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A DUAL-BAND CPW-FED L-SLOT ANTENNA WITH BOTH LINEAR AND CIRCULAR POLARIZATIONS

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Abstract—A design procedure for a dual-band CPW-fed linearly and circularly polarized (CP) antenna based on the L-shaped slot antenna is presented in this paper. The slot antenna and the feeding structure are fabricated on the same plane of the substrate so that circuit processes and position alignment can be simplified. By shortening the length of one arm of the L-slot, an additional mode with two orthogonal electrical fields with a phase difference of 90 degree is excited, so that the circularly polarized wave can also be excited. The enhancement of the resonant bandwidth is achieved by utilizing a stub-protruded feedline, adding one finger slit at the other arm slot, and tuning the dimension of the ground plane. A bandwidth of 22.0% (2.23–2.78 GHz) is achieved with an axial ratio < 3 dB for the optimized case.

1. INTRODUCTION

The rapid increase in demand for telecommunications capabilities in recent years has produced a rapid growth in the number of mobile systems, such as DCS, IMT-2000, SDAR, WLANs, LTE and Hiper-LAN with the operating bands of these technologies distributed at 1.8 GHz, 2.1 GHz, 2.4 GHz, 2.6 GHz, 5.2 GHz and 5.8 GHz, respectively. The CPW-fed circular or rectangular slot antenna with circular polarization has been widely used in practical designs [1–13]. Various techniques for improving the circular polarization bandwidth have been proposed, such as by embedding an arc slot beside the spiral slots, varying the turn number of the spiral slots, and changing the separation between the arc slot and the spiral slots [14]. The L-shaped wide slot

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antenna with a fork-like feeding structure can possess wide bandwidth characteristics [15]. By using an inverted-L feedline and truncating one corner of the ground plane, the L-slot antenna can excite the CP wave [16].

In this paper, a dual-band CPW-fed L-shaped slot antenna with both linear and circular polarizations is demonstrated. The CP radiation is produced by properly adjusting the two unequal side lengths of the L-slot. Good impedance matching is effectively realized with a stub-protruded feeding structure. Furthermore, by etching a finger slit at the terminal of the long arm and varying the geometrical dimension of the ground plane, enhancement of the impedance bandwidth is also achieved.

2. ANTENNA DESIGN

Figure 1 shows the schematic configuration of the proposed CPW-fed L-slot antenna operated at 1.8 GHz, 2.1 GHz, 2.4 GHz, 2.6 GHz, 5.2 GHz and 5.8 GHz. The design parameters of the proposed antenna are listed in Table 1. The proposed antennas are fabricated on a

Table 1. The design parameters of the proposed antenna.

Parameter	G_x	G_y	G_{xl}	G_{xr}	G_{yu}	G_{yd}	G_l
(mm)	66	66	22	3	17	22	16.15
Parameter	G_r	L_1	L_2	W	W_f	g	L_{f1}
(mm)	16.15	13	27	14	4	0.35	15
Parameter	L_{f2}	L_s	W_s	d	W_t	L_t	
(mm)	6	11	10	0.412	3	2	

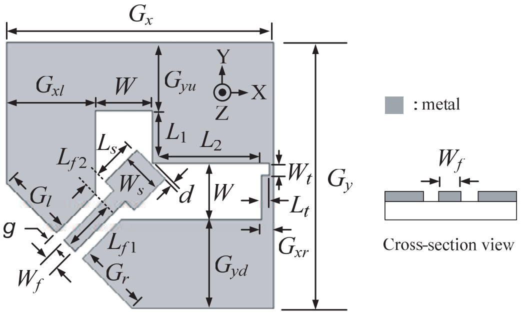


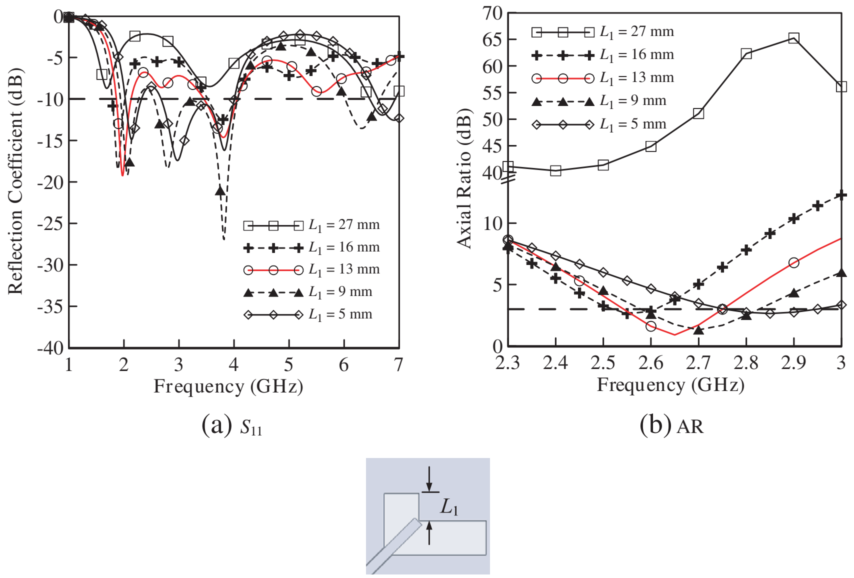
Figure 1. Schematic diagram of the proposed CPW-fed L-slot antenna.

0.8 mm-thick FR-4 substrate having a dielectric constant of $\varepsilon_r = 4.4$ and $\tan\delta$ of 0.0245, and a ground plane size of 66 mm × 66 mm. The proposed antenna is composite of a coplanar-waveguide feedline, a modified L-slot, a protruded stub, and a finger slit connecting to the long arm of the L-slot. The total length $(L_1 + L_2 + 2W)$ of the prototype of the L-slot with equal side lengths is chosen as $0.49\,\lambda$g, where λg is the wavelength in slotline at 1.7 GHz. A 50-Ω microstrip-fed line with a width ($W_f = 4$ mm) is used to excite the antenna. At the end of the feeding line, the protruded stub is applied to form an internal capacitance, which modulates the coupling electromagnetic fields between the feeding and the ground plane. The capacitance could cancel part of the high reactance of the slot antenna, which results from the narrow feedline and wide slot, so the input impedance within the operated band is located inside the circle of VSWR = 2 in the Smith Chart. After decreasing the length (namely L_1) of the vertical arm of the L-slot, two orthogonal modes with a phase difference of 90 degree can be excited so that the circular polarization can be excited around 2.5 GHz. In addition, in order to increase the total length $(L_1 + L_2 + 2W)$ of the radiator, a finger slit is etched at the terminal of the horizontal (long) arm of the modified L-slot, such that the lower resonant frequency can be shifted down. Impedance matching is also optimized by cutting the copper ground plane. The dimensions of the ground plane are experimentally varied to have an improvement of the frequency-response characteristics. Details of the design procedure for the proposed slot antenna are described.

3. RESULTS AND DISCUSSION

Figures 2(a) and (b) describe the effects of shortening the length (L_1) of the vertical arm (slot) of the L-slot on the simulated reflection coefficients (S_{11}) and axial ratios (AR). The simulation study of the antennas was performed using Ansoft HFSS version 11.0.

It is noted that the length (G_{yu}) of the upper part of the ground plane simultaneously increases when L_1 decreases. For the symmetrical radiator without the arm change ($L_1 = L_2 = 27$ mm), the three resonant modes of the antenna prototype are excited at 1.69, 3.56 and 6.70 GHz, respectively. With the vertical-arm reduction, an additional mode is excited around 2.68 GHz. The impedance characteristics are not only improved, but this technique also has a significantly beneficial effect on antenna's CP radiation. When the length of L_1 decreases, the first, second and fourth resonances, approximately at 2.0, 3.0 and 6.0 GHz, increase, resulting in a higher AR frequency. For the three cases of $L_1 = 5$, 16, and 27 mm, the CP radiation is poor. Although



(c) Tuning Parameter (L_1)

Figure 2. The effect of shortening the length (L_1) of the vertical arm of the L-slot on the simulated S_{11} and AR.

the CP performance is also good for the case of $L_1 = 9$ mm, the lower resonant frequency is higher than 1.9 GHz. In order to attain the impedance performance at the 1.8-GHz band and the AR frequency at 2.6 GHz, L_1 is set at 13 mm.

Figures 3(a)–(c) show the distribution of the simulated magnetic fields of the antenna prototype ($L_1 = L_2 = 27$ mm) at 1.69, 3.56, and 6.70 GHz. It is observed that the resonances at 1.69 and 3.56 GHz are the fundamental modes whose lengths are about half a wavelength long. The resonance at 6.70 GHz is the first harmonic mode of the outer sides of the L-slot. Fig. 3(d) is the distribution of the simulated electric fields on the ground plane of the modified L-slot for the case of $L_1 = 13$ mm at two orthogonal modes, the vertical and horizontal modes. The superposition of the two orthogonal resonant modes can eventually generate a good circularly polarized wave in the broadside direction.

The simulated S_{11} and AR results of the modified L-slot antenna at the different widths (W_s) of the protruded stub at the feedline are plotted in Fig. 4. Increasing W_s from 4 mm to 13 mm results in a good impedance matching condition at the lower operated band in addition to decreasing the center frequency of the 3-dB AR band. Because of

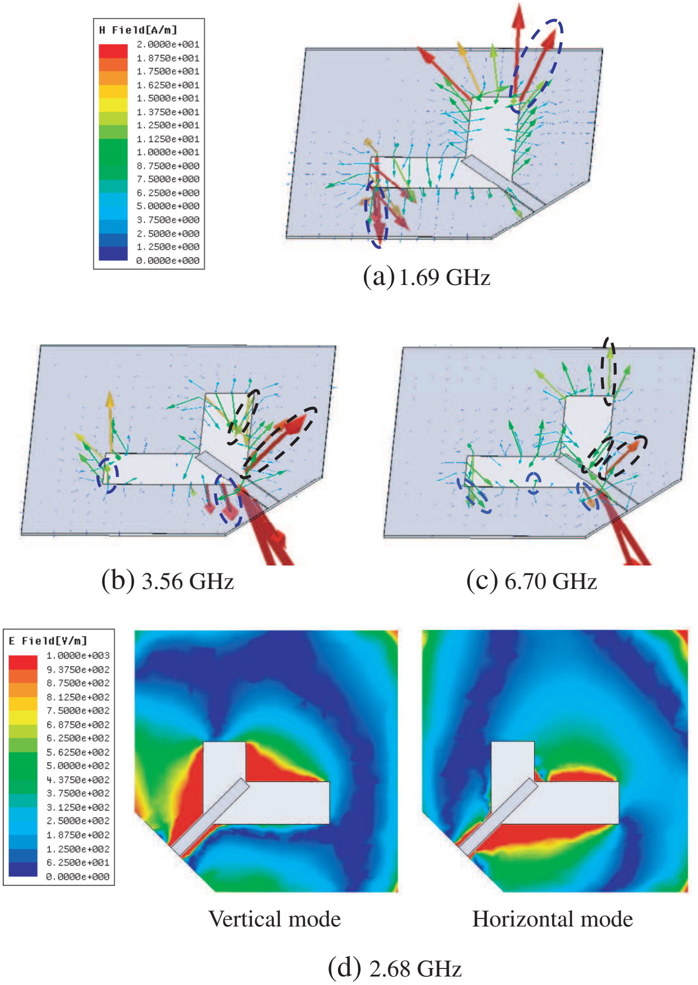
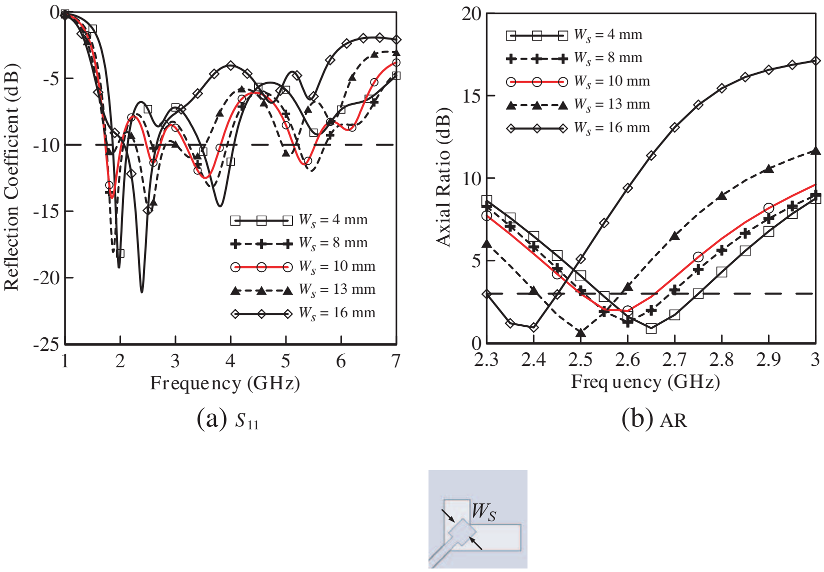


Figure 3. (a)–(c) The distribution of the simulated magnetic filed of the antenna prototype ($L_1 = L_2 = 27\,\text{mm}$), and (d) the distribution of the simulated electric filed of the modified L-slot at the two orthogonal modes ($L_1 = 13\,\text{mm}$).

the consideration of the initial resonant frequency of the lower operated band and the AR band at 2.6 GHz, W_s is 10 mm, and thus the initial resonant frequency is 1.74 GHz.

As shown in Fig. 3(a), the initial resonant frequency of the lower band is controlled by the arm length of the L-slot. The effects of embedding the finger slit in the terminal of the horizontal arm of the



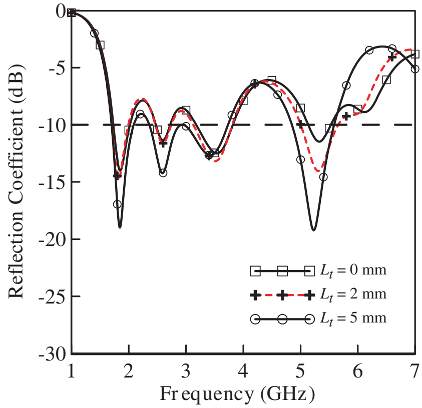
(a) S_{11} (b) AR

(c) Tuning Parameter (W_s)

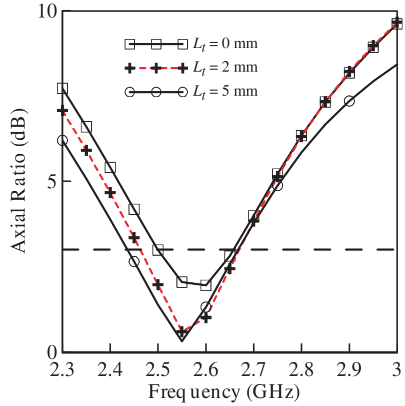
Figure 4. The simulated S_{11} and AR results of the modified L-slot antenna at the different width (W_s) of the protruded stub at the feedline.

modified L-slot on S_{11} and AR are shown in Fig. 5. For the case of $L_t = 2$ mm, the initial resonant frequency shifts from 1.74 GHz to 1.71 GHz when the cutoff frequency is slightly changed at 3.80 GHz. The AR variation of the antenna is slight when embedding the slit. On the other hand, for the case of $L_t = 5$ mm, the initial resonant frequency is also 1.71 GHz, however, the cutoff frequency moves down to 3.73 GHz and the upper operated band (4.85–5.58 GHz) is lower than the 5-GHz band requirement (5.15–5.85 GHz) of WLANs.

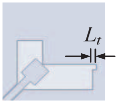
Figures 6(a) and (b) show the comparison of simulated and measured results of the reflection coefficient and axial ratio for the modified L-slot antenna with the protruded stub and finger slit. From the comparison of the simulated and results for the modified L-slot antenna with the feeding stub and slit, because the initial resonant frequencies of the first and second bands shift up and the cutoff resonant frequency of the third band decreases, the measured impedance bandwidths of the lower bands are narrower than those of the simulated bandwidths. Meanwhile, the measured AR band shifts down.



(a) S_{11}

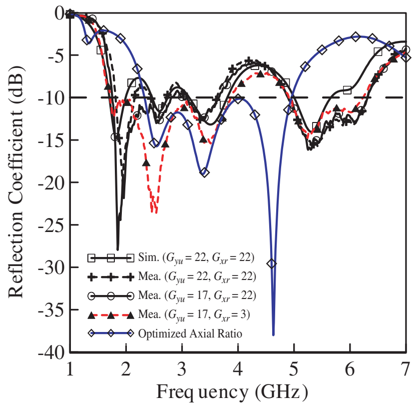


(b) AR

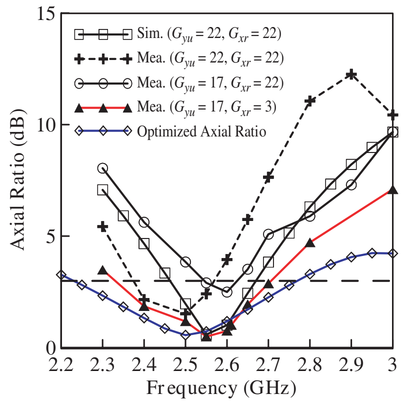


(c) Tuning Parameter (L_t)

Figure 5. The simulated S_{11} and AR results of embedding the finger slit in the terminal of the horizontal arm of the modified L-slot.



(a) S_{11}



(b)AR

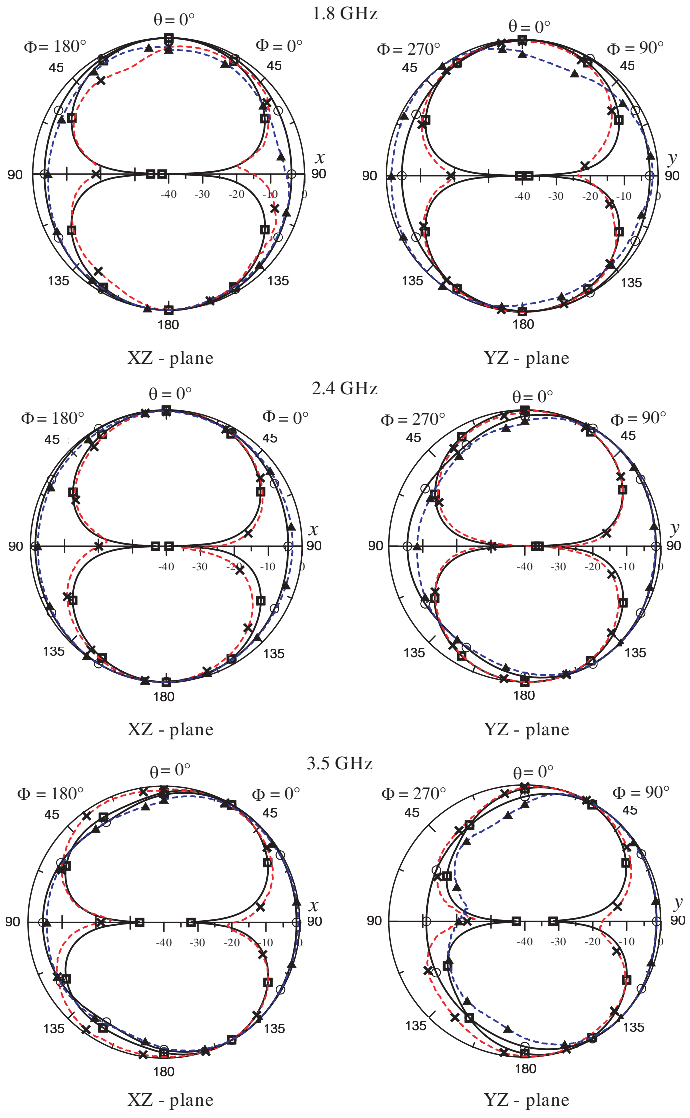
Figure 6. Comparison of the simulated and measured results of S_{11} and AR for the modified L-slot antenna with the protruded stub and finger slit.

To enhance the impedance matching characteristics, following the method reported in Wang and Chen (2009) [17], the dimensions of the ground plane are tuned by optimizing the impedance characteristics. The measured S_{11} and AR results for two cases of ($G_{yu} = 17\,\text{mm}$, $G_{xr} = 22\,\text{mm}$) and ($G_{yu} = 17\,\text{mm}$, $G_{xr} = 3\,\text{mm}$) are also shown in Fig. 6. The initial resonant frequency of the first band could shift down by decreasing G_{yu} and G_{xr}. By decreasing G_{yu}, the bandwidth of the first band increases. By reducing G_{xr}, the bandwidth of the third band is improved, so that the first three bands can be merged into one band (1.71–3.86 GHz).

The measured results of the impedance-bandwidth for the proposed slot antenna are about 2.15 GHz at the lower band (at the center frequency of 2.78 GHz) and 1.32 GHz at the upper band (at 5.57 GHz). The results show that an AR band at the center frequencies of 2.47 GHz can be shifted to 2.59 GHz by decreasing the y-axial length (G_{yu}) of the ground plane. However, due to the apparent variation of the phase difference between the two orthogonal electrical fields, the circular polarization becomes poor and the AR bandwidth decreases. After changing the x-axial length (G_{xr}) of the ground plane, by compensation of the phase difference, a dramatic improvement in circular polarization is achieved. The measured 3-dB AR-bandwidth can greatly extend to about 380 MHz from 2.33 to 2.71 GHz, or about 15.1% with respect to the center frequency at 2.52 GHz. Furthermore, the whole size of the slot antenna can be miniaturized by decreasing the slot length and both sides of the ground plane. In addition, by setting $G_x = 79\,\text{mm}$, $G_{xr} = 1\,\text{mm}$, $G_{yu} = 8\,\text{mm}$, $L_1 = 16\,\text{mm}$, $W_s = 4\,\text{mm}$, $W_t = 11\,\text{mm}$, and $L_t = 15\,\text{mm}$, an additional case for wider CP bandwidth is also given in Fig. 6. It is noted that the other geometrical parameters in Table 1 are unchanged. The AR bandwidth of this antenna increases to about 22.0% (2.23 $\sim$ 2.78 GHz) from 15.1%. The CP bandwidth covers the frequency specification of the SDAR system (satellite digital audio radio system).

The measured normalized radiation patterns at the XY-plane and YZ-plane of the proposed antenna are displayed in Fig. 7 and those at 1.8, 2.4 and 3.5 GHz are bi-directionally eight-like because of the fundamental mode of the modified L-slot. Due to the excitation of the higher order modes, the radiation patterns at 5.2 and 5.8 GHz are butterfly-like. Fig. 8 shows the CP radiation patterns at 2.34 and 2.6 GHz. Although the CP patterns of the proposed slot antenna are right-hand, they are not suitable for the left-hand polarization of the SDAR system. However, the left-hand circular polarization for the proposed slot antenna can be derived by reversing the feedline and slot by following the same design procedure.

Figure 9 shows the measured comparison of the reflection coefficient of the proposed slot antenna with several conditions, free-space, in-case, and hand-hold (one-hand and two-hand). For the in-case and one-hand-hold conditions, the impedance bandwidths increase because some of the radiated power was absorbed by the case material or the human brain, including the cellular tissue, the water, and the skull. However, the impedance-matching condition becomes poor.



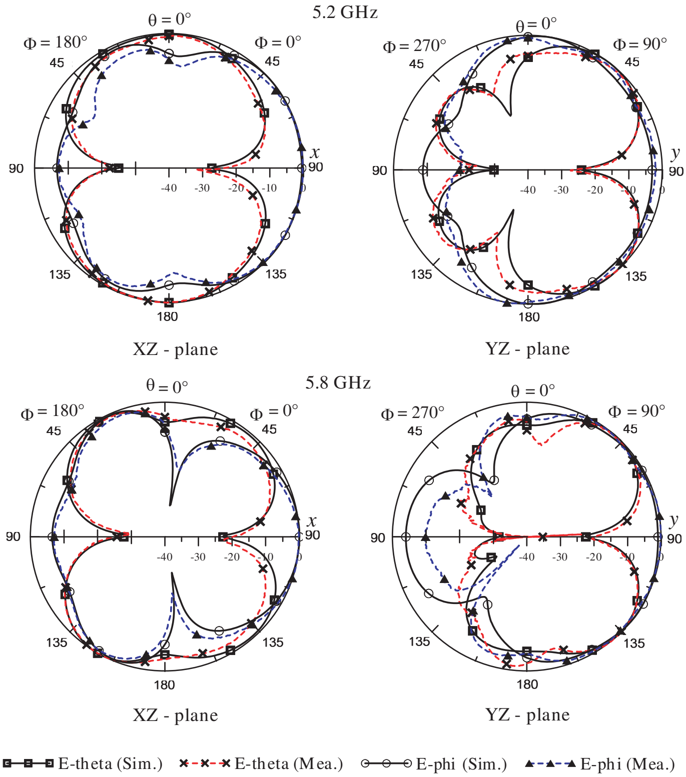


Figure 7. The measured normalized radiation patterns at the XY-plane and YZ-plane of the proposed antenna.

To compare to the study in [16], the proposed slot antenna and the feeding structure are fabricated on the same plane of the substrate so that circuit processes and position alignment can be simplified; meanwhile, the proposed technique of CP excitation utilizes the slot topology, not the feeding structure like [16]. Meanwhile, compared to the conventional single-fed circular polarization design, the proposed antenna utilize the simple method of modifying the ground plane to enhance the impedance and CP characteristics without adding parasitic elements beside the antenna or embedding tuning elements inside the slotted radiator.

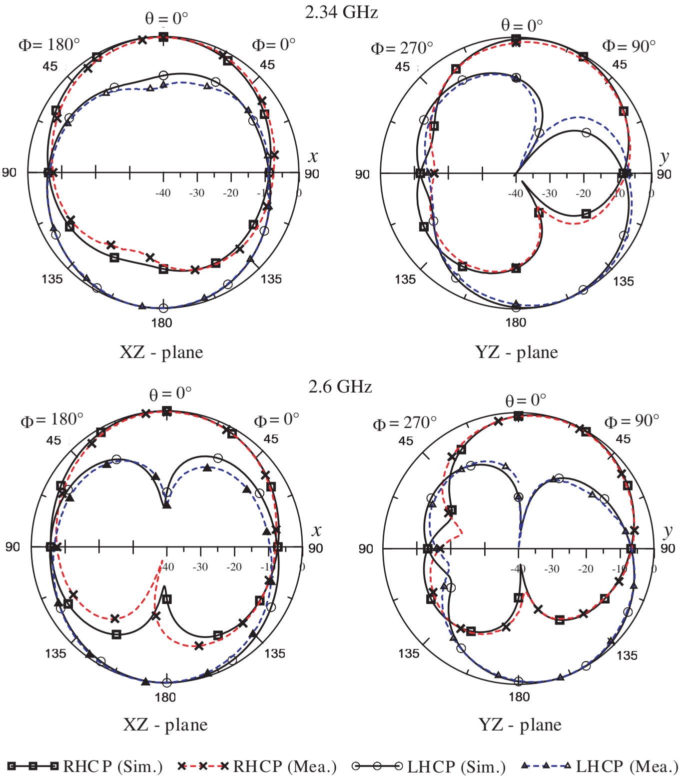


Figure 8. The CP radiation patterns at 2.34 and 2.6 GHz.

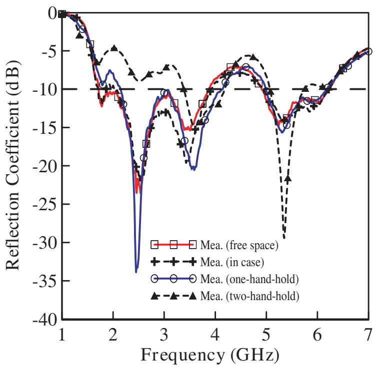


Figure 9. The measured comparison of the reflection coefficient of the proposed slot antenna with several conditions.

4. CONCLUSION

In this paper, the bandwidth enhancement and CP operation of the CPW-fed L-slot antenna have been successfully demonstrated. Two orthogonal resonant paths of the microstrip L-slot antenna were excited simultaneously through a CPW line, thus causing the CP excitation. By carefully tuning the dimension of the ground plane, the band and performance of CP can be improved in additional to size reduction. After the input impedance was studied with respect to those dimensions, a printed CP antenna with good impedance match was successfully constructed by introducing a protruded stub at the feedline. With the good performance of the dual bands and both linear and circular polarizations, the proposed CPW-fed slot antenna is suitable for use as the radiated element in many systems of mobile communication, such as DCS (1710 $\sim$ 1880 MHz), PCS (1850 $\sim$ 1990 MHz), WCDMA (1920 $\sim$ 2170 MHz), SDAR (2332 $\sim$ 2345 MHz), WLANs (2400 $\sim$ 2483.5 MHz, 5150 $\sim$ 5850 MHz), LTE (2500–2690 MHz) and Hiper-LAN (5150 $\sim$ 5350 MHz), etc..

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