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A Novel Design of Folded Dipole for Broadband Printed Yagi-Uda Antenna

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Abstract—In this paper, a printed wideband Yagi-Uda antenna with a novel folded dipole driver is proposed. The folded dipole driver is comprised of a folded dipole and a microstrip feedline which functions as an internal balun to mainly determine its wide impedance bandwidth. With the optimized parameters, an operating band of 1.69 GHz $\sim$ 2.72 GHz can be obtained. Besides the folded dipole driver, the broadband printed Yagi-Uda antenna also consists of three directors and a reflector. Its wideband performance is mainly determined by the folded dipole driver, while the reflector and directors improve its performance slightly. By optimizing the geometrical parameters of the folded dipole driver, a bandwidth of 61.8% (1.53 GHz $\sim$ 2.93 GHz) for return loss being higher than 10 dB is achieved. The proposed printed Yagi-Uda antenna is realized on FR4 substrate with a measured operating bandwidth of 62% (1.51 GHz $\sim$ 2.94 GHz), a flat gain (5.6 dB $\sim$ 7.3 dB), more than 10 dB front-to-back ratio and lower than -15 dB cross-polarization level.

1. INTRODUCTION

A printed Yagi-Uda antenna, firstly introduced in [1], comprises a reflector, a driver and several directors. The truncated ground plane of the antenna acts as a reflector for the transverse-electric surface wave generated by the driver. The parasitic directors are used to enhance the radiation in the forward end fire direction. Owing to the advantages of high gain, end-fire radiation pattern, ease-fabrication and low cost, the printed Yagi-Uda antenna has attracted much interest with many applications in radar, millimeter-wave imaging, wireless communication system and etc.. As the development of wireless communication proceeding, many significant efforts have been made to design printed Yagi-Uda antenna and improve its performance for several wireless communications such as the series-fed two bowtie dipole array for enhancing the front-to-back ratio [2], the Sierpinki or Koch fractals shaped dipole elements for reduction in size [3–5] and dipole driver with derived sections for multiband operation [6, 7].

Also many printed broadband Yagi-Uda antennas [8–10] have been reported in recent years. In the design of these antennas, designing a suitable feed structure is the key procedure to obtain a wide operating band. The described quasi-Yagi antenna in [8] is fed by a microstrip line-to-coplanar strip line (MS-to-CPS) transition is presented. This transition introduced a phase delay of 180° between two MS branches by adjusting their length. A bandwidth of 48% (7.3 GHz $\sim$ 11.9 GHz) for VSWR < 2 is achieved by this transition. In [9], a coplanar waveguide-coplanar stripline (CPW-CPS) transition is utilized to alleviate the complicated feeding network. The antenna consists of two director elements, a driven element and ground plane acting as a reflector while the 10-dB-return-loss bandwidth of this antenna is 44%. A wideband quasi-Yagi antenna fed by microstrip-to-slotline transition is presented in [10]. The transition consists of a microstrip radial stub and slot radial stub, both at 90°, but with different radii, and a wide bandwidth of 46% (4.64 GHz $\sim$ 7.42 GHz) for return loss being higher than 10 dB is achieved. In [11], a quasi-Yagi antenna was designed by using a folded dipole as driver element. Compared with the standard quasi-Yagi antenna, the antenna has a reduction in the length of driver and an operational bandwidth of approximately 1.3 : 1.

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In this paper, a novel design of folded dipole antenna in Figure 1(a) is introduced. The folded dipole antenna consists of a folded dipole and a microstrip feedline. A microstrip feedline acts as an internal balun to enhance its operating band. In Figure 1(a), the outer of SMA is connected with the fold dipole while its inner pin being welded with microstrip feedline. By choosing suitable parameters of structure, a considerable impedance bandwidth of 45.5% (1.69 $\sim$ 2.72 GHz) can be achieved. In order to make the antenna to have a wider bandwidth and good end fire radiation characteristic, the folded dipole is utilized as the driver element in printed Yagi-Uda antenna. In Figure 1(b), the proposed printed Yagi-Uda antenna consists of a reflector, a folded dipole driver and three directors. This antenna also utilizes a rectangular metal strip as a reflector instead of the ground plane reflector in [8–10]. By optimizing the geometrical parameters of feed line structure, an operating bandwidth of 61.8% (1.53 GHz $\sim$ 2.93 GHz) is obtained with a stable gain between 5.6 dB and 7.2 dB. So the proposed antenna can be a good Part in some wireless communication systems such as PCS (1.75 GHz $\sim$ 1.87 GHz), WCDMA (1.92 $\sim$ 2.17 GHz), WLAN (2.4 $\sim$ 2.48 GHz), LTE 2300/2500(2.3 GHz $\sim$ 2.4 GHz/2.5 GHz $\sim$ 2.69 GHz). In many applications [11–13], the planar quasi-Yagi antenna is always designed as an element in antenna array. So another modification of the proposed folded dipole in Figure 1(d) is proposed to make this antenna as an appropriate element in array with printed feeding network.

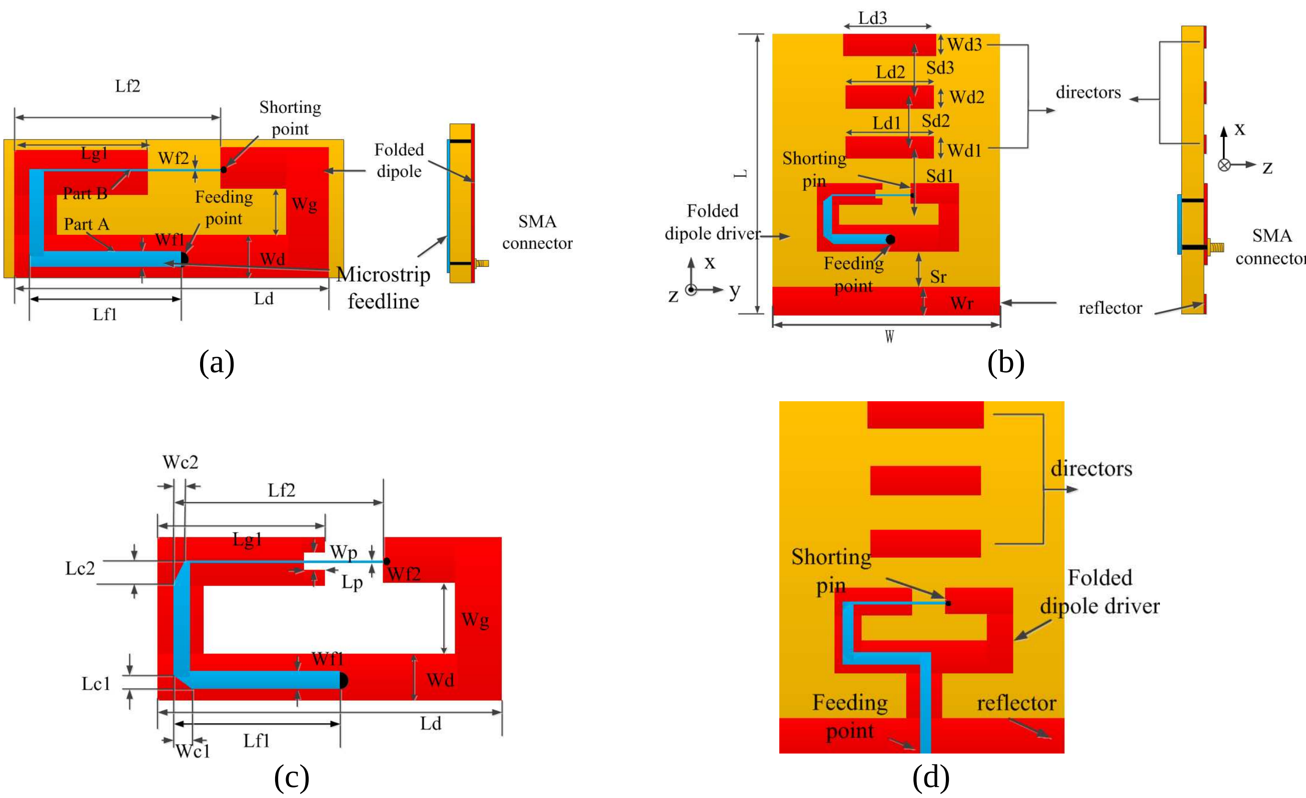


Figure 1. (a) The overview of the folded dipole. (b) The overview of the proposed Yagi-Uda antenna. (c) The detail of the modified folded dipole in printed Yagi-Uda antenna. (d) The modified form of the proposed Yagi-Uda antenna.

2. ANTENNA DESIGN AND PARAMETERS STUDY

2.1. Folded Dipole Antenna Design

As shown in Figure 1(a), the folded dipole is an approximate rectangular metal loop fed at center point. It functions as two parallel $\lambda/2$ length dipoles with the similar current distribution. The proposed folded dipole antenna is designed on a $60 \times 34 \times 1.6\text{-mm}^3$ FR4 substrate ($\varepsilon_\gamma = 4.4$, $\tan\delta = 0.02$). The microstrip feedline is etched on the front side of substrate while the folded dipole on the back. The microstrip feedline can be divided into two parts, A and B, with different widths ($Wf1$ and $Wf2$). Part A is connected with inner pin of SMA while the outer of SMA is connected with folded dipole. Part B and dipole is shorted with via. The length (Ld) of dipole is set as $0.5\lambda_{eff}$. The λ_{eff} refers to the effective wavelength at the center frequency of operation with evaluating the effective dielectric constant value ε_{eff} as $(\varepsilon_r + 1)/2$. In order to have a good impedance characteristic with input feed, the width ($Wf1$) of Part A is set as 3.5 mm while the width (Wd) of folded dipole is 11 mm. Thus the microstrip feedline has 50 Ω characteristic impedance. By the analysis of even and odd mode excitation, it can be obtained that the input impedance of this folded dipole is four times larger than that of half-wavelength dipole. For half-wavelength dipole, its input impedance is about 70 Ω. So the input impedance (Rin) of the proposed folded dipole antenna is about 280 Ω. By the theory of stepped impedance conversion, the microstrip feedline with two different parts is designed as a balun to make the antenna having a broad operating band. The equivalent circuit of feeding structure is shown in Figure 2. The section A is a transmission line with characteristic impedance $Z_{OA} = 50\,\Omega$ while the section B is $\lambda/4$ impedance transformer with characteristic impedance Z_{OB}. The Z_{OB} is equal to about 118 Ω by the equation of $Z_{OB} = \sqrt{Z_{OA} R_{in}}$ in [14]. So the width ($Wf2$) of Part B is about 0.5 mm. By the suitable parameters ($Lf1 = 24.25$ mm, $Lf1 = 3.5$ mm, $Lf2 = 34.5$ mm, $Wf2 = 0.5$ mm, $Ld = 51.75$ mm, $Wd = 11$ mm, $Wg = 10$ mm, $Lg1 = 20.5$ mm), a good impedance bandwidth of 45.5% (1.69 ∼ 2.72 GHz) can be obtained which is shown in Figure 3.

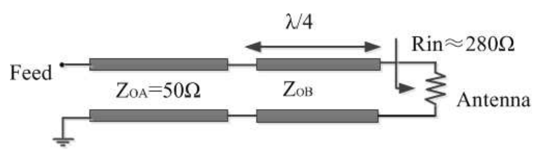


Figure 2. The equivalent circuit of the feeding structure.

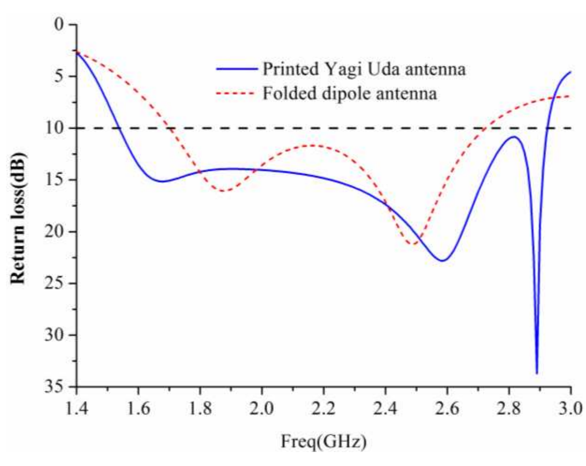


Figure 3. Return loss of the optimized proposed folded dipole and printed Yagi-Uda antenna.

2.2. Printed Yagi-Uda Antenna Design

The configuration of the planar Yagi Uda antenna is shown in Figure 1(b). The proposed antenna is designed on the FR4 substrate ($\varepsilon_\gamma = 4.4$, $\tan\delta = 0.02$) of the size of 117 mm × 90 mm × 1.6 mm. The directors, folded dipole and reflector are printed on the back side of the substrate while the microstrip feedline on the front side. The folded dipole antenna in Section 2.1 is utilized to enhance the broadband performance. In Figure 1(c), the folded dipole and microstrip feedline has a little modification to slightly enhance its performance. Also the directors can moderately improve the wideband performance of printed Yagi-Uda antenna with couple effect between directors and folded dipole. According to the theory of Yagi-Uda antenna, the length ($Ld1$, $Ld2$, and $Ld3$) of director should be about $0.45\lambda_{\mathit{eff}\,\max}$ with the length (W) of reflector being about $0.55\lambda_{\mathit{eff}\,\min}$. The $\lambda_{\mathit{eff}\,\max}$ refers to the effective wavelength at the highest operating frequency about 2.9 GHz while the $\lambda_{\mathit{eff}\,\min}$ refers to the effective wavelength at the lowest operating frequency about 1.5 GHz. The effective dielectric constant value $\varepsilon_{\mathit{eff}}$ is evaluated as $(\varepsilon_r + 1)/2$. The distance between director and driver is about $0.15\lambda_0 \sim 0.3\lambda_0$ while the distance between driver and reflector is near $0.15\lambda_0 \sim 0.3\lambda_0$. The $\lambda_0$is the wavelength of the center frequency ($f_o = 2.2\,\text{GHz}$) in free space. So it is firstly assumed that $Ld1 = Ld2 = Ld3 \approx 28.4\,\text{mm}$, $Sr = Sd1 = Sd2 = Sd3 \approx 26\,\text{mm}$, $W \approx 68\,\text{mm}$. By optimizing the geometrical size of the proposed antenna with Ansoft HFSSv15.0, a broad operating bandwidth of 61.8% (1.53 GHz ∼2.93 GHz) is achieved as shown in Figure 3. The geometrical values are also listed in Table 1.

Table 1. Geometrical size of the proposed antenna (units: mm)

$Ld1$	$Wd1$	$Sd1$	$Ld2$	$Wd2$	$Sd2$	$Ld3$	$Wd3$	$Lc2$
32	10	29	32	10	22	32	10	2.65
Sr	$Wf2$	Wd	$Lf1$	$Wf1$	Wg	Ld	$Sd3$	$Wc2$
12	0.5	10	20.5	3.5	8	54.25	25	1.9
W	Wr	Wp	Lp	$Lg1$	$Lf2$	L	$Lc1$	$Wc1$
90	10	6	4.2	23.8	31.75	117	3.75	4.5

2.3. Parameters Study

For the proposed folded dipole antenna, the design of microstrip feedline is crucial to obtain a broadband operation. In Section 2.1, it can be deduced that the Part B of microstrip feedline has a great effect on the impedance bandwidth with different widths. The return loss and input impedance of the folded dipole antenna with different width ($Wf2$) is shown in Figure 4. In Figure 4(a), the return loss of proposed antenna can be improved with the width ($Wf2$) being decreased from 1.3 mm to 0.5 mm. The simulated result in Figure 4(b) shows that the input resistance and reactance of folded antenna is more and more closer to 50 Ω and 0 Ω when $Wf2$ is decreased from 1.3 mm to 0.5 mm. So a good impedance bandwidth can be achieved when $Wf2 = 0.5\,\text{mm}$.

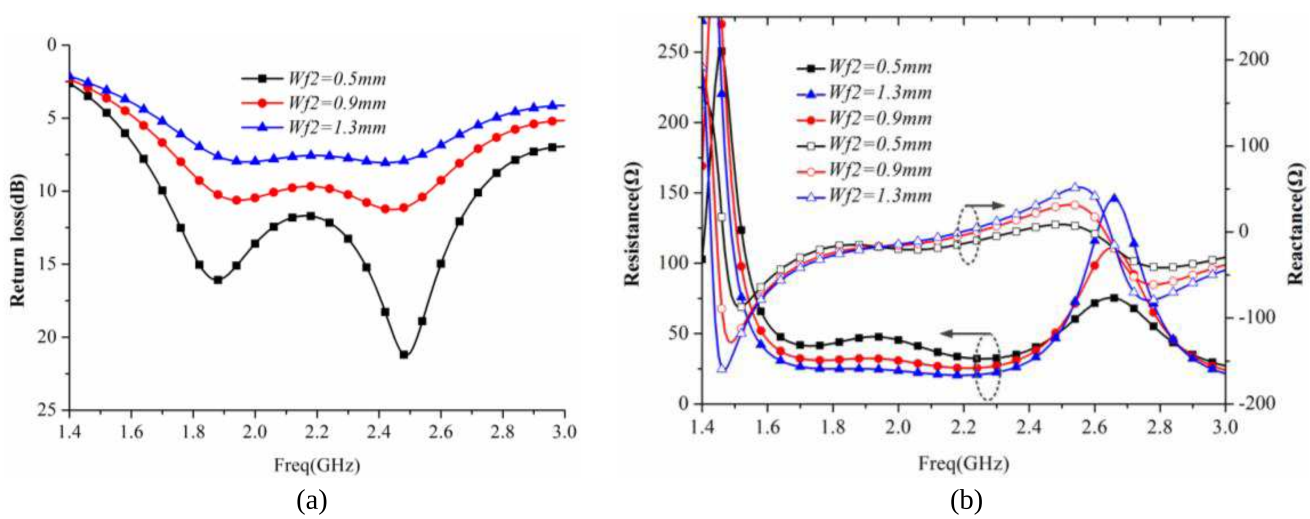
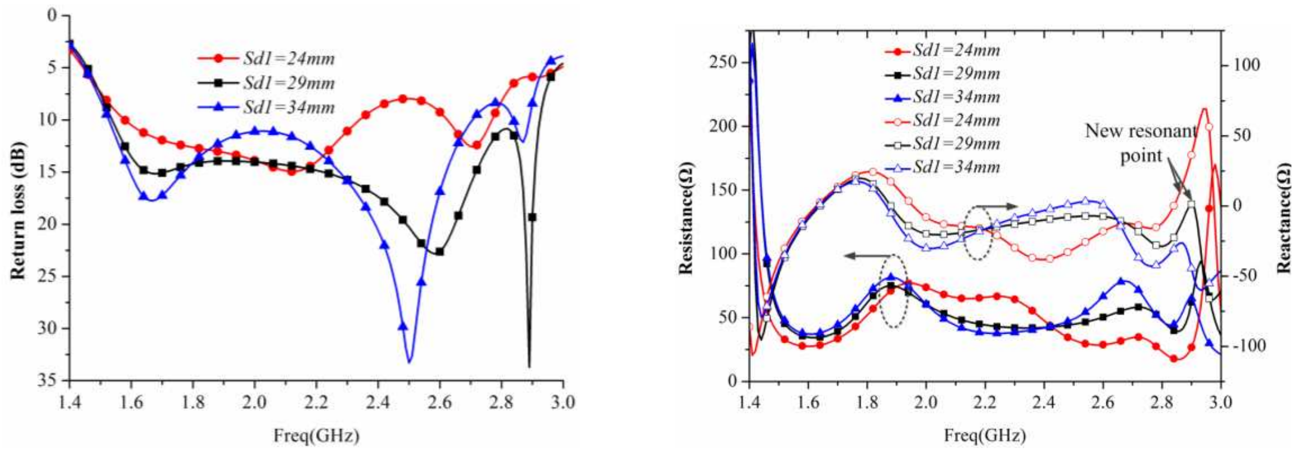


Figure 4. The effect of different $Wf1$ values on the folded dipole antenna. (a) Return loss (b) Resistance and reactance.



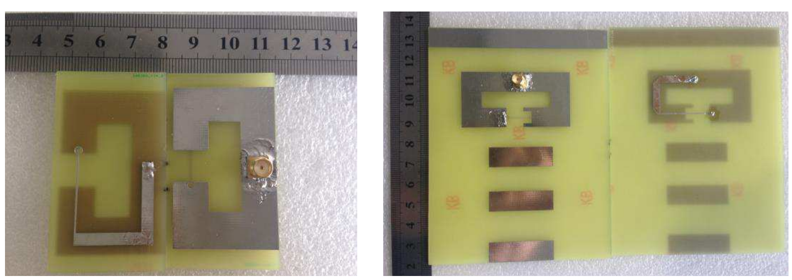
(a) (b)

Figure 5. The effect of different *Sd1* values on the folded dipole antenna, (a) return loss (b) input resistance and reactance.

In the process of designing the printed Yagi-Uda antenna, the distance between the first director and folded dipole affects deeply on the impedance characteristic. The return loss and input resistance and reactance of the proposed antenna with different $Sd1$ are shown in Figure 5. When $Sd1 = 24$ mm or 29 mm, it is showed in Figure 5(b) that a new resonant point at about 2.9 GHz is created by the directors being added and the new resonant frequency becomes lower when $Sd1$ decreases. When $Sd1 = 34$ mm, the influence of first director on the folded dipole is too small to create a new resonant point. It indicates that the return loss becomes bad when director is closer to the folded dipole.

3. SIMULATION AND EXPERIMENTAL RESULTS

The proposed folded dipole and printed Yagi-Uda antenna are fabricated with optimizing value as the photos shown in Figure 6.

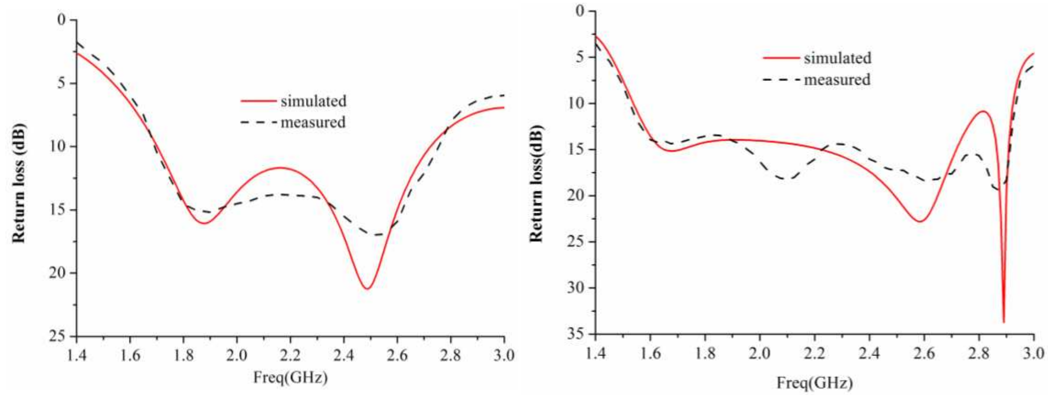


(a) (b)

Figure 6. The photos of (a) the folded dipole antenna, (b) the fabricated printed Yagi-Uda antenna.

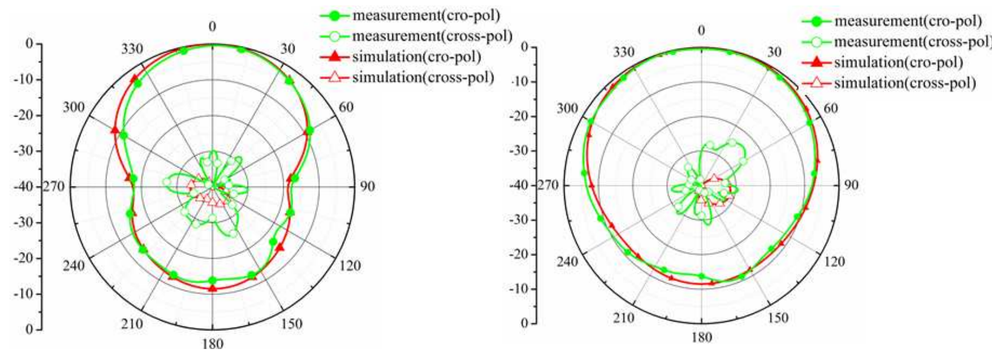
The simulated and measured return losses of the folded dipole and printed Yagi-Uda antenna are shown in Figure 7. As can be seen from Figure 7(a), the measured results show that the folded dipole antenna operates from 1.65 to 2.78 GHz for the return loss being higher than 10 dB, which agrees well with simulated results. In Figure 7(b), it is showed that the printed Yagi-Uda has a measured 10-dB-return-loss operating band (1.51 GHz $\sim$ 2.94 GHz) to cover some required wireless communication system such as PCS (1.75 GHz $\sim$ 1.87 GHz), WCDMA (1.92 $\sim$ 2.17 GHz), WLAN (2.4 $\sim$ 2.48 GHz), LTE2300/2500 (2.3 GHz $\sim$ 2.4 GHz/2.5 GHz $\sim$ 2.69 GHz). The simulated result is well validated by the measured result.

The measured and simulated radiation patterns of printed Yagi Uda antenna are plotted in Figure 8 for the XOZ and XOY planes at frequencies of 1.53 GHz, 1.9 GHz, 2.4 GHz, 2.93 GHz, respectively,

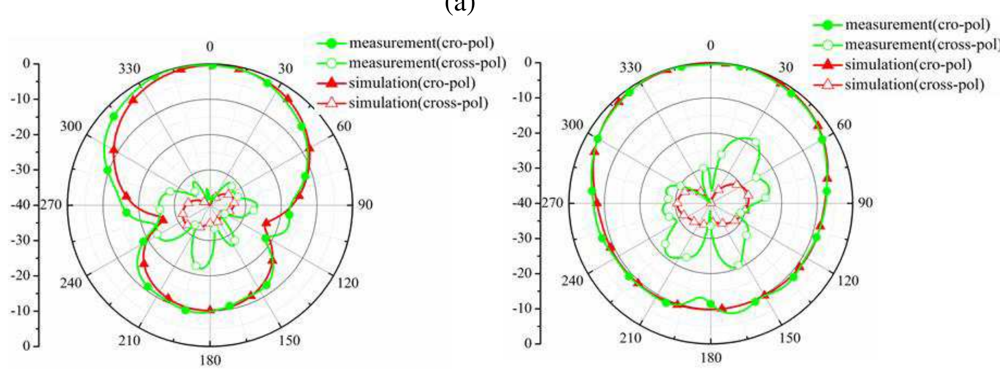


(a) (b)

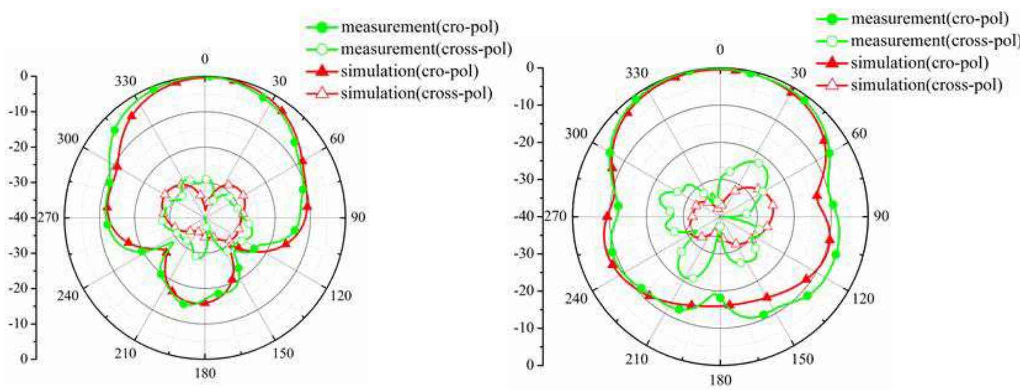
Figure 7. Measured and simulated return loss of (a) folded dipole antenna (b) printed Yagi-Uda antenna.



XOY plane (a) XOZ plane

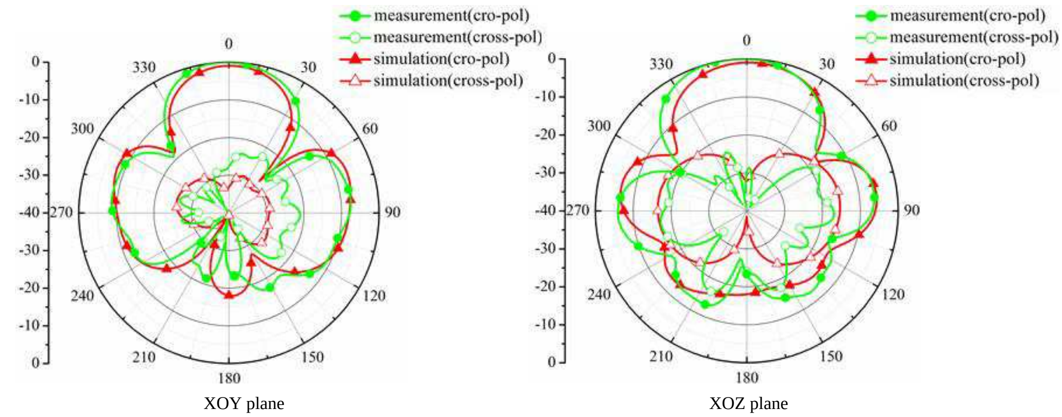


XOY plane (b) XOZ plane



XOY plane XOZ plane

(c)



(d)

Figure 8. Simulated and measured radiation pattern in XOY and XOZ plane at (a) 1.53 GHz, (b) 1.9 GHz, (c) 2.4 GHz, and (d) 2.93 GHz.

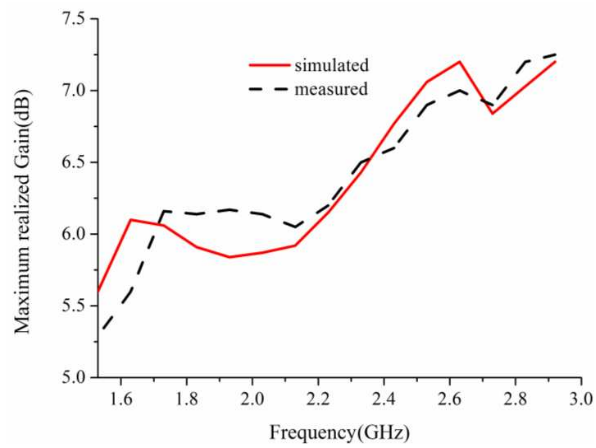


Figure 9. Measured and simulated maximum realized gain.

where a good agreement between the simulations and measurements can be observed. Figure 8 show that the measured and simulated half-power beam widths (HPBWs) are about 70° along the E-plane and 117° along the H-plane at 1.53 GHz. According to the measured and simulated results, the HPBWs are 79° along the E-plane and 115° along the H-plane at 1.9 GHz, while the HPBWs are 80° along the E-plane and 79° along the H-plane at 2.4 GHz. In the Figure 8(d), the radiation pattern at 2.93 GHz degrades with the HPBWs being 54° along the E-plane and 62° along the H-plane. These measurements and simulation also demonstrate a stable radiation pattern with a front-to-back ratio and cross-polarization level better than 10 and -15 dB, respectively.

The measured maximum gain of the printed Yagi-Uda antenna is presented with simulated gain in Figure 9. The measured gain of the antenna is $5.3 \sim 7.3$ dB across the operating bandwidth, which is in close agreement with the simulated gain of $5.6 \sim 7.2$ dB. With a stable radiation pattern and a flat gain ($5.3 \sim 7.3$ dB), the proposed printed Yagi-Uda antenna is a good candidate for transmitting and receiving applications in wideband wireless communication systems.

4. CONCLUSION

This paper describes a novel folded dipole antenna and a wideband planar Yagi-Uda antenna with the folded dipole being added. The internal microstrip feedline in folded dipole antenna operates as a balun to make the antenna having a wide operating band (1.69 GHz $\sim$ 2.72 GHz). A printed Yagi-

Uda antenna consists of a folded dipole, three directors and a reflector. With the effect of directors, a broad bandwidth of 1.53 GHz $\sim$ 2.93 GHz for the return loss being higher than 10 dB, a stable gain of 5.6 $\sim$ 7.2 dB, and a front-to-back ratio higher than 10 dB and cross-polarization lower than -15 dB, are obtained in simulation. All the simulated results are well validated by measured ones. For its nice performance in stable gain and radiation, the broadband printed Yagi Uda antenna can be applied in many wireless communication systems, such as PCS (1.75 GHz $\sim$ 1.87 GHz), WCDMA (1.92 $\sim$ 2.17 GHz), WLAN (2.4 $\sim$ 2.48 GHz), LTE 2300/2500(2.3 GHz $\sim$ 2.4 GHz/2.5 GHz $\sim$ 2.69 GHz).

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