Design of Stacked Microstrip Dual-band Circular Polarized Antenna

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Abstract. *This study introduces a new design of dual-band circular polarized (CP) microstrip antenna for ISM band applications (2.45 GHz and 5.8 GHz). The proposed dual-band CP microstrip antenna with compact design has achieved design intention of having return loss of < −10 dB and axial ratio of < 3 dB for both frequencies of 2.45 GHz and 5.8 GHz. The antenna has been successfully designed, fabricated, simulated, and measured and it shows the advantages of good dual-band and CP performances. Thus, the obtained results confirm satisfactory performance and good agreement.*

Keywords

Microstrip antenna, patch antenna, circular polarized.

1. Introduction

Recently, the applications of wireless local area network (WLAN) and wireless personal area network (WPAN) have received much attention. Mobile communication terminal, such as antenna for WPAN and WLAN is required to be as small as possible in dual frequency band. Microstrip is the best candidate as it can provide favorable features, such as low weight, flat profile, and low cost of production as well as useful radiation characteristic. Circular polarized (CP) antenna [1] on the other hand can reduce the loss caused by misalignment between the signal and the receiving antenna. The CP wave obtained two degenerated orthogonal modes with different resonant frequencies and there is a phase difference of 90° between two orthogonal modes.

The CP antennas are classified as a single feed type or dual feeds type depending on the number of feed point necessary to generate the CP waves. Circularly polarization is achieved by feeding the octagonal signal to radiating edge and non-radiating edge on the antenna patch. The dual feeds method has a complex result in larger geometry [2]. Thus, a single feed CP structure, which has a small occupied volume; less complexity, is desired in situation, where it is difficult to place the dual orthogonal feed. In addition, the single feed also does not require an external polarizer [3].

A dual-band CP antenna using single layer patch has been reported in [4], [5]. In [4], an antenna consists of a circular patch and a narrow annular ring is designed. This antenna achieves its CP operation by an equal cross slot embedded on the circular patch. The design of antenna in [5] consists of a small circular patch surrounded by two concentric annular rings. However, both designs are only suitable for the small frequency ratio application. For the application of ISM band, larger frequency ratio is required. Thus, stacked patches are preferred [6]-[8].

In [6], the lower patch is excited with a coaxial line producing a wideband input impedance and axial ratio at a center frequency of 5.9 GHz. However, the applications discussed in this paper involve a dual-band circularly polarized patch antenna with frequency ratio of about 2.37. A stacked microstrip antenna for dual-band CP antenna that is covering two GPS bands has been introduced in [7] with frequency ratio of 1.28 (L1-1.58 GHz and L2-1.23 GHz). The stacked structure also has an advantage of flexibility by tuning certain parameters in order to get better performance as each frequency is excited by the separate patch [9]. A truncated corner at the edges of patch and embedding a cross and unequal length of slots on triangular patch have been an established technique to obtain a compact CP antenna [9], [10]. However, a stacked technique is seldom used in designing a CP antenna [11].

A dual frequency microstrip antenna with CP capabilities has been also introduced in [12] by stacking two different corner-truncated square patches on the dielectric layer. In [13], another dual-band CP antenna has been obtained with the implementation of 3-layer stacked antenna and a QUAD-EMC structure. The gain of the antenna is enhanced due to introduction of the air behind the substrate. Meanwhile, a wideband CP antenna has been designed in [14] with the combination of stacked antenna approach and slotted annular ring.

In this paper, a CP antenna is introduced, which is the combination of stacked technique with a truncated edge method for both high and low frequency patches. Moreover, by adding semi-groove on the patch, the return loss and bandwidth have been improved in this study. Design details of the antenna together with the measured and the simulated results are provided in Sections 2 and 3, respectively. Finally, a conclusion is presented in Section 4.

2. Antenna Design

Fig. 1(a) shows the geometry of a probe-fed compact dual-band CP patch antenna with two stacked patches. In general, an approximate original value for radius of circular patch is given by equations (1) and (2) as follows [15], [16]:

$$f_r = \frac{1.841 \times c}{2\pi r_{eff}\sqrt{\varepsilon_r}}, \tag{1}$$

$$r_{eff} = a\sqrt{\left(1 + \left[\frac{2h}{\pi a \varepsilon_r}\right]\left\{\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right\}\right)} \tag{2}$$

where f_r is the resonant frequency, c is the velocity of light, r_{eff} is the effective radius, ε_r is the effective dielectric constant, a is the actual radius, and h is the dielectric height.

The top patch (L1) is used as a resonant radiator for 5.8 GHz and the bottom patch (L2) is for 2.45 GHz. The antenna consists of two dielectric substrates FR4 with equal thickness of h1 = h2 = 1.6 mm, relative permittivity ε_r = 4.4, and loss tangent tanδ = 0.019. Both top and bottom patches with radius R1 and R2 have been modified by truncating patch from two sides (parallel to X-axis). The thickness of applied truncated part is denoted as Da and Db. A 50 Ω SMA coaxial probe is used as a feeding structure, mounted at coordinates (X,Y) that laying on the line, making an angle of 45 degree from X-axis and Y-axis. The location of the feed on this line is optimized to get an optimum impedance matching. The lower patch also has been moved as shown by Xa and Ya to provide more flexibility for impedance matching. There are multiple resonant frequencies radiated by each circular patch. Hence, grooves with semi-circular of equal dimensions with radius of Ra and Rb are cut at two sides of both top and bottom patches. As a result, the return loss (S11) is more concentrated. Two important parameters that need to be taken care of are Hp_hole and Hg_hole as shown in Fig. 1(a). The feed is connected to the top patch only and the bottom patch is excited by the field from the top patch. It is found that the performance of S_{11} is very sensitive to Hp_hole. The fabricated CP antenna from an optimized design of simulation is shown in Figs. 1(b)-1(e).

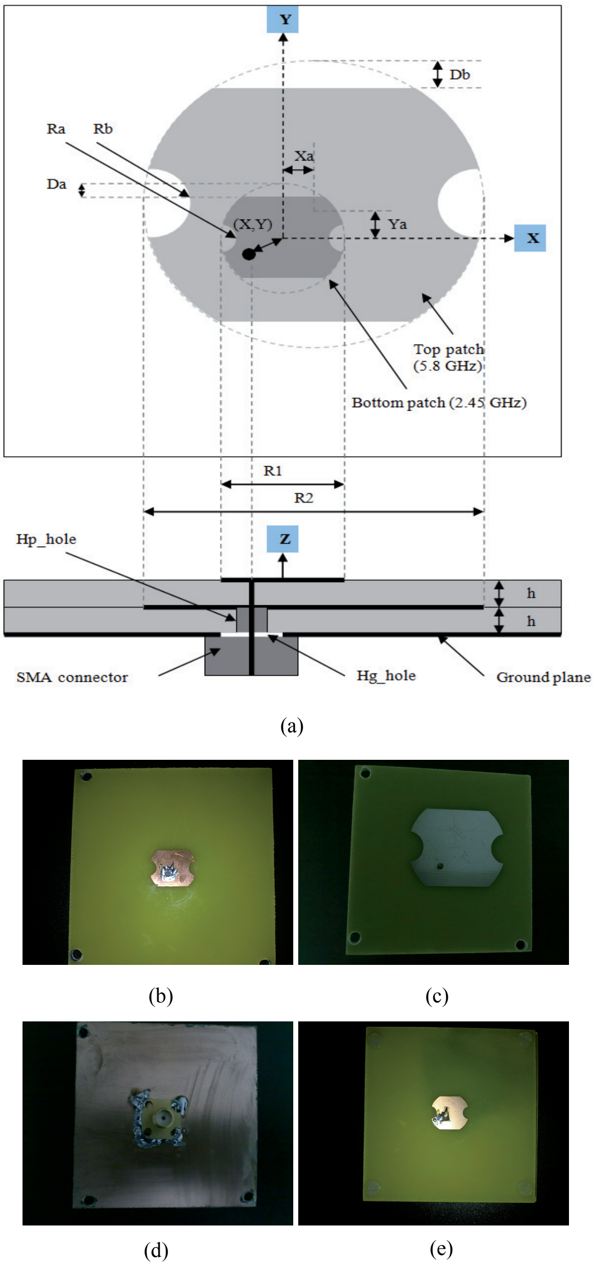


Fig. 1. (a) Overall antenna structure, (b) top patch (L1), (c) bottom patch (L2), (d) ground plane, (e) layout.

Ideally, the ground plane should be infinite as for a monopole antenna. However, in reality, a small ground plane is desirable as small size is the main benefit of a patch antenna. The radiation of a microstrip antenna is generated by fringing field between the patch and the 60 mm × 60 mm of ground plane. The parameters Da and Db are the cutting edges in the circular patch. Those cutting edges allow the excitation of the two near-degenerated orthogonal modes (TM11 modes) along the diagonal of the patch [17]. This has resulted circular polarization, where the axial ratio is less than 3 dB. The grooves with semi-circle of equal dimensions with radius of Ra and Rb are cut at two sides of both higher and lower band patches. It helps to improve the results of S11 and axial ratio. Based on the parametric study, the optimal data for the proposed antenna is given in Tab. 1.

Parameter	Value (mm)	Parameter	Value (mm)
R1	6.8	X,Y	1.3,1.3
R2	16.4	Xa,Ya	3.9,3.9
Da	1	Hp_hole	1
Db	3.8	Hg_hole	1.675
Ra	2.2	h	1.6
Rb	5		

Tab. 1. Optimized design parameters.

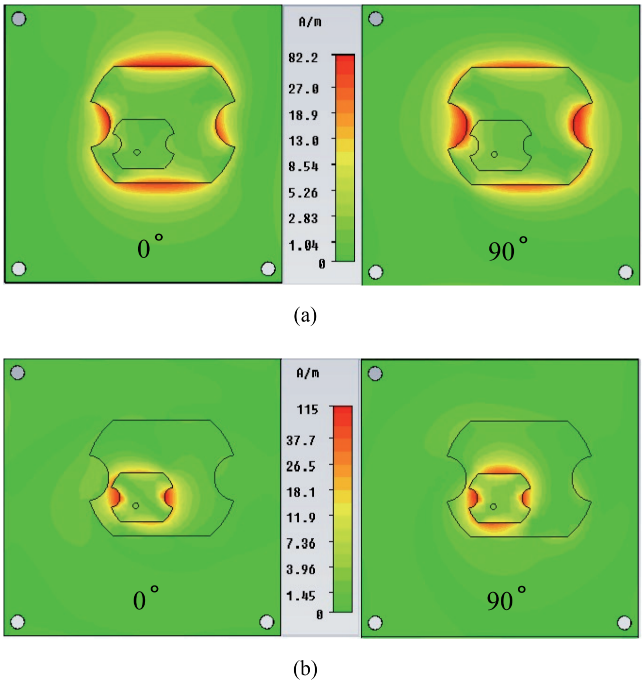


Fig. 2. Surface current distribution at (a) 2.45 GHz, (b) 5.8 GHz.

Figs. 2(a) and 2(b) show the simulated current distribution of the designed antenna. Apparently, the current is mostly distributed at the bottom patch for 2.45 GHz and then distributed at the top patch for 5.8 GHz. The surface currents at both patches are distributed more on the grooves of respective patch during the 0º phase and then shifted along the edge of the patch as the phase increases. The truncated parts of the patches are essential in order to ensure the surface currents are rotating along the edge of the patch. The surface current movements illustrate that this antenna is a circular polarized antenna.

3. Results and Discussion

Tab. 2 shows the measured and the simulated results of return loss for the proposed dual-band microstrip antenna. Apparently, the experimental result is in good agreement with the simulated result obtained from the CST Microwave Studio. By choosing the proper shifting point of lower patch (Xa,Ya) and feed position (X,Y), the proposed single feed antenna can be excited with good impedance matching at both frequencies of 2.45 GHz and 5.8 GHz. From the simulation results as presented in Tab. 2, the obtained impedance bandwidths of -10 dB return loss for L1 and L2 bands are 130 MHz (5.27%) and 550 MHz (9.36%), respectively. On the other hand, from the measurement results in Tab. 2, the obtained impedance bandwidths of -10 dB return loss for L1 and L2 bands are 120 MHz (4.78%) and 600 MHz (9.67%), respectively. These results are coherent with the results of return loss from antenna design in [4], [5], [9], [10], [12]-[14], where the impedance bandwidths are narrow.

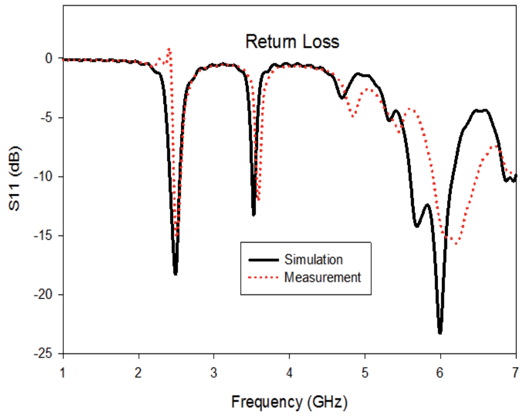
Lower Frequency (L1=2.45 GHz)			
Simulation (GHz)		Measurement (GHz)	
FL	FH	FL	FH
2.40	2.53	2.45	2.57
Return Loss (dB)		Return Loss (dB)	
-10	-10	-10	-10
BW	130 MHz	BW	120 MHz
%BW	5.27%	%BW	4.78%
Higher Frequency (L2=5.8 GHz)			
Simulation (GHz)		Measurement (GHz)	
FL	FH	FL	FH
5.6	6.15	5.9	6.5
Return Loss (dB)		Return Loss (dB)	
-10	-10	-10	-10
BW	550 MHz	BW	600 MHz
%BW	9.36%	%BW	9.67%

Tab. 2. Measurement and simulated data of S11 for low frequency and high frequency (FL and FH) bands.

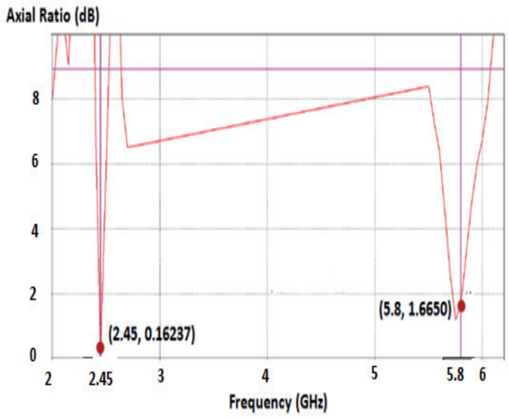
It is found that higher resonant frequency has a broaden bandwidth (BW); however, the measured result is shifted about 300 MHz from the simulated result. It can be said that there is a small difference between the measured and the simulated return loss as shown in Fig. 3(a). It is made compulsory that the axial ratio at each of the radiated frequency should be less than 3 dB in order to ensure the realization capability of circularly polarized antenna. It is found that axial ratios of 0.16237 dB and 1.6650 dB have been achieved by the proposed CP antenna at frequencies of 2.45 GHz and 5.8 GHz, respectively.

The axial ratio bandwidth is narrower than the impedance bandwidth as this is usual for microstrip antenna. The simulated axial ratio in the broadside direction is presented in Fig. 3(b). The obtained CP bandwidths of 3 dB axial ratio for 2.45 GHz and 5.8 GHz bands are 43.2 MHz (or 1.76%) and 155 MHz (or 2.67%), respectively.

Figs. 4(a) and 4(b) show the simulated CP radiation pattern for the proposed antenna at 2.45 GHz and 5.8 GHz, respectively. The proposed antenna is shown to generate left hand circular polarization (LHCP) and right hand circular polarization (RHCP) at both frequencies. The maximum directivity gain is 6.4 dBi at 2.45 GHz and 5.9 dBi at 5.8 GHz. The cross-polar gain is observed to be approximately less than -20 dB compared to the co-polar gain. The 3D simulation results of radiation pattern at 2.45 GHz and 5.8 GHz are shown in Figs. 5(a) and 5(b). The simulated maximum realized gain across the desired frequency is shown in Fig. 5(c). Based on the simulated result, the gains are 2.84 dB and 4.32 dB at 2.45 GHz and 5.8 GHz, respectively. The gain of the antenna is higher than a single FR4 substrate antenna since the two stack-up substrates will effectively double the substrate thickness and thus improving the gain.

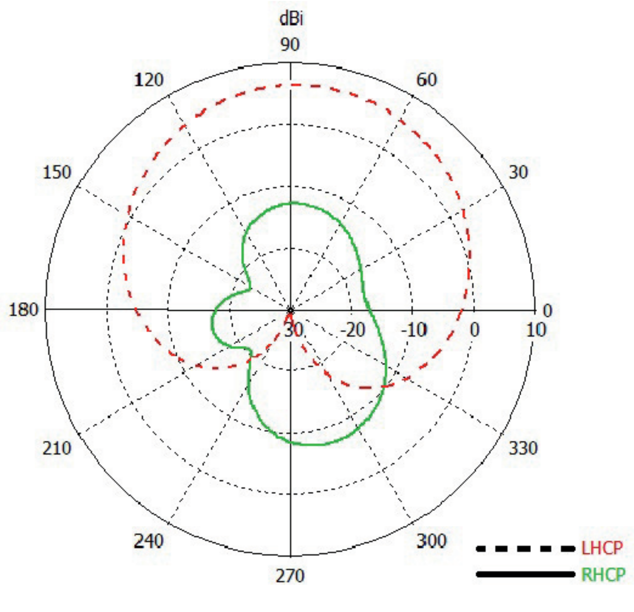


(a)

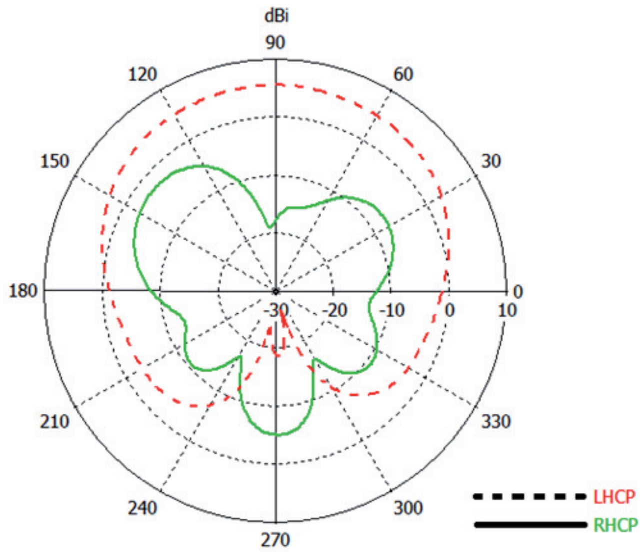


(b)

Fig. 3. (a) Measurement and simulated graph of S11. (b) Simulated axial ratio at 2.45 GHz and 5.8 GHz.

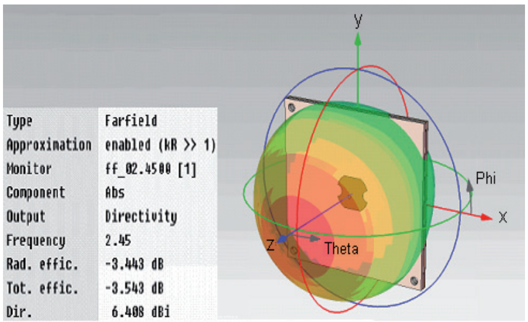


(a)

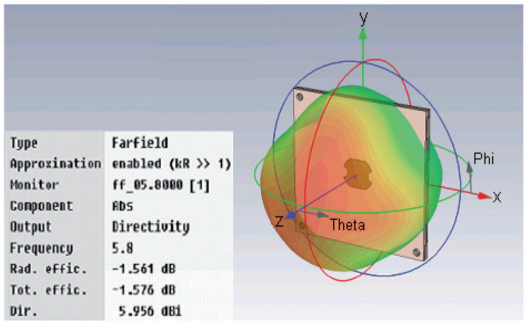


(b)

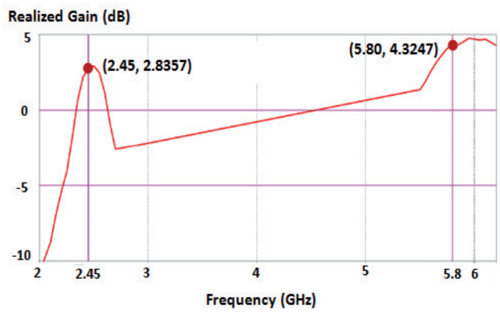
Fig. 4. (a) CP radiation pattern at 2.45 GHz. (b) CP radiation pattern at 5.8 GHz.



(a)



(b)



(c)

Fig. 5. (a) 3D radiation pattern at 2.45 GHz. (b) 3D radiation pattern at 5.8 GHz. (c) Simulated broadband realized gain across frequency (dB).

4. Conclusion

A new design of stacked microstrip dual-band antenna with CP is presented in this paper that operates at dual ISM bands of 2.45 GHz and 5.8 GHz. The proposed CP antenna with dual-band capability has been realized by combining the stacked configuration with a truncated edge technique at its top and lower patch. Both edges of geometry (parallel to X-axis) are truncated and the antenna is fed at an angle between X-axis and Y-axis of circular patch. The semi-groove structure located at other side of both patches empowered the antenna return loss and bandwidth (especially, for 5.8 GHz, it has a broaden bandwidth for the simulated and the measured results). The obtained simulation and measurement results show good agreement in terms of return loss. The proposed antenna is obviously proficiently functioning as CP antenna since it produces axial ratio of less than 3 dB; that is, axial ratios of 0.16237 dB and 1.6650 dB have been achieved with 43.2 MHz (1.76%) and 155 MHz (2.67%), respectively at both the desired frequencies. The two stacked patches also contribute to the significant reduction in size of the proposed CP antenna compared to the conventional antenna that could yield the same antenna gain, which are 2.84 dB and 4.32 dB, respectively. The designed antenna can be proposed for WLAN applications, which use the unlicensed ISM band center frequencies at 2.45 GHz and 5.8 GHz.

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