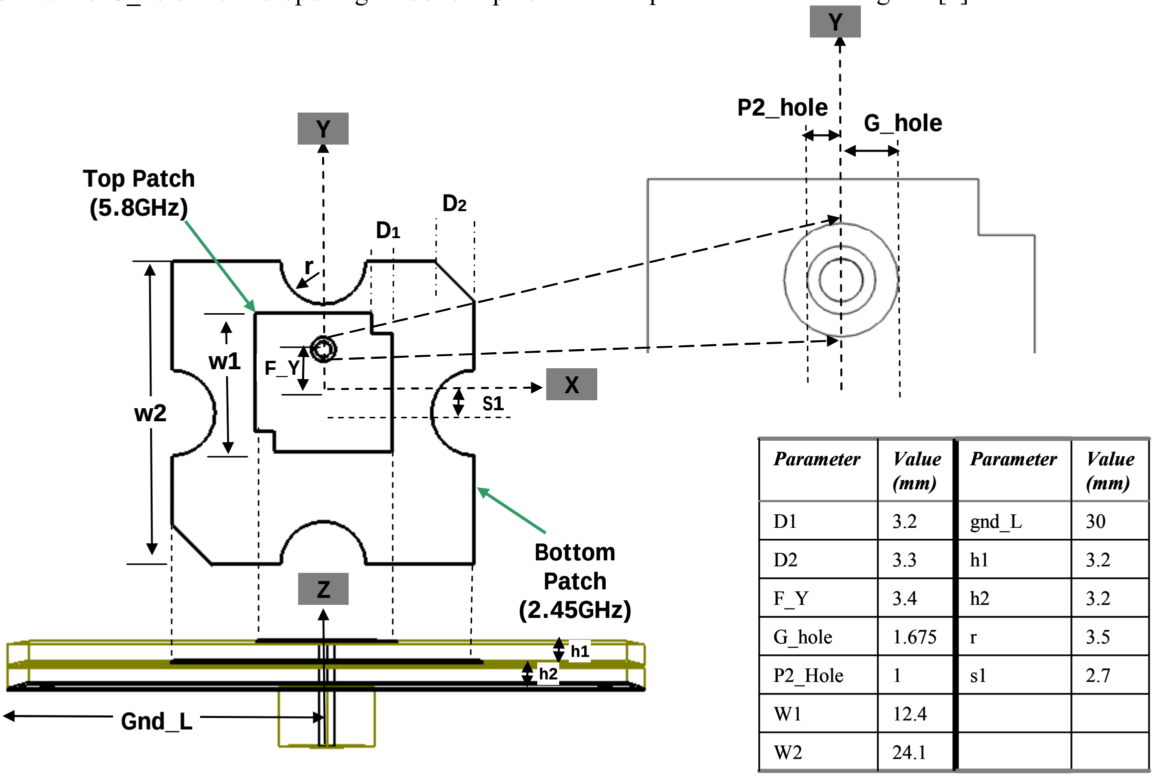
In this paper, the WLAN application 802.11b/g and 802.11a, which using the unlicensed ISM band center frequencies at 2.45GHz and 5.8GHz, has been selected for the study. The frequency band corresponding to the standards are 2.4GHz - 2.5GHz; and 5.725GHz - 5.875GHz [1]. A single antenna which can effectively operate in these frequencies is of course more efficient and cheaper than deploying two antennas in which each operates for each frequency band. This motivates the new trend in antenna technology, where there are many devices that require the implementation of the dual-band wireless antenna. A number of microstrip antennas have been designed for dual-bands operating at 2.45GHz and 5.8GHz with circular polarization, though only with narrow bandwidth [2, 3]. A lot of works have been conducted in order to increase the bandwidth of microstrip antenna, and the most extensively used techniques are to increase the electrical thickness of the structure [4] or multilayer structure by stacking up the patch structure [5]. Other techniques use parasitic element, which is chip-resistor [6], with U-slots in the patch [7], designed with high permittivity ceramic and FR4 stacked structure [8], high-permittivity substrate in stacked structured [9] and multilayer ceramic package integrated microwave antennas in [10].

In order to enhance the bandwidth of antenna design in [2], substrate thickness had been doubled from 1.6mm to 3.2mm for both stacked patches. The advantage of this design approach is that the lateral size is not increased, even though the height of the microstrip antenna is increased. The design of a new patch antenna operating at 2.45GHz and 5.8GHz with circularly polarized with enhanced bandwidth has been presented in this paper. The antenna design, simulation using the CST Microwave Studio® and comparison of simulation and measurement results are fully discussed.

2. Antenna design

Fig. ***1*** shows a coaxial probe-fed dual-band circularly polarized compact microstrip antenna. The microstrip antenna was constructed with two stacked patches, using FR4 substrate of thickness $h1=h2$ = 3.2mm. Each substrate has relative permittivity ε_r = 4.4 and loss tangent, $\tan\delta$ = 0.019. The top patch has side length $W1$ with a pair of $D1 \times D1$ truncated square corners. Also, the bottom patch has side length $W2$ with a pair of $D2 \times D2$ truncated isosceles triangular corners. The cutting corners in the square patches allow the excitation of the two near-degenerate orthogonal modes (TM10 and TM01 modes) along the diagonal of the patch [11].

Input probe position (***F_Y)*** and L1 patch shifted from center point at Y direction (***S1)*** are adjusted for optimum impedance matching. In order to achieve compact design, all four sides of bottom patch are cut with equal dimensions of a semicircular shape with radius (***r***). Additionally, P2_hole and the G_hole are the opening at bottom patch and ground plane respectively for feeding probe to go through. The feed is only connected to the top patch, whereas the bottom patch is excited by the field from top patch. 60mm x 60mm ground plane is used for this design. The S11 performance is very sensitive to P2_hole. When the substrate thickness was increased to 3.2mm, with further optimization on other parameters, the antenna bandwidth is increased significantly while maintaining CP performance at both 2.45 GHz and 5.8 GHz frequencies compared to antenna design in [2].



Parameter	*Value (mm)*	*Parameter*	*Value (mm)*
D1	3.2	gnd_L	30
D2	3.3	h1	3.2
F_Y	3.4	h2	3.2
G_hole	1.675	r	3.5
P2_Hole	1	s1	2.7
W1	12.4		
W2	24.1		

Fig. 1. Geometry of the proposed bandwidth enhanced dual-band circularly polarized Antenna.

3. Analysis of simulation and test result

For Voltage Standing Wave Ratio (VSWR), the measurement and simulation results have been compared. It is glaring from Fig. 2 that the experimental results reasonably agree well with the simulation results. The graph plotted at 2.45GHz has a very good matching between simulation and measurement results; while at 5.8GHz, the simulation result is slightly better than measurement result. This is due to assembly alignment tolerance between the two stacking PCB. It is worth mentioning that the 5.8GHz band is a higher frequency and is more sensitive to manufacturing tolerance.

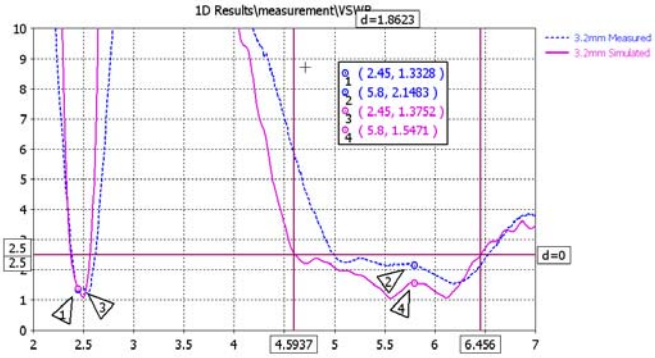


Fig. 2. VSWR comparison, simulation vs. measurement result for design 2.

To demonstrate the bandwidth improvement, the results of using an antenna with 3.2mm substrate thickness is compared to the previously proposed design in [2] with 1.6mm substrate thickness. From simulation results on VSWR at 2.5 limits, doubling antenna's substrate thickness increased the impedance bandwidth from 3.47% to 7.92% for the 2.45 GHz band, and from 6.21% to 32.03% at the 5.8GHz band.

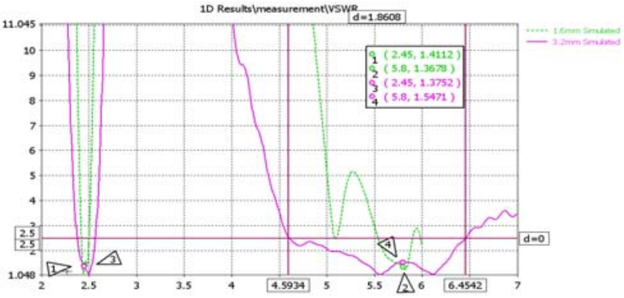


Fig. 3. VSWR comparison, simulation result for design 1 and design 2.

Table 1. VSWR comparison, simulation result for design 1 and design 2.

Design1 with H1=H2 = 1.6mm				Design2 with H1=H2=3.2mm			
Resonance Frequency (GHz)	VSWR	BW (MHz)	BW (%)	Resonance Frequency (GHz)	VSWR	BW (MHz)	BW (%)
2.45	1.411	85	3.47	2.45	1.375	194	7.92
5.80	1.368	360	6.21	5.80	1.547	1858	32.03

Fig. 4 shows the measured results of the VSWR for the proposed dual-band microstrip antenna, (design 2 versus design 1). At 2.5:1, it is clearly shown that the actual measurement of the impedance bandwidth improves significantly. For instance for 2.45GHz, the impedance bandwidth increases from 4.01% to 9.1%; while for 5.8 GHz, it increases from 13.32% to 26.20%.

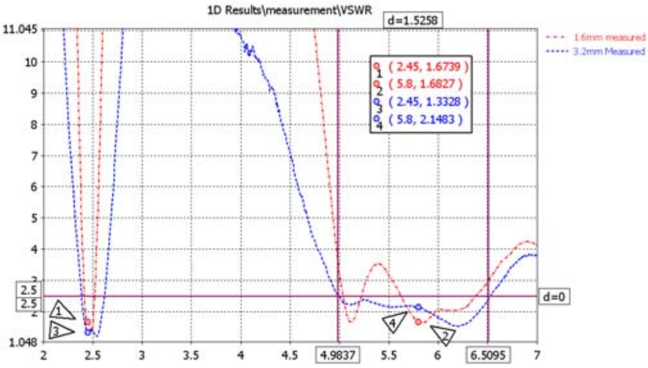


Fig. 4. VSWR comparison, measurement result for design 1 and design 2.

Table 2. VSWR comparison, measurement result for design 1 and design 2.

Design1 with H1=H2 = 1.6mm				Design2 with H1=H2=3.2mm			
Resonance Frequency (GHz)	VSWR	BW (MHz)	BW (%)	Resonance Frequency (GHz)	VSWR	BW (MHz)	BW (%)
2.45	1.673	102	4.01	2.45	1.332	223	9.10
5.80	1.6827	773	13.32	5.80	2.148	1520	26.20

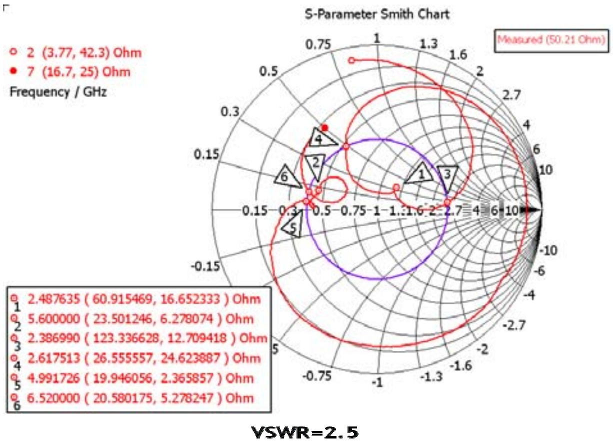


Fig. 5. Measured Smith Chart

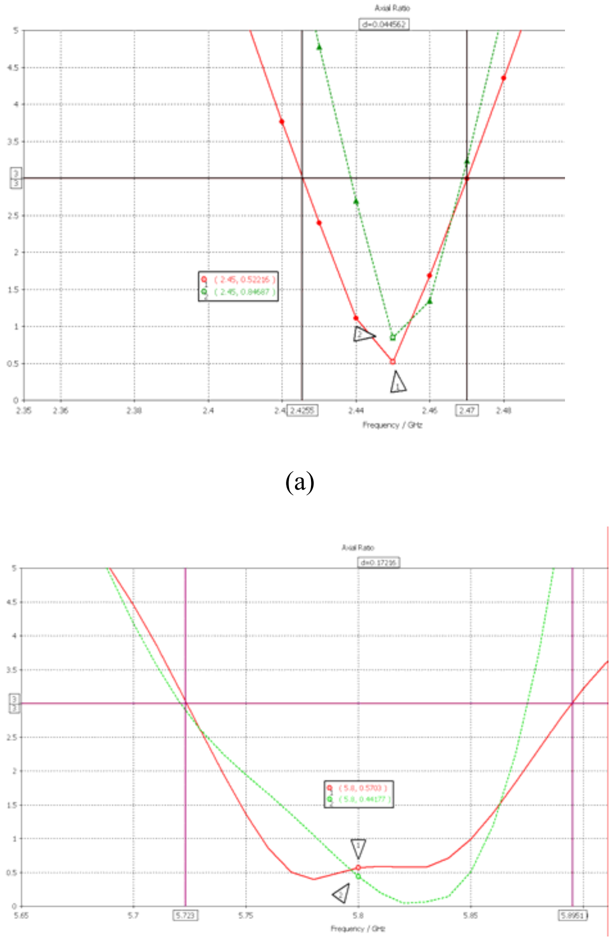
From the measured Smith Chart in Fig. 5, a dip at 2.487 GHz indicates that there are two resonant modes excited at very close frequencies, which is very close to the proposed design frequency (2.45GHz). This suggests that the fundamental TM10 mode in the present design is split into two near-degenerate resonant modes, which can be excited with equal amplitudes and a 90◦ phase difference, resulting in CP radiation. Note that if the two modes are excited at frequencies far apart, a loop will be observed instead of a dip, and if only one resonant mode is excited, there will be no dip in the chart [12]. For L2, there is also a dip at 5.6 GHz and a 3.4% shift from 5.8GHz. As 5.8GHz is more sensitive being the higher frequency, the shift might be caused by actual assembly alignment between the 2 stacking PCBs.

The axial ratio (AR) bandwidth is narrower than the impedance bandwidth, which is usual for microstrip antennas. The simulated AR in the broadside direction is presented in Fig. 6. The CP bandwidth of 3dB axial ratio for the L1 band has been improved from 30 MHz (or 1.22%) to 45 MHz (or 1.842%) at 2.45 GHz. Similarly for L2 band, the bandwidth has been improved from 155 MHz (or 2.67%) to 172 MHz (or 2.97%) at 5.8GHz. It can be observed that the improvement for 2.45GHz AR is more significant.

For gain and radiation pattern, only design 2 simulation results are shared.

Fig. 7 shows the gain for each frequency of interest. Based on the simulation results, the gains are 5.93dB and 4.91dB at 2.45 GHz and 5.8GHz, respectively. As can be noticed, the non-symmetrical effect could be due to the mutual coupling between the two simultaneously radiating elements (2.45GHz and 5.8GHz). Furthermore, the center point of the 5.8GHz element is not aligned at the centre of the 2.45GHz element as shown in antenna geometry view in Fig. 1.

Simulated radiation pattern in Fig. 8 clearly shows that the antenna operates with right hand circular polarization for both 2.45GHz and 5.8GHz. At 2.45GHz, the right hand CP (RHCP) main lobe has a magnitude of 5.9dB, which is 28dB higher than left hand CP (LHCP). At 5.8GHz, on the other hand, the RHCP main lobe has magnitude of -1.1dB, which is 22 dB higher than LHCP.



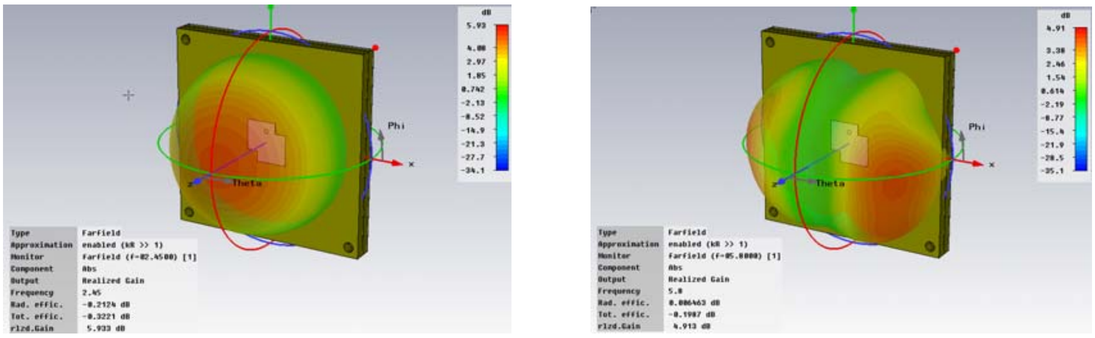
(a)

(b)

Fig. 6. (a) Simulated Axial Ratio at L1, (b) Simulated Axial Ratio at L2.

Table 3. AR comparison, simulation result for design 1 and design 2.

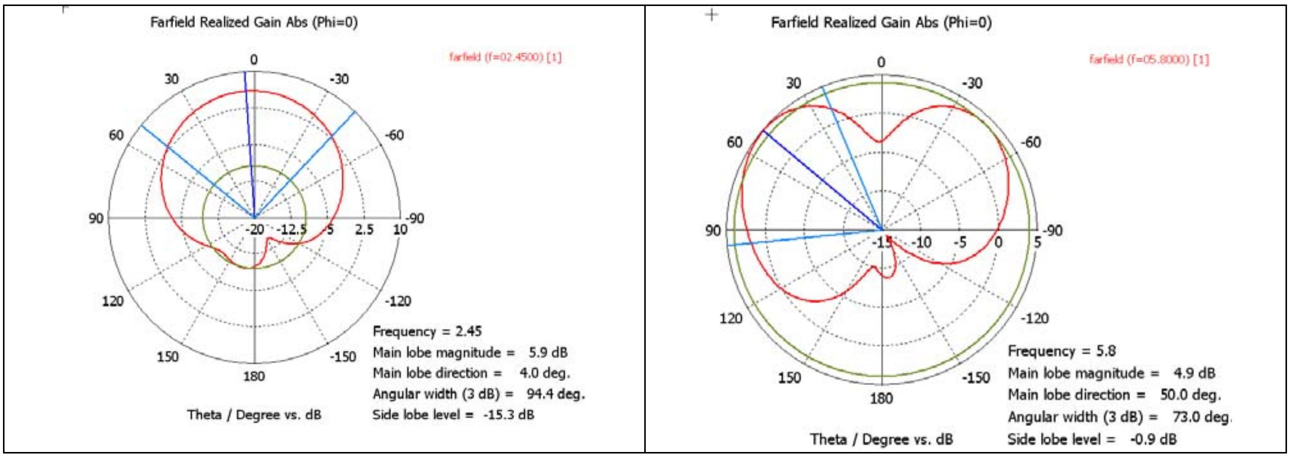
Design1 with H1=H2 = 1.6mm				Design2 with H1=H2=3.2mm			
Resonance Frequency (GHz)	AR (dB)	BW (MHz)	BW (%)	Resonance Frequency (GHz)	AR (dB)	BW (MHz)	BW (%)
2.45	0.85	30	1.22	2.45	0.44	45	1.84
5.80	0.44	155	2.67	5.80	0.57	172	2.97



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=02.4500) [1]
Component Abs
Output Realized Gain
Frequency 2.45
Rad. effic. -0.2124 dB
Tot. effic. -0.3221 dB
rlzd.Gain 5.933 dB

Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=05.8000) [1]
Component Abs
Output Realized Gain
Frequency 5.8
Rad. effic. 0.006463 dB
Tot. effic. -0.1987 dB
rlzd.Gain 4.913 dB

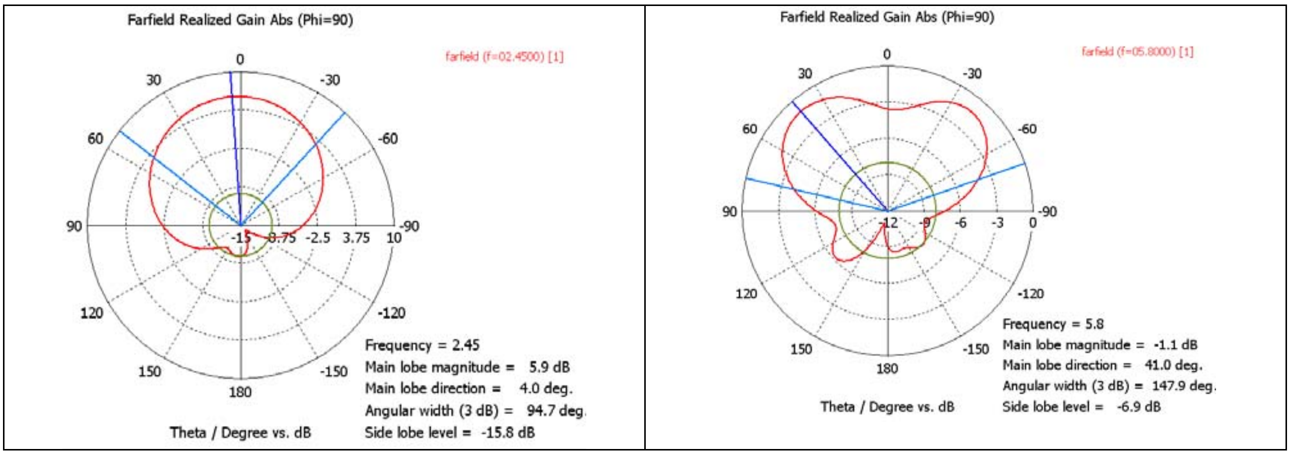
(a) 2.45 GHz 3D radiated pattern (b) 5.8 GHz 3D radiated pattern



Frequency = 2.45
Main lobe magnitude = 5.9 dB
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 94.4 deg.
Side lobe level = -15.3 dB

Frequency = 5.8
Main lobe magnitude = 4.9 dB
Main lobe direction = 50.0 deg.
Angular width (3 dB) = 73.0 deg.
Side lobe level = -0.9 dB

(c) 2.45 GHz Phi=0, x-z plane (d) 5.8 GHz Phi=0, x-z plane



Frequency = 2.45
Main lobe magnitude = 5.9 dB
Main lobe direction = 4.0 deg.
Angular width (3 dB) = 94.7 deg.
Side lobe level = -15.8 dB

Frequency = 5.8
Main lobe magnitude = -1.1 dB
Main lobe direction = 41.0 deg.
Angular width (3 dB) = 147.9 deg.
Side lobe level = -6.9 dB

(e) 2.45 GHz Phi=90, y-z plane (f) 5.8 GHz Phi=90, y-z plane

Fig. 7. (a)-(f) Radiation pattern with Realized gain.

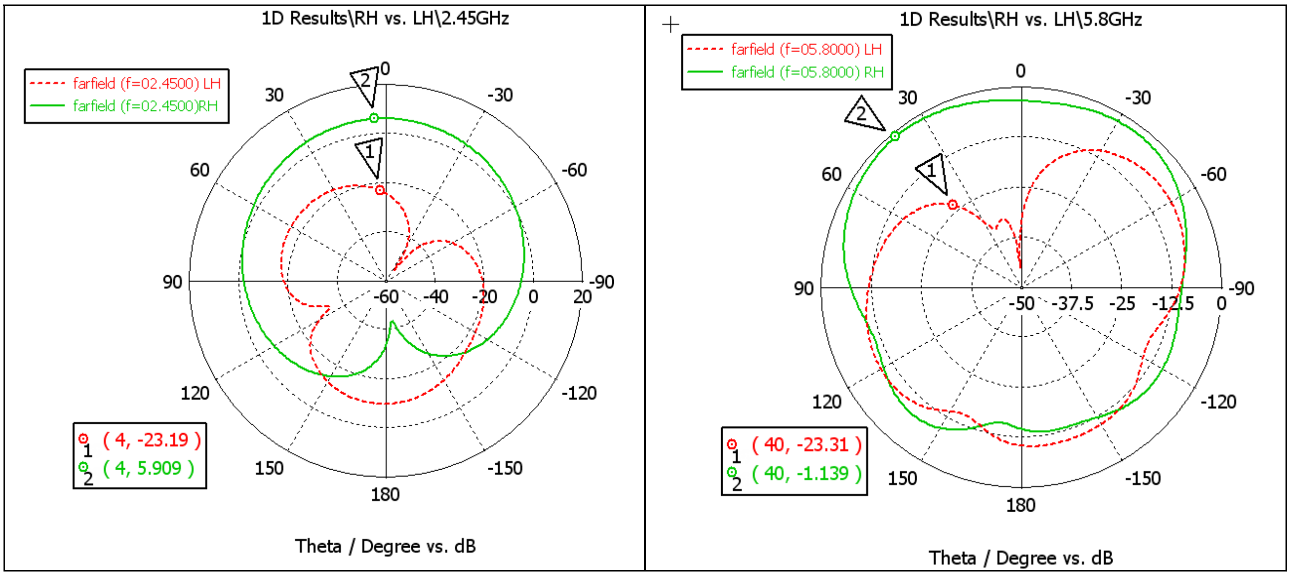


Fig. 8. Simulated RHCP versus LHCP radiation pattern.

4. Conclusions

An enhanced bandwidth circularly polarized antenna structure has been presented in this paper. The proposed antenna operates at dual band frequencies (2.45GHz and 5.8GHz), and can be used for ISM applications. Both the simulation and the measured results show reasonable agreement. In the proposed design, the achieved impedance bandwidth of the prototype antenna is measured at 13.3% and 26.2%. This dual band CP microstrip antenna with compact design has achieved the design objectives of improving bandwidth at VSWR of 2.5:1 and axial ratio (AR) bandwidth of <3dB for both 2.45GHz and 5.8GHz frequencies. In addition to the achieved dual-band characteristics and circular polarization, the proposed antenna design also has wider band characteristics, thereby enabling wider applications.

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