Hindawi
International Journal of Antennas and Propagation
Volume 2018, Article ID 6846193, 13 pages
https://doi.org/10.1155/2018/6846193

Research Article

Design of L-Shaped Open-Slot Antenna Used in UAV Airborne Communication System

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Received 21 June 2018; Accepted 2 September 2018; Published 21 November 2018

Academic Editor: Giorgio Montisci

According to the communication demands of communication system used in the UAV (Unmanned Aerial Vehicle) communication system, a ladder-shaped open-slotted antenna design is presented. The impedance effects and directional radiation performance of designed antenna are improved with adopting a pair of L-shaped narrow slot and a passive resonator among the antenna structures. The measured results show that the impedance bandwidth of the antenna is about 90%, the frequency range can cover from 3 GHz to 12 GHz, and the antenna has a relative small size just as 22 mm × 24 mm. The antenna is realized through adopting improved ground structure, and its electrical length is increased simultaneously. To improve its impedance matching effect, the ladder structure is adopted in the antenna. The measured results show that the proposed design scheme is useful and effective, the antenna size can be controlled within the size of 22 mm × 24 mm and the good impedance bandwidth can also be obtained, its frequency bandwidth is from 3 GHz to 13.2 GHz, and the designed antenna has good group delay characteristics at the same time.

1. Introduction

With the increased applications of UAV in different fields, the UAV antenna system plays increasingly prominent roles in its communication system. As the airborne antenna works in the aerial movements of UAV, it should not only have excellent electric and electrical characteristics but also it must be met with related external conditions under different aerial environments. In order to improve the UAV airborne antenna performance, the antenna radiation power should be more concentrated on certain direction, its radiation efficiency and gain should be high at the same time, while the side-lobe size of its radiation pattern should be small.

With the miniaturization and integration developments in UAV, many kinds of mini-UAV have been developed, as shown in Figure 1, it is one kind of mini-UAVs. The UAV communication system needs to be compatible with other different communication equipment. Sometimes even a single antenna needs to cover two or more frequency bands simultaneously in the data-link systems of UAV. Thus, UAV airborne antenna should have small size and most important it must have the ability of multiband or ultra wide-band working frequencies. Multiband antenna has the advantage of covering different communication frequencies at the same time; it can reduce the number of antennas in the UAV communication systems, and related total manufacturing costs of UAV will be reduced accordingly.

The open-slot antenna is evolved from the slotted antenna. The traditional slot antenna was realized by etching a narrow slot with size of half wavelength on the metal patch. Due to the resonance characteristics, the slot seam will radiate electromagnetic waves along both sides of the slot. Since the half-wavelength narrow slot antenna belongs to the resonant antenna, it has a large input impedance.

Figure 1: Control and communication equipment of four-rotor UAV system.

Therefore, the antenna's bandwidth is very narrow and it is not easy to match the feed structure. At the same time, it requires a larger area to achieve it. These disadvantages limit the application of narrow slot antenna.

In order to reduce the size of the antenna, Ko and Murch [1] adopted the symmetry of the slot antenna structure, where the half-wavelength slot antenna is cut off from the center symmetry line. Due to the lacking of slot limitations, the truncated antenna will generate surface currents on the metal edges on both sides of the slot section, From the basic knowledge of antenna radiation, it is known that the surface current will produce electromagnetic radiation, which in turn forms a one-quarter wavelength slot antenna.

At present, most of the microstrip antennas adopt broadband feed line structure. As the structure of the slot antenna can further broaden the bandwidth, therefore, most of the broadband communication systems adopt slot antennas. Now, the 1/4 wavelength open-slot antenna is widely used in the mobile communication systems and the UWB communication systems, and its size is only half of the size of 1/2 wavelength slot antenna. This feature makes the antenna to be extremely miniaturized, and as the antenna has resonant mode similar with monopole antenna, it is called unipolar slotted antenna [2].

In the paper [3], it divides the 1/2 wavelength slot antenna from the center point to form a 1/4 wavelength slotted antenna, and thus the antenna combined with a unipolar antenna is formed. In the paper [4], it proposes a miniaturization antenna which has three open-slot lines, and the designed antenna works at 1/4 wavelength resonant mode, which can provide two different resonant frequencies through using different slots.

In the papers [5, 6], a unipolar slotted antenna with wide slot structure is designed, and its structural parameters are analyzed in detail, and the method of improving bandwidth of the antenna is also proposed. In the paper [7], an asymmetrical open-slot antenna is proposed, and its impedance bandwidth can cover the UWB frequency band. In the paper [8], it adopts the same design principle, it changes the 1/4 wavelength slot structure into the trapezoidal structure, which makes the antenna have a high-frequency resonance point, and it can also cover the UWB communication frequency band. The above studies show that the aperture antenna of 1/4 wavelength has the ability to cover the UWB frequency band, and meanwhile many miniaturization design can also be done.

UWB antenna miniaturization design in this paper will adopt the basic form of a 1/4 wave slot line. At present, most of miniaturization slotted antennas adopt line structure, but there are a few studies concern on changing slot line width to meet with the requirements of UWB and each slot on both sides of the design adopts the asymmetric structure, so it will expand the frequency bandwidth of antenna to be about 105%.

In the paper [9], it designs the opening groove line to be a step structure, and UWB frequency coverage is realized. However, the UWB antennas proposed in the papers are bulky and have no advantage of the miniaturization characteristics of open-slot antenna. Therefore, in order to realize broadband coverage without changing the antenna structure, it only can be performed through changing feed type. In the paper, it designs a ladder broadband symmetry slotted feed structure to realize the UWB frequency coverage.

The slotted antenna has two basic structures, one of which is the opening slot structure with the 1/4 wavelength. Due to the development of microstrip slot line structure, the 1/4 opening slot antenna has widely been used. Compared with the narrow slotted antenna with a half wavelength, the 1/4 wavelength opening slot antenna has the advantage of small size. The slot line antenna adopting this structure usually has the omnidirectional radiation ability. In order to realize the directional radiation ability, the open-slot antenna usually adopts another typical structure, which is the tapered slot structure in antenna. The common structures of tapered slot antenna all belong to the traveling wave antenna, and they have good time-domain characteristics. In most of the slot antennas adopting the gradient structure, the surface currents flow along the smooth path thus to achieve impedance transformation in wide band range, and thus the antenna size is relatively large, and in the small communication devices, the antenna will be unsuitable or restricted. Based on the theory of short circuit, it concerns on the 1/4 wavelength slot antenna and focuses on how to use the techniques of passive dipoles and narrow slot loading to increase the impedance bandwidth of the opening slot antenna and how the directional radiation ability of antenna can be increased. The designed antenna should achieve the requirements of UWB frequency band and good directional radiation, simultaneously.

As the structure of microstrip antenna has been developed into grooved wire conversion structure, the impedance bandwidth of the antenna has been further widened. Song et al. [10] added a T-shaped branch to the terminal of the microstrip feeder, and the impedance matching characteristics of the antenna in the frequency range of 6.5 to 11 GHz are improved. The test results show that the antenna can cover a frequency range from 2.3 to

11.1 GHz, while the antenna size is only 30 mm × 35 mm. Su et al. [11] added the terminal of the microstrip line into a ladder structure, and an opening slot antenna based on the microstrip slot wire conversion structure is designed. The antenna can operate in the frequency range from 2.95 to 12 GHz.

Chen et al. [12] designed different structures of microstrip grooves, such as rectangular, diamond-shaped, or circular structures. The measured results show that the opening grooved antenna can obtain 105% to 109% of the relative impedance bandwidth. Zhu and Su [13] designed an open-slot antenna by using a circular microstrip terminal. The antenna can operate in the frequency range from 2.5 to 12.5 GHz, and the antenna size is only 30 mm × 35 mm. Chen et al. [14] designed the circular patch into a semicircle, and the purpose of reducing the antenna size was realized. The measured results show that the antenna can obtain 139% of the relative impedance bandwidth, which can cover the frequency range from 2.57 to 14.23 GHz, while the antenna size can be reduced to 20 mm × 35 mm. The above research shows that the open-slot antenna has the advantages of ultrawide working frequency and size miniaturization at the same time, so it has a wide range of applications.

2. Bandwidth Broadening Method of Slotted Unipolar Antenna

As known, the planar printed slot antenna has been widely used and studied, and in the recent years, the researchers have already put forward a variety of slot structures of antenna. The line opening slotted antenna based on microstrip line feed [8] can obtain the wider impedance bandwidth and better bidirectional radiation performance. For example, the 1/4 wavelength open-slot antenna adopted microstrip line feed method added with horizontal and vertical regulation stub that can obtain the impedance bandwidth ranging from 3 GHz to 5 GHz [9].

By using the improved opening slot antenna of microstrip line feed [10], it can reduce antenna size to achieve the purpose of miniaturization. Through using different shapes of slot, it can increase the impedance bandwidth of slot line antenna [11]. Taking the pentagon open-slot seam as the radiating element of the antenna can generate the additional resonance frequency, and the antenna can achieve good broadband characteristics [12]. In the paper [13], when the nonsymmetrical layer structure is adopted in the antenna structure, it can also achieve a very wide impedance bandwidth. Through adding open slot [14], Chen et al. make the impedance bandwidth of the antenna to be increased from 84% to 130.3%. However, the characteristics of omnidirectional radiation of slot antenna mentioned above do not meet with the improving requirements of directional broadband radiation.

In order to realize the directional radiation characteristics, some improvements are proposed in the open-slot antenna to improve direction ability of the antenna. A metal plate is added below the printed slot antenna, and the rear radiation of the antenna will be reduced, so the antenna directional radiation ability in free space will be improved.

As the distance between the antenna radiation unit and the bottom layer must be larger than 1/10 of the wavelength, it will increase the size of the total antenna. Another method is to adopt a directed structure to make the open-slot antenna obtain the ability of directional radiation. Lee and Sun [15] adopt the passive resonator and three group slots with eight elements to form the slot antenna which has good directional radiation ability, but this method is at the expense of increasing the size of antenna. If two narrow slits are etched with different length and shape on the bottom of the slot [11], the backward radiation of antenna has been obviously suppressed and the direction ability of antenna has been significantly improved, but the size of antenna is still large.

In antenna design, the most commonly used broadband technology is to adopt a gradient structure. As for the monopole antenna, the performance of the antenna is depended on the ground part, and the impedance bandwidth of the antenna can be effectively expanded by adopting the gradient floor structure.

In the paper, it presents a 1/4 wavelength stepped opening slot antenna through adopting the resonator and the narrow slotted loading method is also introduced; it can increase the impedance bandwidth of the opening slot antenna and improve the directional radiation ability accordingly. Usually, the part of $|S11| < -10$ dB is defined as the impedance bandwidth of the antenna; test results show that the antenna can obtain about 105% of relative impedance bandwidth and the gain of the test results are more than 4 dB, and most importantly, the antenna will have a relatively small size.

In the paper, it proposed a ladder-like open-slot antenna, by near the slot of open-slot antenna is introduced into a passive resonator to expand the antenna impedance bandwidth and improve the ability of the directional antenna radiation. At the same time, the L-shaped narrow slot etched on both sides of the floor can expand the impedance bandwidth of the antenna at low-frequency band and ability of antenna directional radiation is also improved compared to the other designs mentioned in the papers [16–20].

3. The Structure of Proposed Antenna

In Figure 2(a), the structure and parameters of the L-shaped opening slotted antenna proposed in the paper are shown, which is printed on the dielectric substrate and the substrate material is FR-4; its dielectric constant is 4.2, and the thickness of the dielectric substrate is 0.7 mm. As shown in Figure 2(b), the open-slot antenna proposed is composed of a stepped opening slot etched on the ground part, and it is composed of a resonator and a pair of L-shaped narrow slot.

The L-shaped narrow slot is etched symmetrically on both sides of the layer, and the resonator is printed on the bottom layer of the middle. The feed structure of the antenna adopts the microstrip slot line transition structure, and the

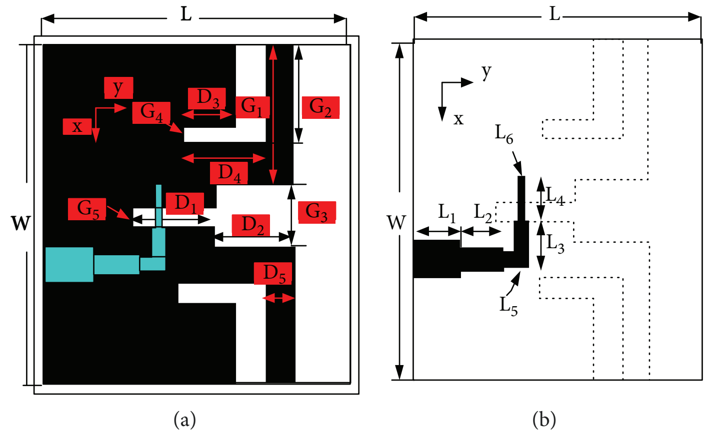


FIGURE 2: Antenna structure and related parameters. (a) The front structure. (b) The back structure.

TABLE 1: Related parameters of antenna.

Parameters	Values (mm)	Parameters	Values (mm)
W	24	D_2	5.8
L	22	D_3	1.6
L_1	5	D_4	10.2
L_2	1.8	D_5	3.5
L_3	2.2	G_1	13.8
L_4	6.8	G_2	9.2
L_5	2	G_3	4
L_6	0.6	G_4	2
D_1	8	G_5	0.8

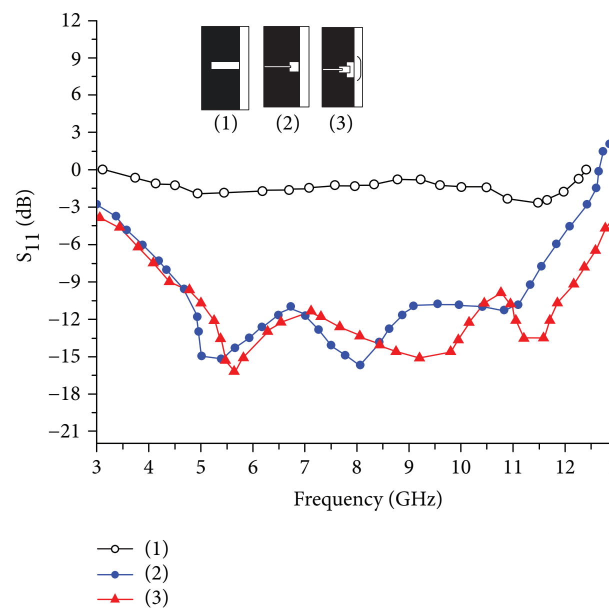


FIGURE 3: The reflection coefficients of different types of slot antennas under different frequencies.

microstrip feed line with three-step impedance conversion stub is added on top of the dielectric substrate. In the paper, the low-frequency band radiation performance of the stepped aperture slot antenna is mainly determined by the narrow slot of the L-shape, and the radiation performance of the antenna in the high-frequency band is mainly depended on the resonator. Then, the simulation analysis of the structure and key parameters of the ladder open-slot antenna is conducted below. In order to achieve the purpose of good impedance matching and high gain, the size of the antenna should also be optimized.

Through the parameter optimization, the designed parameters are as shown in Table 1. The influence of antenna structure on the performance of the antenna is discussed and analyzed in detail. In addition to the analysis of the structural parameters, some other parameters will also be discussed.

4. Influences of Passive Resonator

Due to the weak radiation direction of the open-slot antenna, in the paper, we studied the influence of the resonator on the radiation performance among the high-frequency band. And the effect of the L-shaped narrow slot seam on the low-frequency radiation performance of the open-slot antenna will also be discussed. In order to study the effect of passive dipoles on the radiation performance of open-slot antenna, Figure 3 shows the simulation results of the reflection coefficient of open-slot antenna with the different structures, which are the straight line open-slot antenna, ladder-shaped open-slot antenna, and stepped open-slot antenna loaded by the passive dipole.

As shown in Figure 3, due to the effects of truncation, the surface currents generated in the slot line section on both sides of the metal edge will produce electromagnetic radiation, but as the weak radiation ability of linear open-slot antenna, the impedance matching characteristics of straight line opening slot antenna are relatively weak. This is mainly due to the relatively strong coupling effects of the narrow groove line on the electric field, and the surface current intensity caused by the metal edge on both sides of the slot line section is relatively weak. In order

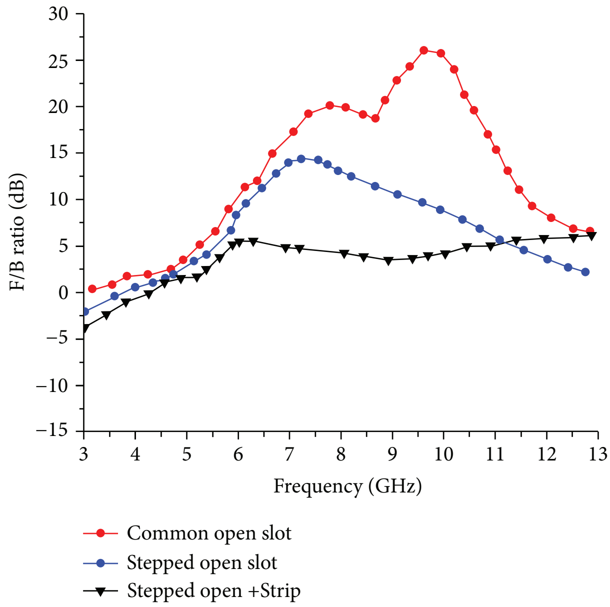


FIGURE 4: The front and back ratio of different types of slot antennas under different frequencies.

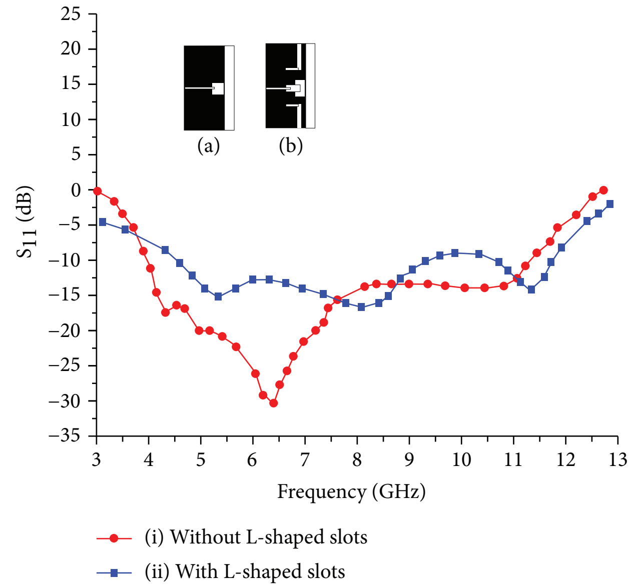


FIGURE 5: The influence of L-shaped open slot on the reflection coefficient of the antenna.

to reduce the coupling effects of the slot line on the electric field, the step shape structure is adopted to increase the width of the slot line and enhance the radiation ability of the antenna.

Due to the increasing slot width, the coupling effects of the slot on the electromagnetic field will be weakened accordingly, and as to electromagnetic wave, its radiation power of the slot will be enhanced at the same time. Figure 3 shows the reflection coefficient of the simulation of the stepped aperture slot antenna. As shown in Figure 4, compared with the linear open-slot antenna, as it adopts the ladder-shaped connection structure, the impedance matching of antenna in the frequency band from 3 GHz to 13.2 GHz is significantly improved, and the impedance bandwidth of the antenna is effectively increased at the same time.

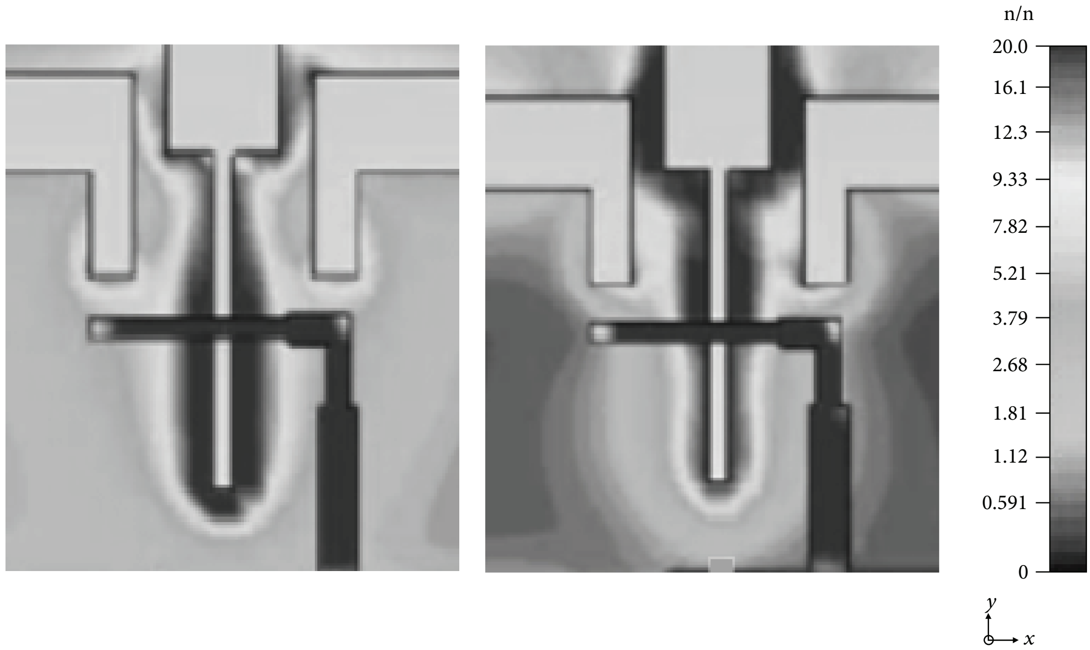
When the resonator is placed near the terminal of the stepped slot, as shown in Figure 4, a new resonant frequency (which is about 12 GHz) is introduced in the high-frequency band of the antenna. Due to the larger input impedance of open-slot antenna in the high-frequency band, when the passive dipoles are near to the opening slot, the passive dipoles will be equivalent to a short-range loading unit; thus, the input impedance of opening slot antenna in high-frequency part will be reduced, and it is easy to match with 50-ohm feeding port.

As impedance matching of antenna in the high-frequency has been improved, the impedance bandwidth of the antenna will be broadened. At the same time, it can be seen that the resonator has little effects on the impedance matching of antenna in the low-frequency band, as the effect of resonator is weaker in the low-frequency band. The influence of the resonator on the front and back ratio of the antenna is shown in Figure 4. It can be seen from Figure 4, when the open slot adopts the ladder shape, that the front and back ratio of the antenna in the frequency range from 6 GHz to 12 GHz will be significantly improved. However, the ladder-shaped design has less influence on the front and back ratio of the antenna in the low-frequency band. When the resonator is added, the front and back ratio of the antenna in the frequency band from 6 GHz to 12 GHz will be further improved.

Because the passive dipoles produce a new resonant frequency at 11 GHz, as for the frequency band which is less than 12 GHz, the passive resonator is equivalent to the direction device, so in the frequency band less than 12 GHz, the radiation direction of antenna will be enhanced. As for the frequency band higher than 12 GHz, the passive resonator is not equivalent to the director device, so the passive resonator cannot improve the radiation direction of the antenna in the frequency band higher than 12 GHz.

5. Effects of Etching L-Shaped Slot

The effects of L-shaped narrow slot on the performance of the antenna will be discussed and analyzed below. In Figure 5, it presents the effect of the L-shaped narrow slot on the antenna reflection coefficient. It can be found that the L-shaped slot etched has a very large influence on the impedance matching especially in the low-frequency band. When the L-shaped narrow slot is etched, band part of the antenna where $|S_{11}| < -10$ dB will significantly shift to the low-frequency part, and the changes of bandwidth edge in high frequency of the antenna will be relatively small, so the impedance bandwidth of the antenna is broadened effectively. As it can be seen from the simulation results in Figure 5, the impedance bandwidth of the antenna will be increased from 87.2% (which is from 3 GHz to 11.2 GHz) to 105.3% (which is from 3 GHz to 13 GHz).



(a) (b)

Figure 6: Surface current distribution of antenna at different frequency points. (a) 6 GHz. (b) 10 GHz.

Here, the purpose of etching L-shaped narrow slotted on both sides of the layer is to reduce the surface current intensity of both sides of the layer to reduce the back radiation of the antenna. Therefore, the surface current distribution of etching L-shaped slotted antenna should be analyzed.

In Figure 6, it presents the surface current distribution at the frequency points of 5 GHz and 9 GHz after etching L-shaped slot seam. If we compare Figures 6(a) and 6(b), it can be found that the surface current density of the antenna on the edge of both sides of the layer is lower than that in the frequency point of 5 GHz. This means that using the etching L-narrow slotted method to reduce the surface current intensity on either side of the floor is very effective. It can also be found that surface current intensity of the antenna on either side of the layer in the frequency band 9 GHz has been significantly reduced. In addition, it can also be found that the surface current intensity of the antenna along the x-axis edge region B is still unchanged, which means that the influence of the L-shaped slot on the forward radiation performance of the antenna is very small.

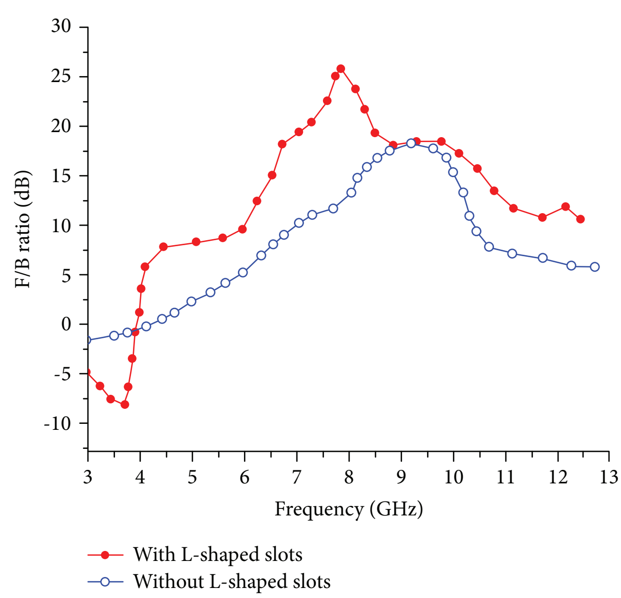
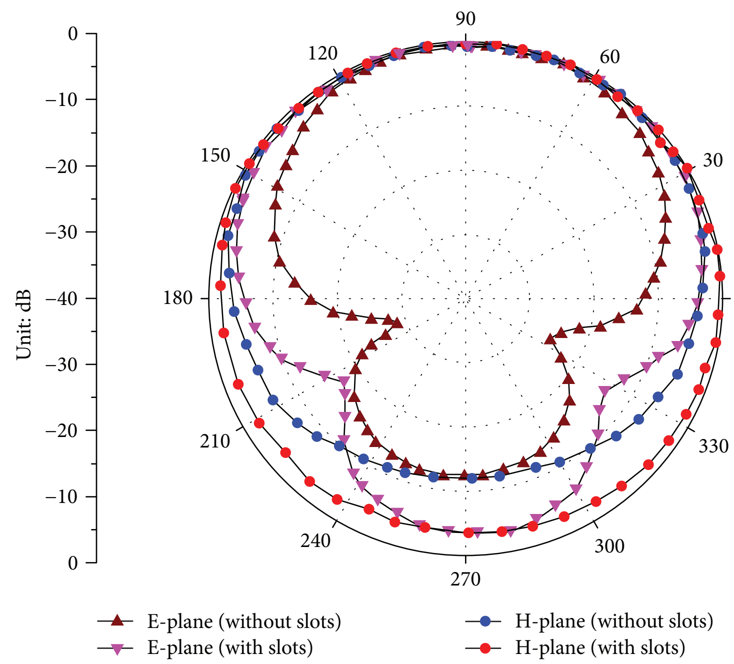


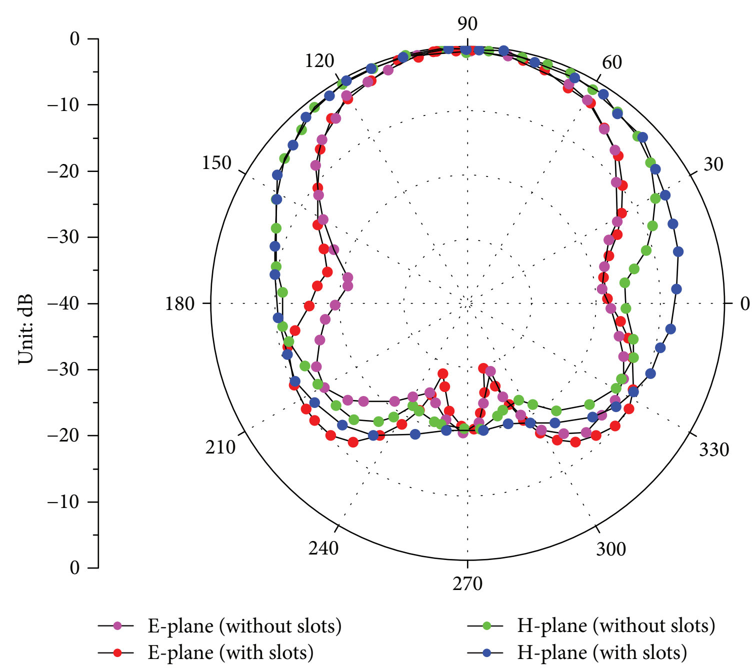
Figure 7: The influence of L-shape slot on front and back ratio of antenna.

In order to explain how the L-shaped narrow slot can improve the characteristics of the directional radiation of antenna, the comparison results of L-shaped narrow slot without etching and the L-shaped narrow slot with etching can be seen from the Figure 7; the related ratio of the antenna in the low-frequency band has been significantly improved, in the frequency band from 3.6 GHz to 8 GHz; the simulation of the ratio is larger than 10 dB. Figures 8(a) and 8(b) give out the comparison results of the radiation pattern of the antenna at frequency points 6 GHz and 10 GHz, respectively. As it can be seen from Figure 8, in the frequency point 6 GHz, as the introducing of L-shaped narrow slot on both sides of the floor, the side lobe of radiation and back radiation of antenna radiation pattern have been significantly reduced. At the same time, it can also be observed that the side lobe of antenna radiation pattern also has obvious inhibitions.

Therefore, from the discussions above, we know that etching L-shaped narrow slot has made great contributions to the improvement of the antenna radiation direction, and the antenna can also obtain broad band feature and good



(a)



(b)

Figure 8: The influence of L-shape slot on radiation pattern of antenna. (a) 6 GHz. (b) 9 GHz.

directional radiation ability through etching L-shaped narrow slot.

In order to illustrate the size effect of L-shaped narrow slot on the performance of antenna, it analyzes the parameter of L-shaped narrow slot, as shown in Figure 8. Figures 9(a)–9(d), respectively, show the effects of parameters G_1–G_2, $D4$–D_3, D_3, and G_1 on reflection coefficient of the antenna. From Figure 9, it can be found that the impedance of the antenna width is mainly determined by the parameters of the G_1, and the changing of D_3 almost does not affect the impedance matching of the antenna, and the changes of parameters of the G_1 and D_3 have the great influence on the impedance matching of the antenna. Through changing parameters of G_1 and D_3, the antenna can obtain the good impedance matching effects among frequency band. From the above discussions, we can find that the radiation pattern and impedance matching of the antenna can be improved by

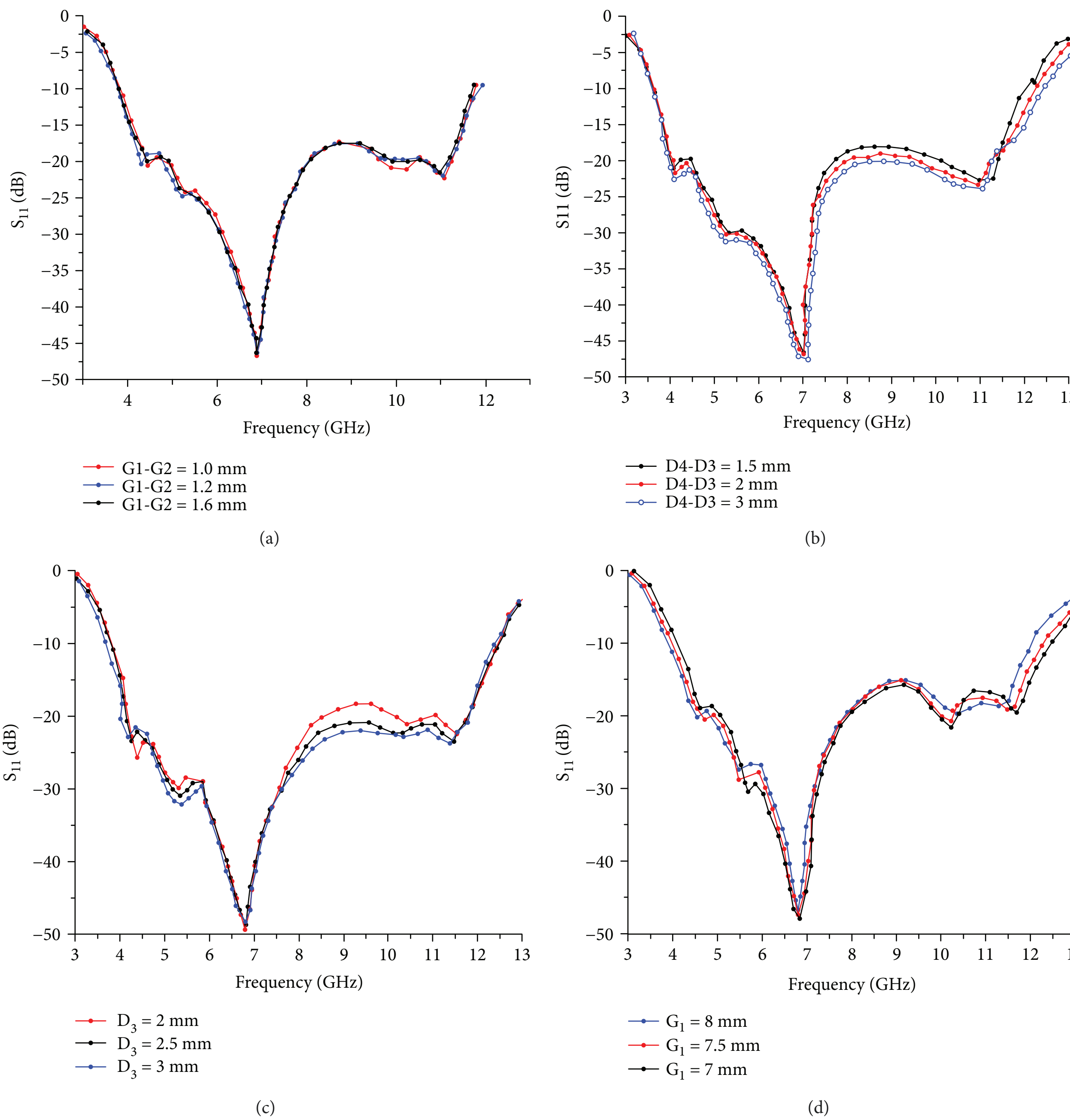


Figure 9: The influence of L-shape slot on front and back ratio of antenna.

using the passive resonator and the L-shaped narrow slot. Through the two methods, the open-slot antenna can achieve good directional radiation and wide band characteristics at the same time, and the antenna also has a relative small size. The size of the antenna medium substrate is $W \times L = 22\,\text{mm} \times 24\,\text{mm}$. The measured results of the antenna will be discussed in the following part.

6. Experimental Results

In order to verify the validity of designed antenna, some related measure experiments are made, and the physical picture of the proposed antenna is shown in Figure 10. It adopts a 50-ohm SMA connector in the antenna feeding port. The

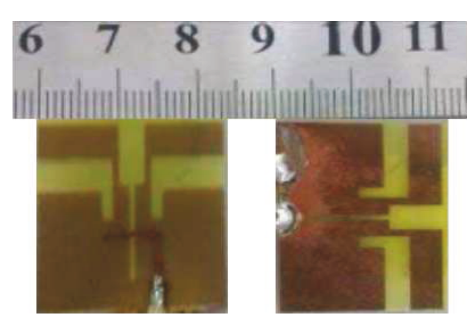


Figure 10: The designed antenna photo.

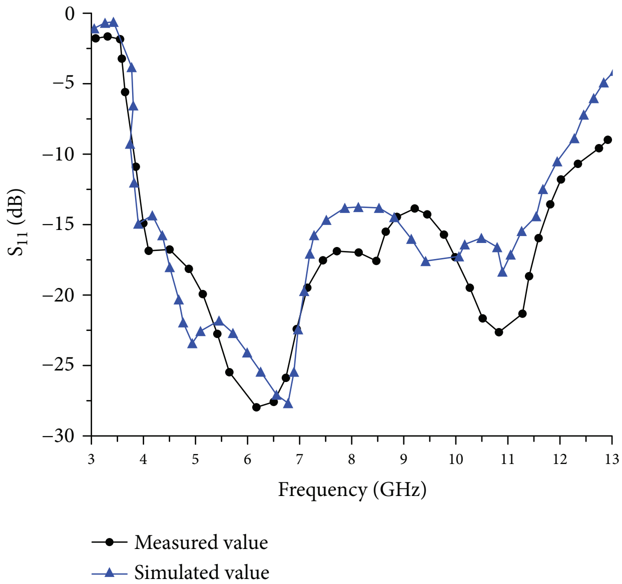


FIGURE 11: The measured and simulated value of antenna reflection coefficient.

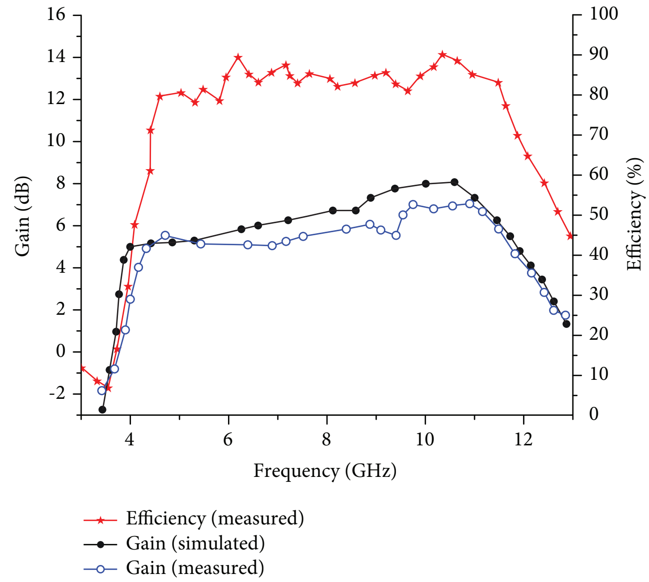


FIGURE 12: The measured and simulated value of antenna gain.

impedance width of the antenna is tested through Agilent E5071B network analyzer in the laboratory environment, and the radiation pattern and gain of antenna are obtained through the designed antenna measurement system and according to related tested standard.

The simulation and experimental results of the antenna reflection coefficient are given out in Figure 11. It can be seen from the figure that the measured results and simulation results of the reflection coefficient are nearly agreed with each other. $|S_{11}| < -10$ dB is defined as the impedance width of the antenna, and the impedance width of the antenna simulation is about 87.2%, covering the frequency from 3 GHz to 11.2 GHz. The measured impedance bandwidth of the antenna is 105.3%, covering the frequency from 3 GHz to 13 GHz.

The difference between the measured results and the simulation results may be caused by the SMA joint and the test errors. Compared with the antenna proposed in the paper [11, 12], the open-slot antenna presented in the paper can obtain a relative wide impedance bandwidth and a relative small antenna size.

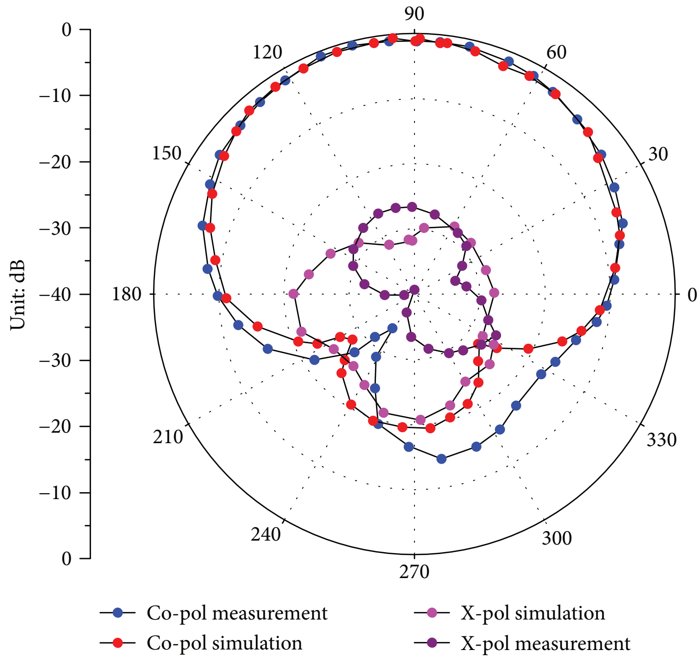
The simulation and experimental results of antenna gain are shown in Figure 12. From Figure 12, it can be seen that the measured and the simulation results of antenna gain are in good agreements. The minimum value of measured gain of the antenna is at 3.5 GHz frequency point, the gain value is 1.4 dB, and the maximum value of antenna gain is at 10.2 GHz frequency point, gain value of which is 6.2 dB. The result shows that the antenna can obtain a moderate gain larger than 4 dB.

Figure 12 also gives the measured radiation efficiency of the antenna. The measured value of the radiation efficiency is given directly by the antenna test system. According to the measured results, it can be known that in the effective working frequency band of the antenna (from 3.15 GHz to 12.8 GHz), the measured radiation efficiency of the antenna is about 80%. And in the frequency band which is higher than 12.8 GHz, the radiation efficiency of the antenna will be decreased rapidly due to the effect of the mismatching impedance.

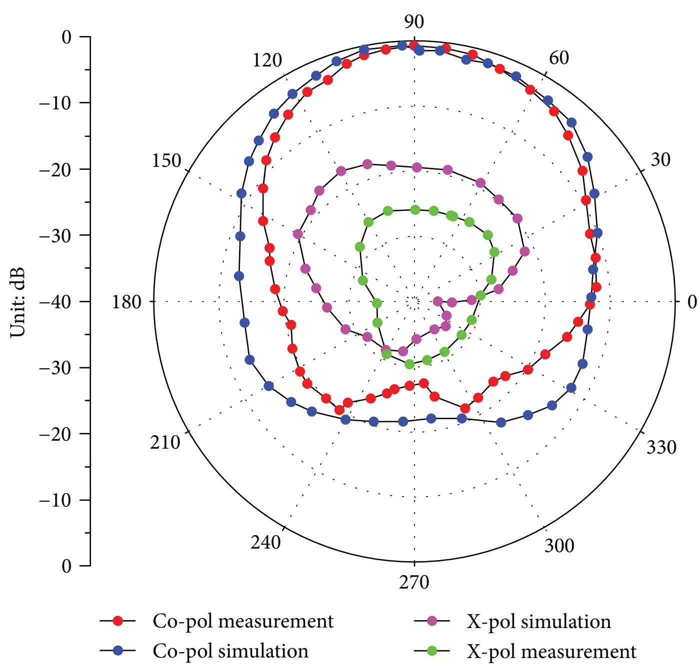
Figure 13 shows the radiation pattern of the simulation and test of the antenna at different frequency points on E-plane. Figure 14 gives out the radiation pattern of the simulation and measure of the antenna at different frequency points on H-plane. Through the observation of Figures 13 and 14, the radiation pattern of the antenna and the radiation pattern of the simulation are nearly matched at the four frequency points. At the same time, the simulated and measured results of radiation pattern show that the opening slot antenna has good characteristics of directional radiation, the main-lobe beam of radiation pattern of the antenna points to the direction of y-axis, and within the effective bandwidth of the antenna, the main-lobe direction of radiation antenna has no obvious changes, which indicates that the antenna has stable radiation direction ability.

Figures 13 and 14 give out the simulation and test results of the cross-polarization level of the open-slot antenna at different frequency points. It can be seen that the cross-polarization characteristics of open-slot antenna designed are weak. In the effective operating frequency range of the antenna, the maximum cross-polarization power level of E-plane is −17 dB and 18 dB. In addition, in the maximum radiation direction of the antenna, the cross-polarization power level of the E-plane is less than −18 dB.

As for the directional radiation antenna, the other key parameter is the front-back signal ratio of the radiation pattern, it is the parameter to reflect the directional



(a)



(b)

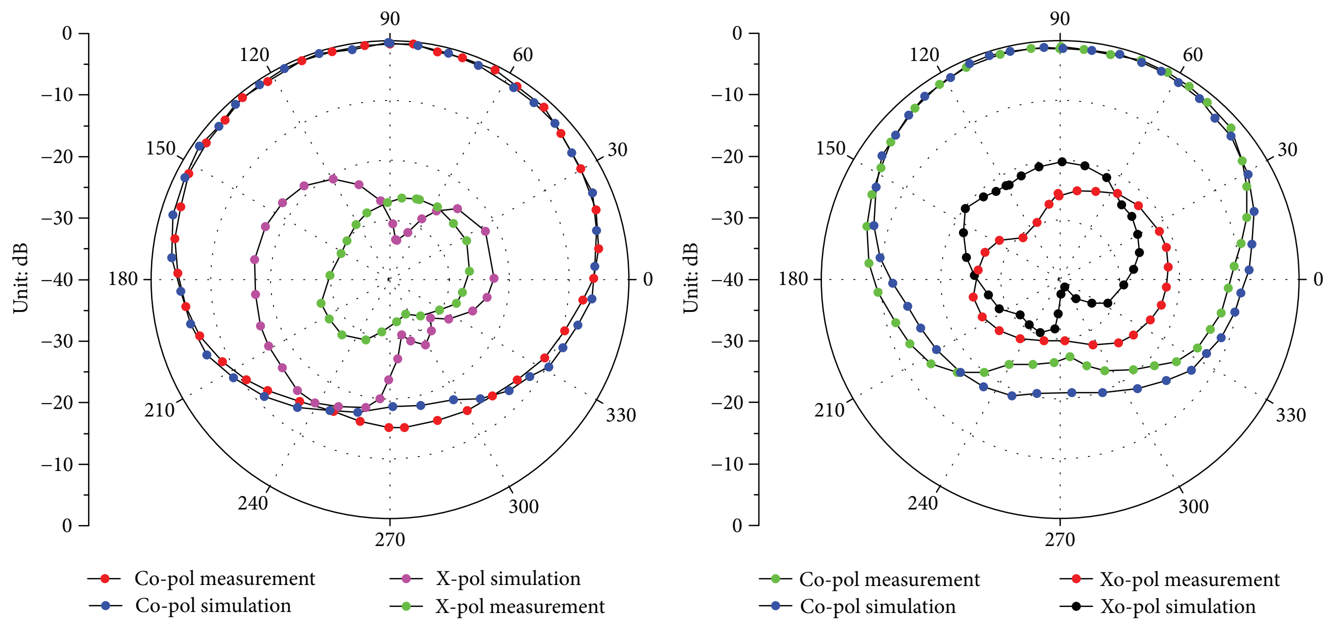
FIGURE 13: The simulated and measured radiation pattern on E-plane of antenna. (a) 6 GHz. (b) 8 GHz.

radiation capability of the antenna. In Figure 15, it shows the simulation and measured results of the front and back ratio of the antenna. As it can be seen from Figure 15, in the effective working band of the antenna, the measured results of the front-back signal ratio are basically consistent with the simulation result. Time-domain characteristics of UWB antenna in the main radiation direction are shown in Figure 16.

As shown in Figures 17 and 18, we adopt the designed antenna, and it can be found that the image quality is improved apparently, which indicates that the bandwidth of the antenna is improved.

7. Conclusions

According to the basic theory of radiation and conduction slot, the slot antenna feed structure and slot shape are researched thoroughly, and it presents a miniaturized microstrip feed structure and proposes a new type of slot antenna through which the broadband impedance matching



(a)

(b)

Figure 14: The simulated and measured radiation pattern on H-plane of antenna. (a) 6 GHz. (b) 8 GHz.

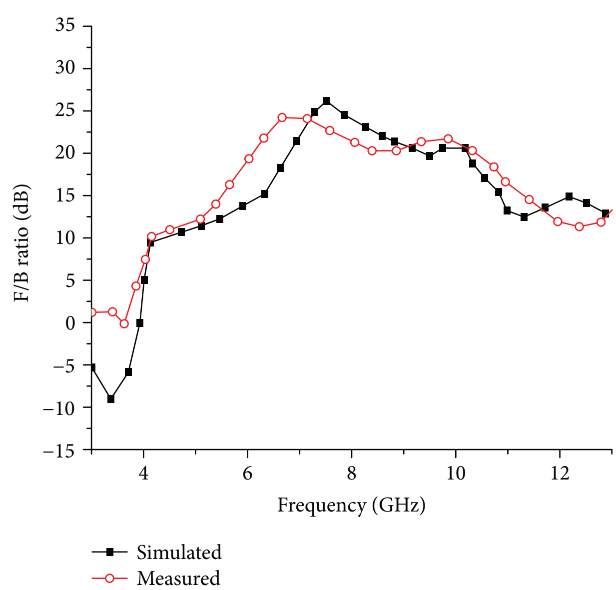


Figure 15: The simulated and measured front and back ratio of radiation pattern of antenna.

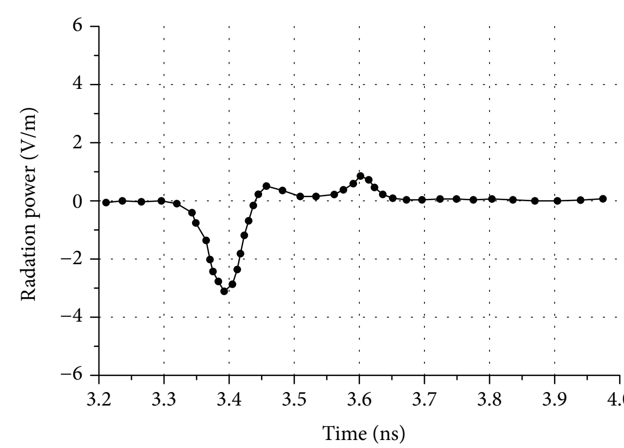


Figure 16: Time-domain characteristics in the main radiation direction.

characteristics can be achieved. Through the related measurements, we find that the common slot antenna radiation parameters, such as the gain, power bandwidth, and side-lobe size, cannot be changed among a broad frequency band, and the antenna's broadband applications are limited. At the same time, as a kind of commonly used broadband detection antenna, the antenna is required to have smaller side lobe and lower lobe power level at the same time. Therefore, it designed a ladder-like open-slot antenna, and then through the adoption of a pair of narrow L-shaped slot, the antenna impedance bandwidth is broadened and the ability of the directional antenna radiation is also improved. According to the test results of the antenna, $|S_{11}| < -10$ dB is defined as the impedance width of the antenna, which can obtain the relative impedance width of 105.3%, covering the frequency range of 3 GHz to 13 GHz. The antenna adopts the improved floor structure to increase the electrical length of the outer edge of the antenna and realize the miniaturization of the antenna, and it can improve the impedance matching in the antenna band with a stairway connection structure. The simulation and test results show that the proposed technical scheme is very effective and the purpose of antenna

(a) (b)

Figure 17: Images received from the UAV through old antenna.

(a) (b)

Figure 18: Images received from the UAV through designed antenna.

miniaturization and ultrawide frequency band expanding are both achieved. In addition, the antenna has good directional radiation characteristics and group delay characteristics, so the designed antenna can be used in UAV airborne communication system.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

We declare that there are no conflicts of interests.

Acknowledgments

The work is supported by the National Nature Science Foundation of China for Northwestern Polytechnical University under Grant No. 11472222.

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