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NOVEL PRINTED YAGI-UDA ANTENNA WITH HIGH-GAIN AND BROADBAND

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Abstract—A high-gain and broadband printed Yagi-Uda antenna is proposed. The microstripline-to-balance microstripline technique is adopted in the feeding mode of the active dipole, which can help to realize the balanced-unbalanced transformation. The ground of the microstrip feeding line can function as a reflector, and both the longer reflector and the shorter director can also help the antenna achieve wideband. By altering the area of the substrate, the antenna gain can be effectively improved. A printed Yagi-Uda antenna operating at 3.5 GHz has been designed and manufactured. Both the simulated and measured results indicate that there is a high positive correlation between antenna gain and the substrate area extended from the front of the director, and antenna broadband characteristic would not be changed at the same time. Moreover, the impedance bandwidth of the proposed antenna can achieve 27.4%, and the maximum gain in the operating band can reach 10.6 dBi.

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1. INTRODUCTION

The rapid development of the civil and military wireless communications technology makes higher demands on the antenna performance. The miniaturization of the communication devices requires antennas with corresponding compact size. The compatibility of multiple communication systems and the prolongation of the communication distance also demand that antennas should possess broadband and high-gain characteristic. Therefore, the antenna miniaturization technique, broadband technique and high-gain technique become the hot spots in modern antenna research fields. Currently, researches in these areas mainly include the following aspects. First, the miniature broadband antennas, including various heterotype pole-antennas [1–5], and the circular monopole antenna is a representative, but this antenna cannot achieve high-gain unless organizing the antenna array [6, 7]. Second, the high-gain and broadband antennas, of which TEM horn antenna is one of their main research objects, and the planar TEM horn antenna, which is the deformation of the former [8, 9]. Third, the log-periodic dipole antenna and its deformations are also the hot issues [10, 11]. Moreover, the antennas above usually adopt a large metal sheet to obtain high-gain, which is not good for antenna stealth in military field.

A high-gain and broadband printed Yagi-Uda antenna is proposed in this paper. A longer ground as the reflector and a shorter director are introduced to achieve a wide band. Controlling the substrate area extending from the front of the director can effectively improve antenna gain, which can realize the goal of using less metal to obtain higher gain. Design of the proposed antenna, as well as the simulated and experimental results, will be presented in the following sections.

2. ANTENNA SIMULATION AND ANALYSIS

2.1. Antenna Structure

The geometrical configuration of the proposed novel printed Yagi-Uda printed antenna with relevant parameters is shown in Fig. 1.

The antenna adopts a dipole as the radiator, as shown in Fig. 1(a). One arm of the dipole is connected to the balanced microstrip line on the back side of the substrate with a plated via-hole, as shown in Fig. 1(b). The microstripline-to-balanced microstripline technique is adopted for the dipole feeding. In this case, the ground of the microstrip feeding line functions as the reflector. In addition, a parasitic pole is introduced as the director in the front of the dipole. Structural parameters of the antenna are presented in Fig. 1, which

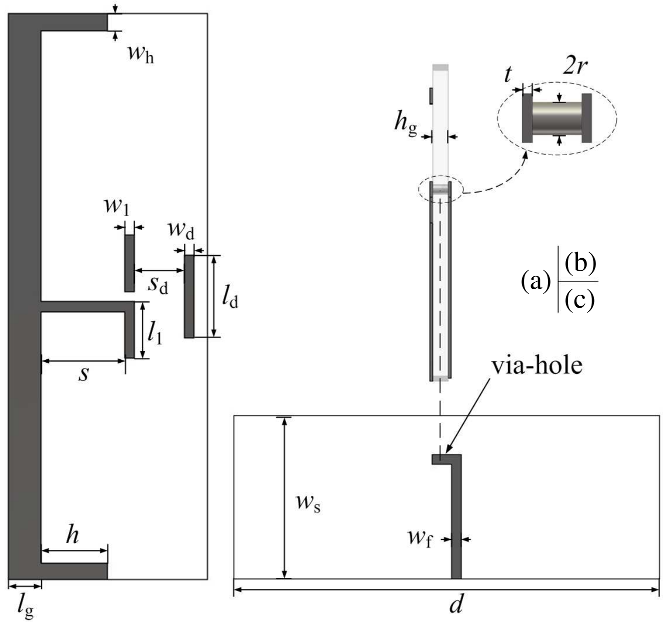


Figure 1. Sketch of the proposed antenna with associated geometrical parameters, (a) Front-view, (b) Left-view, (c) Back-view.

include s, the height of the dipole, l_1, the arm length of the dipole, s_d, the distance between director and dipole, d, the length of the substrate, w_s, the height of the substrate, l_d, the length of the director, h, the folded length of the ground, h_g, the thickness of the substrate, and r, the radius of the plated via-hole. The total antenna structure is similar to the traditional Yagi-Uda antenna, which also consists of the active dipole, reflector and director, except that their dimensions, as well as the feeding structure, have been greatly improved in this proposed antenna. The relative permittivity of the dielectric substrate is $\varepsilon_r = 4.4$. The antenna model is simulated by CST Microwave Studio®, a 3-dimentional full wave electromagnetic simulation software. The simulated results indicate that the structural parameters most influencing the antenna performance mainly include s, d, h and w_s.

2.2. Effects of Dipole Height on Antenna Performance

The simulated results of reflection coefficient with varying dipole height, s, are shown in Fig. 2. It can be seen that with the increase of s,

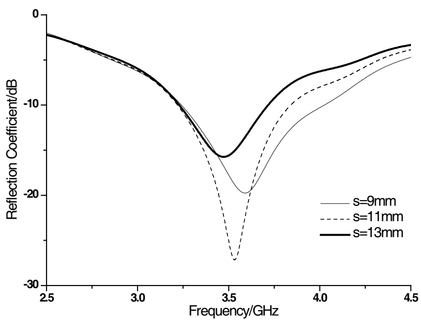


Figure 2. The simulated results of reflection coefficient with varying dipole height.

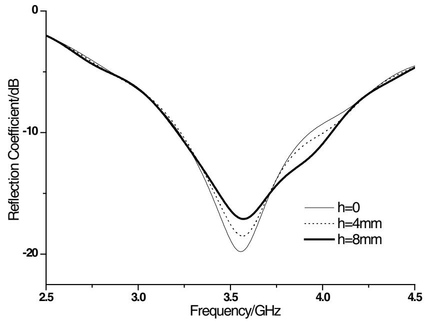


Figure 3. The simulated results of reflection coefficient with varying folded length.

the central frequency of the operating band with reflection coefficient less than -10 dB will reduce, and specifically, the lower limit of the band remains unchanged when the upper limit decreases, which causes the bandwidth reduction. The further simulation indicates that the decrease of s would improve bandwidth and gain. Therefore, adjusting s appropriately can broaden antenna bandwidth and improve gain.

2.3. Effects of Substrate Length on Antenna Performance

The length of the dielectric substrate, d, mainly influences antenna gain and the simulated results of antenna performance with varying d presented in Table 1. When d increases, the central frequency of the impedance bandwidth almost remains the same, and bandwidth has a slight fluctuation. However, antenna gain fluctuates obviously. Hence, altering the value of d can control the antenna gain and bandwidth to some extent.

2.4. Effects of the Ground Folded Length on Antenna Bandwidth

Figure 3 shows that the simulated results of the reflection coefficient with varying folded length of the ground, h, and it can be seen that the major impact of h on the antenna performance reflects in the bandwidth. As h increases, the lower limit of the impedance bandwidth remains unchanged when the upper limit increases, which can broaden the antenna bandwidth. The further simulation indicates that h has no impact on antenna gain. Therefore, values of h can adjust antenna bandwidth.

Table 1. The simulated results of antenna performance with varying d.

d (mm)	Central frequency (GHz)	Bandwidth (GHz)	Gain (dBi)
100	3.60	0.68	7.21
150	3.62	0.72	6.28
180	3.59	0.67	6.46
200	3.59	0.79	6.97
240	3.61	0.68	6.54
300	3.61	0.72	6.22

2.5. Effects of Substrate Height on Antenna Gain

With the height of the dielectric substrate unchanged, the shape of the substrate which is placed in front of the director is designed into different types, as shown in Fig. 4 ($w_s = 200\,\mathrm{mm}$), to alter the substrate area. The simulated results of antenna performance are presented in Table 2. It can be seen that the larger the substrate is, the higher antenna gain can be obtained, but the central frequency and bandwidth almost remain unchanged when the substrate possesses large area. Namely, there is a high positive correlation between antenna gain and the substrate area. When the substrate is in rectangle shape, antenna has the maximum gain. The relationship between antenna gain and the substrate area extending from the front of the director, namely altering w_s, has been further simulated, and the results are presented in Table 3. It also indicates that increasing w_s can effectively improve antenna gain.

Table 2. The simulated results of antenna performance with different substrate shapes in the same w_s.

Shape	Central frequency (GHz)	Bandwidth (GHz)	Gain (dBi) at 3.5 GHz
Rectangle	3.46	0.85	7.97
Triangle	3.45	0.85	6.85
T shape	3.71	0.73	5.83
Semicircle	3.45	0.86	6.97
Dome	3.45	0.85	7.26

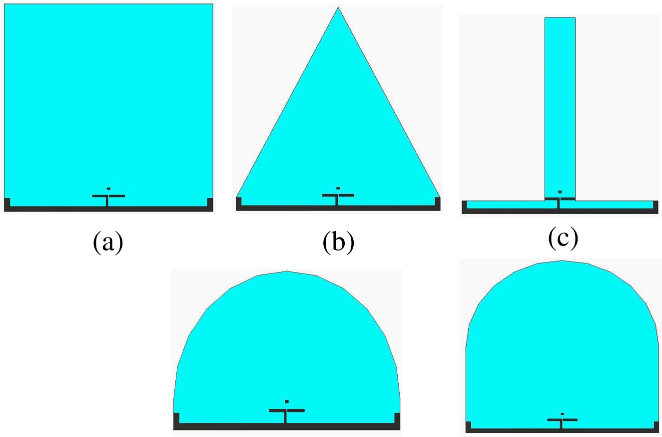


Figure 4. Different shapes of the substrate, (a) Rectangle, (b) Triangle, (c) T shape, (d) Semicircle, (e) Dome.

Table 3. The simulated results of antenna gain at 3.5 GHz with different w_s.

w_s (mm)	100	200	300	400	500
Gain (dBi)	6.40	7.97	9.51	11.15	12.56

2.6. Substrate Splicing

According to the discussion and analysis above, the increase of the substrate height, w_s, can obviously improve antenna gain, and the antenna effective size is small. However, if high-gain is required in practical manufacture, it is required to enlarge the PCB, which would increase the production costs. Hence, the antenna performance has been simulated under the situation that there is a gap occurring when the proposed antenna is spliced with a large substrate to improve gain, the model as presented in Fig. 5. The simulated results show that this method can also achieve high-gain when antenna bandwidth unchanged. Therefore, the method can be applied to antenna manufacture to reduce costs. Especially, a waste substrate can be used to improve antenna gain.

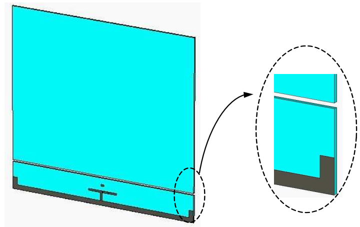
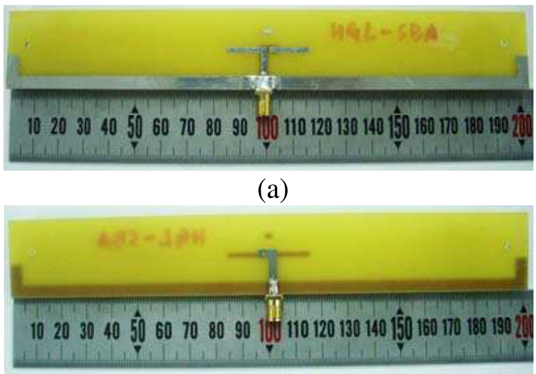


Figure 5. The model of substrate splicing.



(a)

(b)

Figure 6. The prototype of the proposed antenna, (a) Front-view, (b) Back-view.

3. DESIGN AND MEASUREMENT OF THE ANTENNA OPERATING AT 3.5 GHZ

After analyzing the simulated results above, the optimal structural parameters of the proposed antenna operating at 3.5 GHz can be obtained as the following: $s = 9$ mm, $d = 200$ mm, $h = 8$ mm, $w_s = 30$ mm, $l_1 = 15$ mm, $l_d = 3$ mm, $s_d = 5$ mm, $h_g = 1.5$ mm, $l_g = 5$ mm. Prototype of the antenna has been manufactured and measured in the anechoic chamber using the Agilent E8363B vector network analyzer, as shown in Figs. 6 and 7. The simulated and measured results are presented in Fig. 8. From the results, the impedance bandwidth of the proposed antenna can achieve 3.05–4.02 GHz with reflection coefficient less than -10 dB, and the relative bandwidth is 27.4%. Antenna gain with different substrate-spliced lengths have also been measured and shown in Table 4. The gain is actually improved with the increase of substrate height, which can verify that the design idea is feasible. When the substrate-splicing length takes 570 mm, antenna gain at

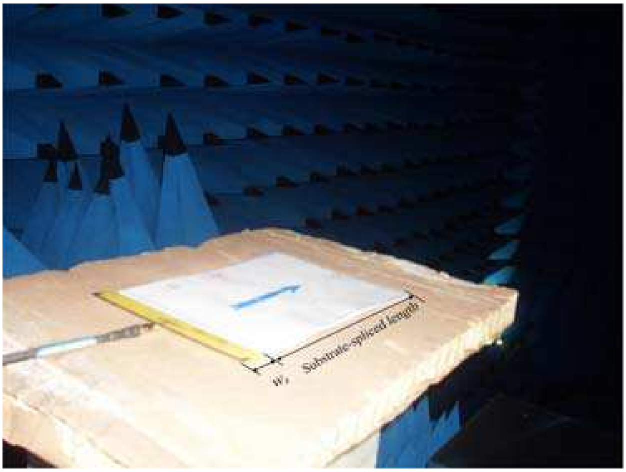


Figure 7. The measurement in anechoic chamber.

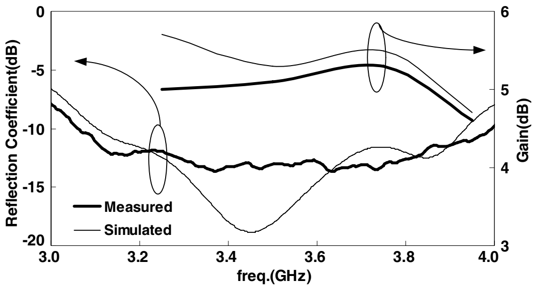


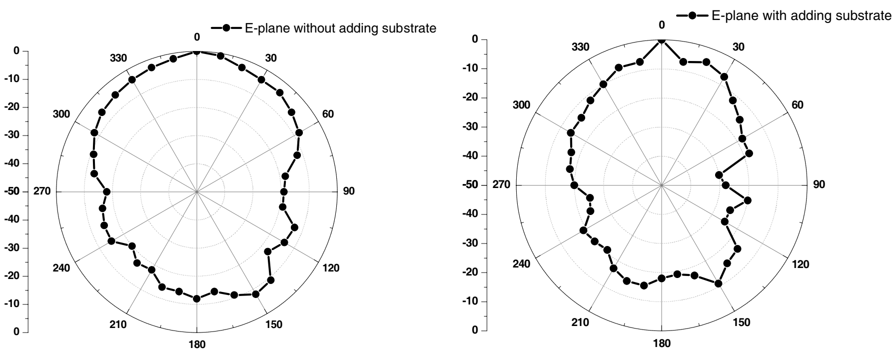
Figure 8. The simulated and measured results of the proposed antenna.

Table 4. The measured results of antenna gain with different substrate-spliced length.

Substrate-spliced length (mm)	260	330	570
Increase of gain (dB, @3.5 GHz)	1.1	4.7	5.5

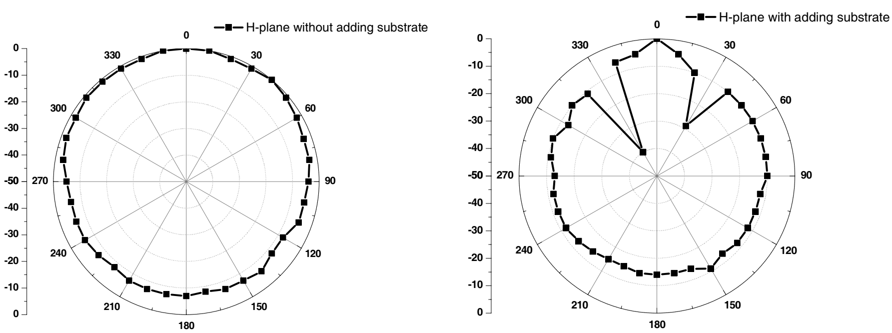
3.5 GHz can be improved 5.5 dBi higher and reaches 10.6 dBi, but the antenna effective size remains the same.

In addition, Fig. 9 and Fig. 10 show the measured results of radiation pattern at 3.5 GHz. It can be seen that patterns in E- and H-planes have been compressed when splicing the substrate. And the mainlobe width decreases from 60° (E-plane), 160° (H-plane) without adding substrate to 14° (E-plane), 17° (H-plane) with adding substrate, respectively, so that antenna gain can be greatly improved. It also demonstrates that aggregation effect occurs in the radiation direction after splicing the substrate, which functions as the lens. Table 5 draws a comparison of antenna performance between the proposed antenna and Reference [12, 13]. Therefore, the novel printed Yagi antenna possesses broadband and high-gain. Especially, the improvement of gain has little influences the bandwidth, which is remarkably different from the design of Un-YPA proposed in [12]. In addition, raising gain dose not depend on increasing the director's number, and less metal is used to manufacture the proposed antenna, which is significant to antenna stealth characteristics.



(a) (b)

Figure 9. The measured results of radiation pattern in E-plane. (a) E-plane without adding substrate. (b) E-plane with adding substrate.



(a) (b)

Figure 10. The measured results of radiation pattern in H-plane. (a) H-plane without adding substrate. (b) H-plane with adding substrate.

Table 5. The comparison between the proposed antenna and References [12, 13].

Antenna Type	Central Frequency (GHz)	Relative Bandwidth (%)	Gain (dBi)
Proposed Antenna	3.5	27.4	10.6
Un-YPA [12]	2.47	15	7.9
Bi-YPA [12]	2.39	15.8	5.5
Quasi-Yagi Antenna [13]	26	31	9.8

4. CONCLUSION

A novel printed Yagi-Uda antenna with high-gain and broadband is proposed. Increasing the reflector length and reducing the director length can both broaden antenna bandwidth without introducing complicated balanced-unbalanced transformer, which can miniaturize the antenna size obviously. Moreover, prolonging the length of the substrate which is placed in front of the director can effectively improve antenna gain and will not increase the area of antenna metal sheet. This antenna design for improving gain is significant to antenna stealth.

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