A Low-profile Wideband PIFA with Co-design of Ground Plane for WLAN Applications

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***Abstract* –** In this paper, a novel low-profile wideband planar inverted-F antenna (PIFA) with co-design of the ground plane for WLAN applications and IoV applications is proposed. This antenna consists of three parts: a slotted radiating patch, a vertical shorting plate and a ground plane with a cross-shaped slot. The influence and the parameter of the slot are discussed. The antenna is fed by a 50 Ω coaxial line and a shorting pin is also used in this design. The overall size of the antenna is $30 \times 44 \times 3.5$ mm^3. The whole structure is simulated in ANSYS Electronics Desktop 2018.0 and several prototypes are made to verify the simulation results. The bandwidth of the antenna can reach 3.96 GHz (-10 dB) and cover the frequency range of $5.64-9.6$ GHz. The max gain of the antenna is 5.4 dBi.

***Index Terms* –** low-profile, multi-resonant modes, planar inverted-F antenna, wideband.

I. INTRODUCTION

The planar inverted-F antenna (PIFA) has been widely used in many sub-areas of the modern wireless communication systems because of its high gain and small size, and slots on the radiating patch make it easy to achieve multiband feature. However, due to the single resonant mode, typical PIFA has the disadvantage of a narrow impedance bandwidth, which restricts its application in many wideband-required situations. So, for the PIFA, the enhancement of impedance bandwidth to cover the range of $5-6$ GHz or even more is important for the current communication technology such as 5G wireless applications and 6G wireless systems in the future [1, 2].

A number of papers on the expanding bandwidth of the PIFA have been published. Traditional methods to improve the bandwidth include introducing parasitic patches near the radiating patch [3, 4], enlarging the size of the ground plane [5], and increasing the height of the whole structure. In [3], a vertical parasitic element is loaded and the impedance bandwidth is enhanced to about 48%, while the overall size is increased and the fabrication becomes more difficult. In [6], the influence of the ground plane on the impedance bandwidth is studied and then four different PIFA designs are evaluated. The results show that altering the slots on the ground plane can effectively change the bandwidth and the slots must be perpendicular to the dominant current direction, which provides some design guides in this paper.

Furthermore, adjusting the resonant frequencies to combine the bandwidth of two or more resonant frequencies has become a prevalent method in recent years. By combining TM_{10} and TM_{12} modes, the bandwidth of the antenna in [7] increases to about 10%. In [8], the bandwidth increases to 11.8% through a similar method. A pair of shorting pins are loaded and a slot is etched in [9], and $TM_{0,1/2}$ and $TM_{0,3/2}$ modes are combined. The bandwidth increased to 18% and could meet the requirements for 5G WLAN applications. In [10], a small rectangular strip is loaded on the top of the feeding probe and $TM_{1/2,2}$ and $TM_{3/2,0}$ modes are combined, and the impedance bandwidth is enhanced to about 33% (from 5 to 7 GHz). However, the position of the strip might bring challenges for the fabrication, and the height of the substrate (0.254 mm) is hard to control during manufacturing.

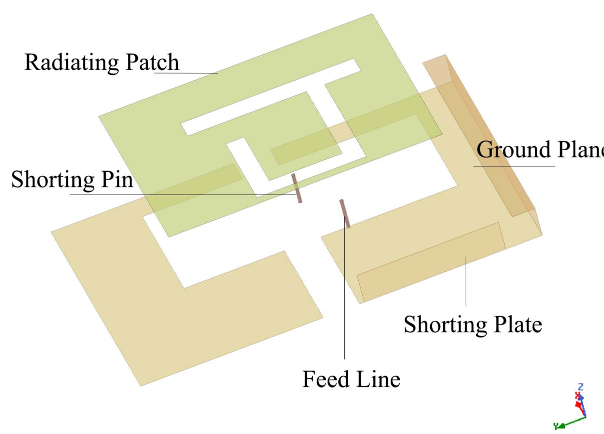

Fig. 1. Components of the proposed antenna.

In this paper, a novel low-profile wideband planar inverted-F antenna with co-design of the ground plane is

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proposed as shown in Fig. 1. The design process is introduced and some important parameters are studied. A cross-shaped slot is loaded on the ground plane and the size and position of the slot are studied to enhance the impedance bandwidth. The results show that the slot that parallels to the dominant current direction on the ground plane can change the bandwidth of the antenna effectively. The data from the simulation and the measurement of the proposed antenna show that the bandwidth ($S_{11} < -10$ dB) can be expanded to 51%, covering the range of 5.64 GHz to 9.6 GHz. The max gain can be 5.4 dBi and the vertical omnidirectional performance is also better than typical PIFAs.

II. GEOMETRY AND FABRICATION

The proposed antenna is shown in Fig. 2, consisting of a radiating patch, a shorting plate, a ground plane, a shorting pin and a 50 Ω coaxial feed line. The slot on the radiating patch is designed to excite multiple radiation modes. The positions of the shorting pin and the feed point are well-chosen to realize the wideband feature, and the details will be shown in the next section. The ground plane is etched with a cross-shaped slot to combine the radiation modes and the influence of the width is studied. The values of the design properties are shown in Table 1. The entire structure is simulated using ANSYS Electronic Desktop 2018.0.

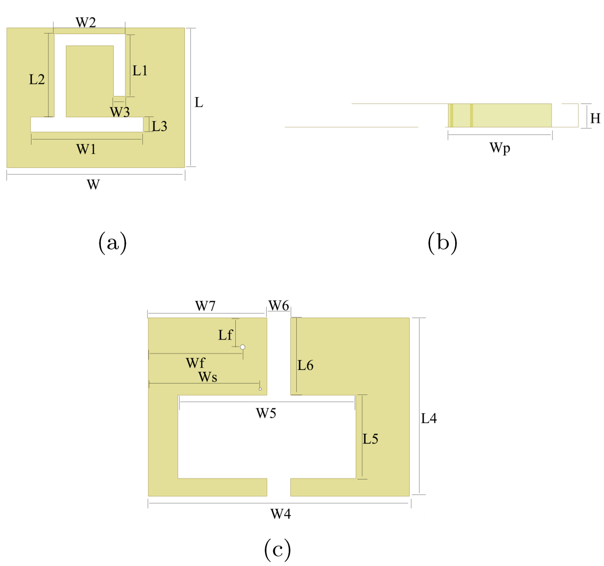


Fig. 2. Design parameters of components. (a) Patch. (b) Shorting plate. (c) Ground plane.

III. DESIGN APPROACH AND PARAMETRIC STUDIES

A. Design approach

Figure 3 shows the design approach of the proposed antenna. In Fig. 3 (a), a traditional single mode PIFA

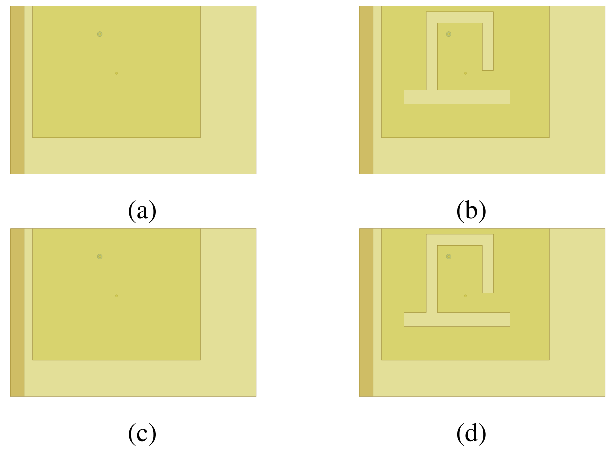


Fig. 3. Design process. (a) Original PIFA. (b) Slot on the patch. (c) Slot on the ground plane. (d) Wide slot.

Table 1: Design parameters

Parameters	Dimension	Parameters	Dimension	Parameters	Dimension
L	23.5 mm	L_f	5 mm	W_6	4 mm
L_1	10.5 mm	W	30 mm	W_7	20 mm
L_2	14 mm	W_1	19 mm	W_f	16 mm
L_3	2.5 mm	W_2	12 mm	W_s	19 mm
L_4	30 mm	W_3	2 mm	W_p	15.5 mm
L_5	14 mm	W_4	44 mm	H	3.5 mm
L_6	13 mm	W_5	30 mm		

with narrow bandwidth is shown and its resonant frequency is 2.75 GHz. A winding slot similar to U-shape is loaded in Fig. 3 (b) to excite multiple resonant frequencies. The antenna becomes a tri-band PIFA with the slot. The basic principle for the expanding of bandwidth is to pull these resonant frequencies closer and combine those receptive frequency ranges. In Fig. 3 (c), a narrow slot parallel to x-axis on the ground plane is loaded to widen the bandwidth of each frequencies. Finally, a wide slot vertical to the narrow one is loaded to combine these resonant frequencies further as shown in Fig. 3 (d) and the effect will be discussed later. The positions of the feed point and shorting pin are well-chosen to achieve a better bandwidth, and the sizes of the patch and the ground plane have been adjusted during the design process.

B. Parametric studies

In the PIFA, the relative position between feed point and slot can effectively change the radiating performance. Usually, etching a winding slot between the feed point may excite more than one radiating mode and alter the current distribution on the patch. Hence, the parameter L_f is important for the whole radiating feature. Figure 4 shows the results of different values of L_f, and it can be seen that as the value increases, the impedance bandwidth (-10 dB) decreases significantly and the shape of the curve becomes sharper. This can be attributed to the difference between the two resonant

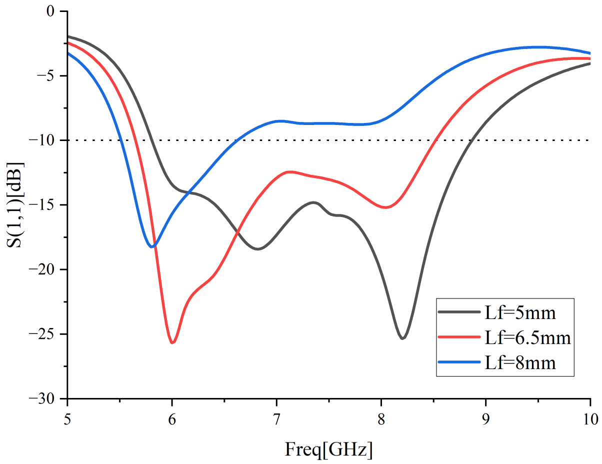


Fig. 4. The influence of L_f.

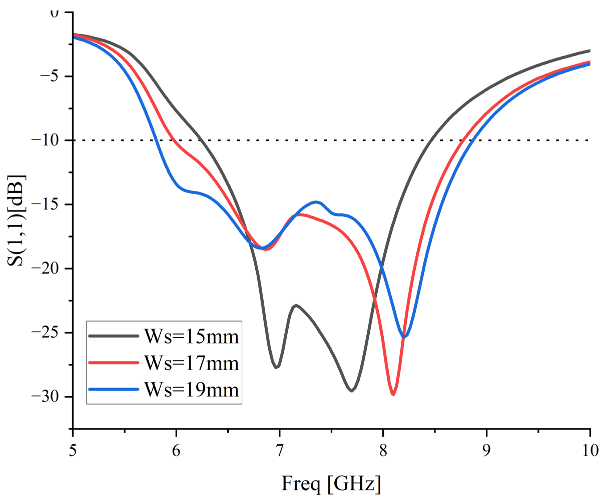


Fig. 5. The influence of W_s.

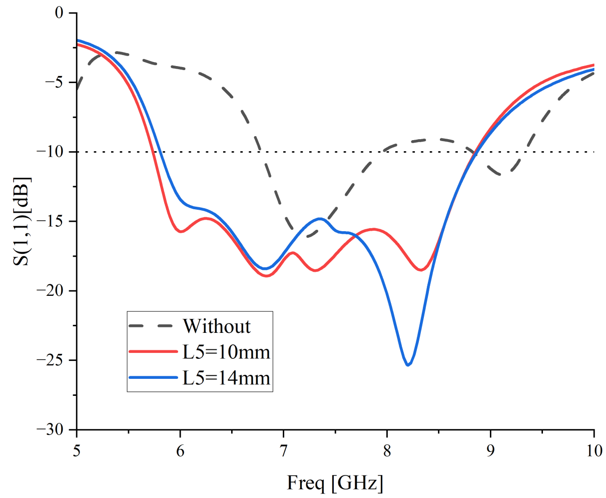
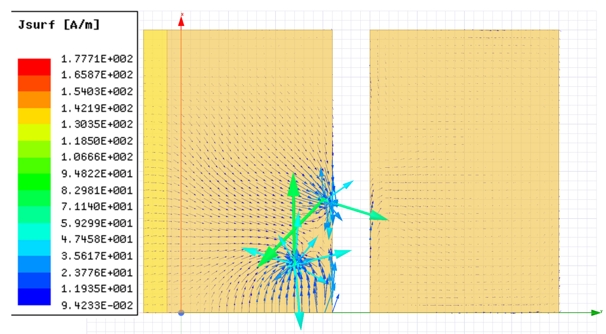
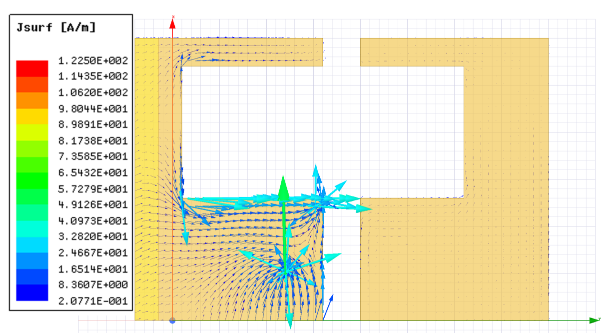


Fig. 6. The influence of L_5.



(a)



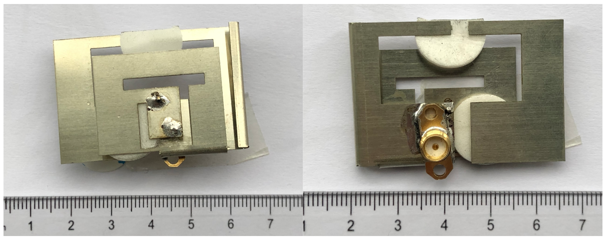
(b)

Fig. 7. Current density on the ground plane. (a) Without the wide slot. (b) With the wide slot.

frequencies decreasing as the value of L_f increases. The value of L_f is chosen to be 5 mm to reach a better bandwidth performance.

Additionally, the influence of the shorting pin's position is also studied. The results are shown in Fig. 5. Moving the shorting pin does not change the whole radiating performance as significantly as the feed point. The impedance bandwidth decreases slightly as the value of W_s decreases, while the magnitude of return loss increases. In this case, $W_s = 19$ mm is chosen to expand the -10 dB range further.

The design of the ground plane is a convenient way to improve the radiating performance without adding extra components and complicating the whole structure. According to [6], it is found that altering the ground plane using slots can allow for greater bandwidth and the direction of the slots must be perpendicular to the predominant current direction. For the proposed antenna, a perpendicular slot is used on the ground plane. In addition, a wide vertical slot is added and a cross-shaped slot is made. Figure 6 shows the influence of the wide slot and the radiating performance is improved after adding it. The width of the wide slot L_5 is chosen to be



(a) (b)

Fig. 8. Prototype of the proposed antenna. (a) Top view. (b) Bottom view.

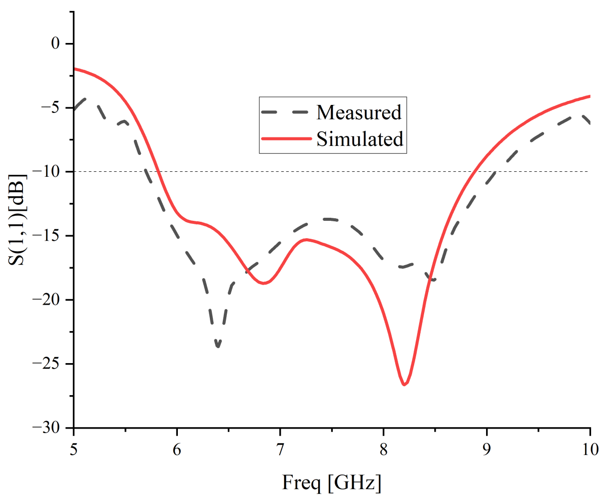


Fig. 9. Return loss of simulation and measurements.

14 mm. Figure 7 shows the current flow distribution on the ground plane with and without the wide slot. It can be seen that the slot does not change the main current concentration points, but the current density does become larger in the slot edge area.

IV. RESULTS AND DISCUSSION

The prototypes of the antenna are fabricated and measured, in order to verify the results of simulation. A vector network analyzer is used to measure the return loss, and the far-field antenna test system is used to measure the radiation patterns. The pictures of the prototype are shown in Fig. 8, including top and bottom views.

A. Return loss

The simulated and measured results of return loss are shown in Fig. 9. For simulated results, the impedance bandwidth (−10 dB) covers the range of 5.64 GHz to 8.37 GHz, and the fractional bandwidth is 39.0%. For measured results, 5.64 – 9.60 GHz is covered, and the total bandwidth is 3.96 GHz with a fractional bandwidth of 51%. It can be concluded that the results of

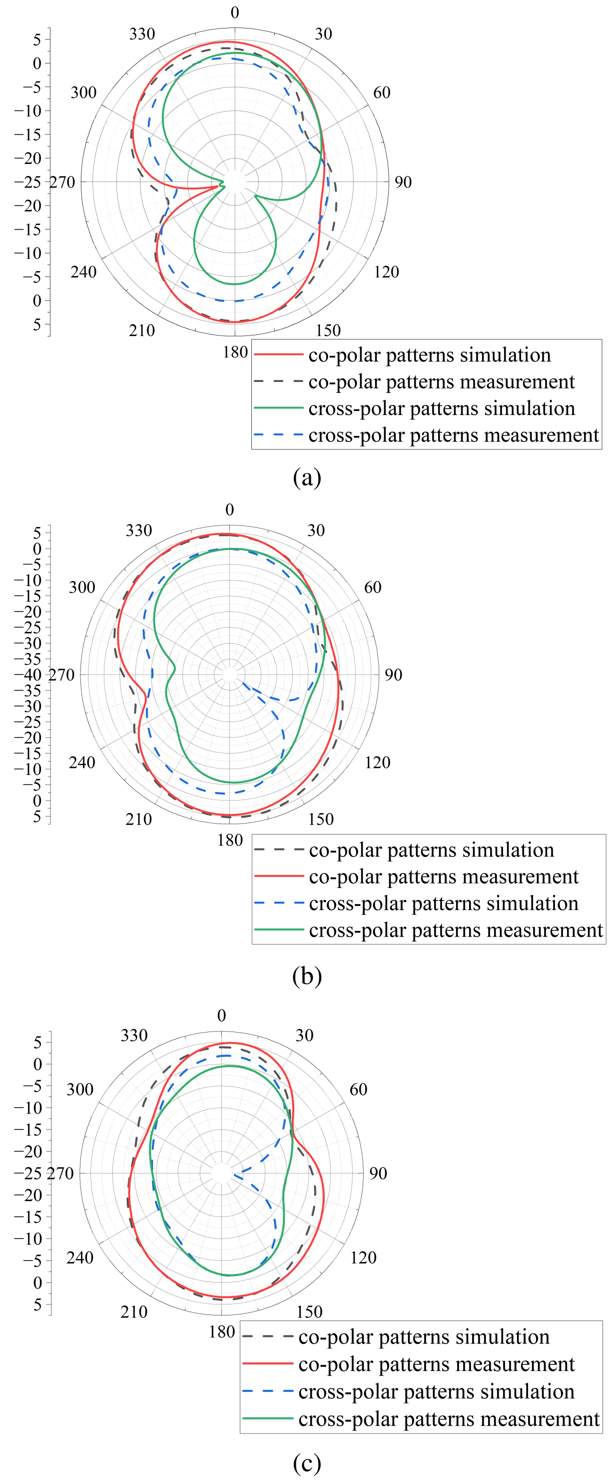


Fig. 10. Radiation patterns at 5.89 GHz, 6.56 GHz, and 8.14 GHz on the *xoz* plane. (a) 5.89 GHz. (b) 6.56 GHz. (c) 8.14 GHz.

the simulation and the measurement are in quite good agreement. The results of different prototypes are not

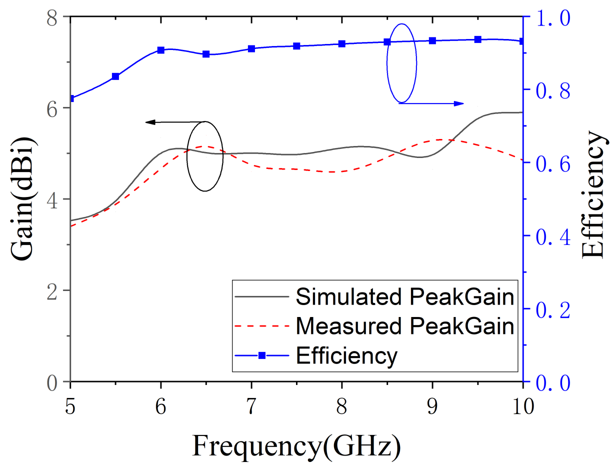


Fig. 11. Gain and efficiency.

the same due to fabrication errors, and a position deviation of only 1.5 mm of the feed point may cause a huge difference in results, as shown in the parameter studies section. The proposed antenna can meet the requirement of 5G and 6G WLAN. The bandwidth has been expanded several times compared to the traditional PIFA.

B. Radiation patterns

The radiation pattern of the proposed antenna is shown in Fig. 10. The gains at 5.89 GHz, 6.56 GHz, and 8.14 GHz on the *xoz* plane are measured and the peak gain is 5.4 dBi, obtained at 8.14 GHz according to measurement. At high resonant frequency points, the radiation patterns are approximately omnidirectional and the minima of gain is more than −10 dBi, which achieves a better vertical omnidirectional performance compared to traditional PIFAs. That might be attributed to the folded ground plane and is about to study in the future.

C. Peak gain and efficiency

The gain and simulated efficiency are shown in Fig. 11. The results show that the peak gain of the proposed antenna remains stable in this wide bandwidth. The simulated efficiency remains about 90% in the entire frequency range.

Table 2: Comparisons of the proposed antenna to other PIFAs

Ref.	Area (mm^2)	Profile (mm)	f_0 (GHz)	BW (GHz)	Peak Gain (dBi)	Size Comparison
[9]	46×36	5.5	5.5	0.94(18%)	5.90	197.1%
[10]	53×41.4	1.754	6	2(33.33%)	10.82	83.3%
[11]	42×28	4	5.5	0.94(17.09%)	6.70	101.8%
This work	44×30	3.5	7.62	3.96(51%)	5.40	100%

V. CONCLUSION

A low-profile wideband planar inverted-F antenna is proposed in this paper. A cross-shaped slot is used on the ground plane to combine three resonant modes and achieve the wide bandwidth feature. Several prototypes are fabricated to verify the simulation results. The proposed antenna has a measured −10 dB bandwidth of 3.96 GHz and the fractional bandwidth is 51%. A peak gain of 5.4 dBi is measured and the gain remains stable in the bandwidth. The proposed antenna can meet the requirements for wireless local area networks (5725 – 5825 MHz), and IoV applications (5905 – 5925 MHz). The latest 6G-band of WiFi 6E (5946 – 7105 MHz) is also covered. The comparisons between the proposed antenna and other PIFAs are shown in Table 2.

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