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Novel Miniaturized Broadband Quasi-Yagi Antennas Based on Modified Bowties Driver for Wireless Technology Applications

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Abstract—This paper presents two novel miniaturized broadband Quasi-Yagi antennas which adopt compact layouts and two different modified bowties as driven dipoles. In these antennas, the microstrip feed and $\lambda/4$ impedance transformer are placed horizontally and rearranged in a same horizontal line with balun to reduce the vertical size. The horizontal size is reduced by loading the vertical metallic strips at the sides of bowtie driven dipole and ground patch. Compared with the conventional Quasi-Yagi antenna, the sizes of the two proposed antennas are decreased to approximately 50%. The experiment results exhibit that they have wide bandwidths of 2.27–3.35 GHz and 2.14–3.3 GHz for reflection coefficient below -10 dB. Their gains reach 4 dBi over the operation frequency band, which indicate that they can be applied conveniently in wireless communications and recognition fields like WLAN, RFID, WiMAX and LTE frequency bands.

1. INTRODUCTION

Yagi-Uda antenna was invented by Japanese researchers H. Yagi and S. Uda, and first published in an English language journal in 1928 [1]. It has been widely used in wireless communication, remote sensing and TV application for its advantages of high gain, end-fire radiation characteristics and simple structure [2]. For all that, the defects of conventional Yagi-Uda antenna are prominent such as large size and heavy weight. Many scholars have done much research to overcome them. Prof. T. Itoh [3] presented a novel planar Yagi-Uda antenna which is printed on a printed circuit board. It has similar principles to Yagi-Uda antenna and named Quasi-Yagi antenna. It not only retains the advantages of the conventional Yagi-Uda antenna, but also possesses the property of microstrip antenna such as low profile, light weight and easy fabrication [4, 5]. Quasi-Yagi antennas are used widely in these days [6, 7].

However, with the development of wireless technology and microwave circuit, the demand for wide bandwidth and small size is increasing continuously. How to design a novel Quasi-Yagi antenna has become a research focus [8–11]. Wang et al. presented an antenna that adopts a C-shape reflector to improve the bandwidth [8], but the size of the proposed antenna is a little large. Another antenna with metamaterial is designed by Sarkar et al. [9], and its size has been reduced 26.67% compared with an ordinary one, but it is a pity that there is little improvement in the bandwidth. Kan et al. [10] presented a novel antenna with a coplanar waveguide-fed and curve strip. Though this antenna has a small size about $0.3\lambda_0 \times 0.5\lambda_0$, its bandwidth is still narrow. Wu et al. [11] adopt a stepped connection structure in their antenna. Nevertheless its gain bandwidth is still not wide enough.

This paper presents a novel miniaturized broadband Quasi-Yagi antenna #1 with splitting bowtie driven dipole first. The total size is only $0.39\lambda_0 \times 0.42\lambda_0$, and its impedance bandwidth covers the range of 2.27–3.35 GHz. Then, an improved antenna #2 is implemented based on the same principle where a modified bowtie is acted as a driven dipole, and it obtains a much wider bandwidth. The measured

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result shows that its impedance bandwidth is from 2.14 GHz to 3.3 GHz. Especially, the latter achieves 1.02 GHz bandwidth with the reflection coefficient below −15 dB, and its size is only $0.39\lambda_0 \times 0.47\lambda_0$. The two proposed antennas' bandwidth and realized gain can both cover the 2.4 GHz WLAN, 2.45 GHz RFID, 2.3 GHz and 2.5 GHz WiMAX, and 2.6 GHz LTE bands.

The antennas here have good performance compared with the other wideband antennas. Ooi and Selvan [12] provide a broadband antenna which is suitable for PCS 1.85–1.99 GHz, UMTS 1.92–2.17 GHz, IMT 1.9–2.2 GHz, ISM 2.4–2.484 GHz, Bluetooth 2.3–2.55 GHz, RFID 2.45 GHz and WLAN 2.4–2.484 and 5.725–5.825 GHz wireless applications. Though its operation bands can cover 1.83–2.73 GHz and 5.36–7.63 GHz, its gain is a little lower during 1.83–2.73 GHz. On the other hand, their antenna has a higher reflection coefficient than our antenna, and its side length reaches 50 mm. In [13], the antenna has a high gain as our antennas. Its bands can cover DCS/PCS/UMTS/LTE from 1.71 GHz to 2.69 GHz, while its size is too large somehow.

2. PRINCIPLE OF MINIATURIZATION AND BROADBAND

As shown in Figure 1, a conventional Quasi-Yagi antenna consists of a microstrip feeding line, $\lambda/4$ impedance transformer, balun phase shifter, microstrip to coplanar strip-line (CPS), driver, director and ground plane [14]. The horizontal size is determined by the width of the ground plane and length of the driver, and the vertical size depends on the height of microstrip feed, $\lambda/4$ impedance transformer, balun and the distance from the ground patch to the director. According to Quasi-Yagi antenna's design principles, the size of a conventional 3-unit Quasi-Yagi antenna is about $0.5\lambda_0 \times 0.6\lambda_0$ [15], which is relatively big in practice application. So, the proposed antennas adopt two means to reduce its size. Figure 1 illustrates that much void space is wasted beside microstrip feed and $\lambda/4$ impedance transformer. If the microstrip feed, $\lambda/4$ impedance transformer and balun are rearranged in a same horizontal line as shown in the Figure 2(a), the vertical size can be shorten 25%. On the other hand, the strip loading technology [16] is an efficient miniaturization way and leads to reducing horizontal size. In this paper, the vertical strips are applied to the two sides of driver and ground plane. The principle of strip loading is shown in Figure 2(b), when the strips are loaded to the two sides of the driven dipole, and the original current path will be prolonged. It is indicated that the shorter dipole can be efficiently resonant at the original resonant frequency.

The gradual shape is a simple and efficient way to broaden bandwidth. Our antennas adopt the splitting and whole modified bowties as the driven dipole, as mentioned in [17].

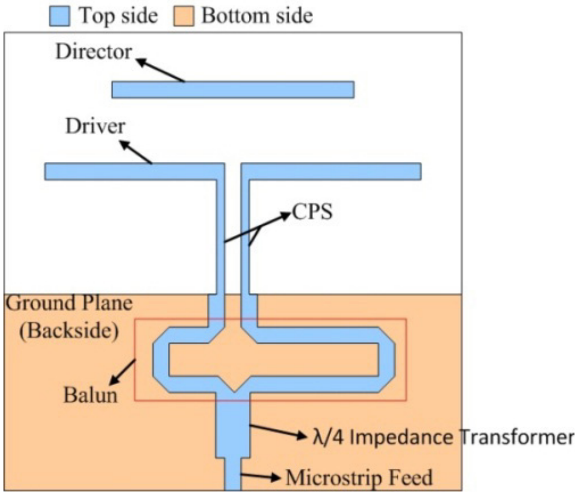
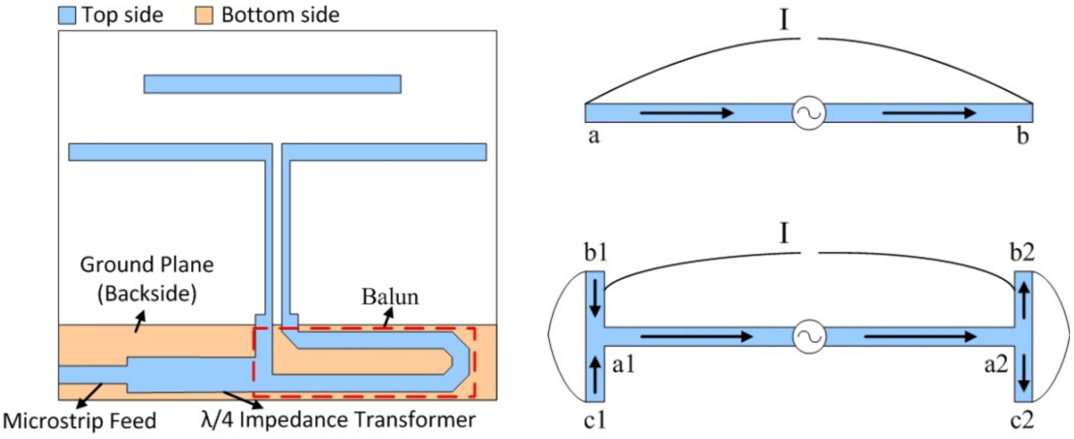


Figure 1. Structure of conventional Quasi-Yagi antenna.



(a) (b)

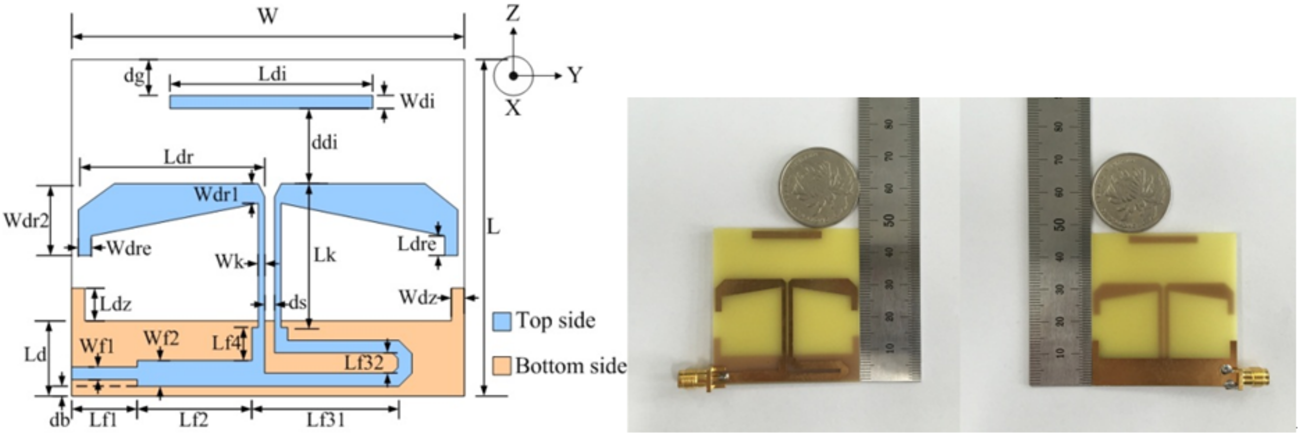
Figure 2. (a) Miniaturization layout of novel Quasi-Yagi antenna; (b) Miniaturization technology of strip loading.

3. ANTENNA DESIGN AND MEASURE

According to the above analysis, the two antennas presented in this paper are designed. With the same layout of microstrip feed and $\lambda/4$ impedance transformer, the first proposed Quasi-Yagi antenna, antenna #1, adopts a modified splitting bowtie as the driver, and the other, antenna #2, adopts a modified whole bowtie. These antennas are both etched on a 1 mm FR4 substrate whose permittivity is 4.4 and loss tangent 0.02. To verify the scheme in this paper, the antennas are simulated and optimized by the software HFSS.

3.1. Design and Measure of Antenna #1

A photograph of antenna #1 with splitting bowtie driven dipole is shown in Figure 3. The size of antenna #1 is $L \times W = 45\,\text{mm} \times 47.6\,\text{mm}$ which is about $0.39\lambda_0 \times 0.42\lambda_0$. Figure 4 illustrates the results of four different structures including the proposed antenna, the antenna shown in Figure 2(a), the antenna only with strip loading and the antenna only with bowtie driven dipole. It is exhibited that their performances are obvious different, and the proposed antenna has a wider bandwidth.



(a) (b)

Figure 3. (a) Geometry of the antenna 1; (b) Photograph of the fabricated antenna.

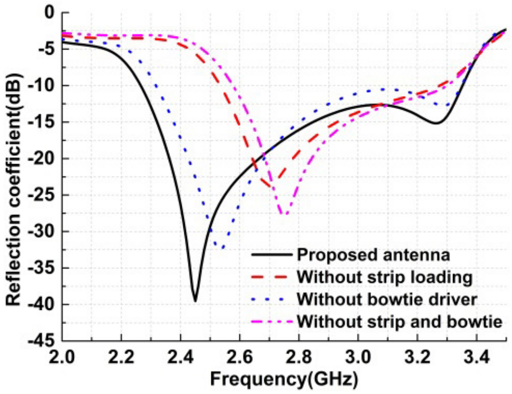
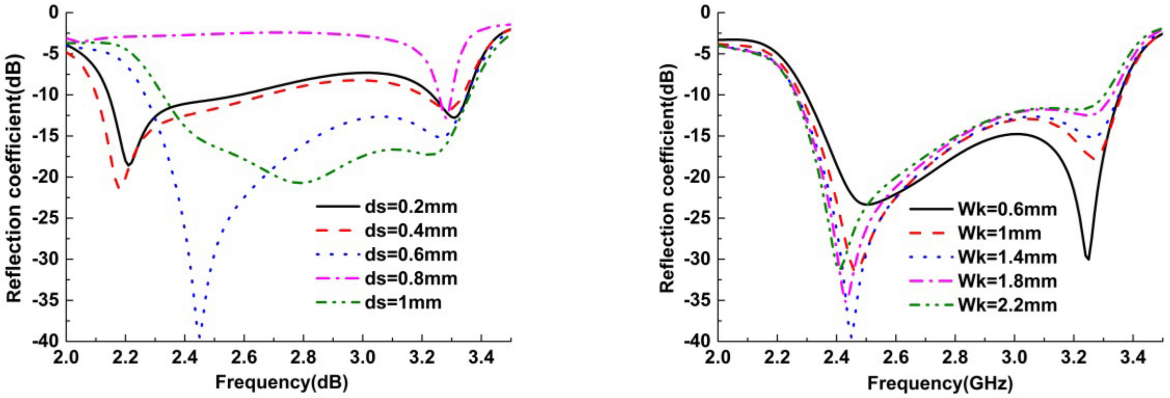


Figure 4. Simulated reflection coefficients of different structures.



(a) (b)

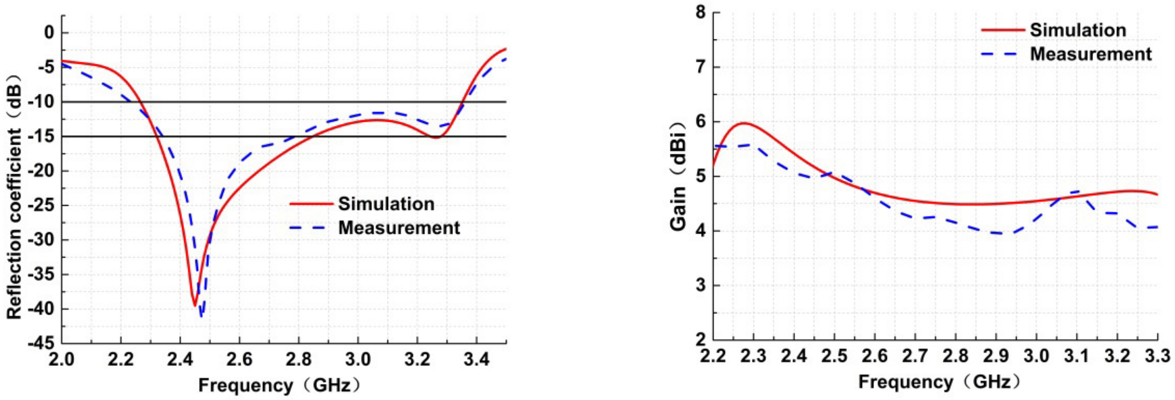
Figure 5. (a) Simulated reflection coefficient of antenna #1 with different ds; (b) Simulated reflection coefficient of antenna #1 with different Wk.

Table 1. Final design parameters of antenna #1 (unit: mm).

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
W	45	$Lf31$	21.2	Wdz	2.3	$Wdr2$	9.9
L	47.6	$Lf32$	1.2	ds	0.6	$Wdre$	2
$Wf1$	2.3	$Lf4$	3.6	Wk	1.4	$Ldre$	4.5
$Lf1$	9.3	db	0.7	Lk	24.3	ddi	12.4
$Wf2$	3.3	Ld	8.6	Ldr	21.5	Ldi	21.5
$Lf2$	10.6	Ldz	5.5	$Wdr1 = Wdi$	2.3	dg	1

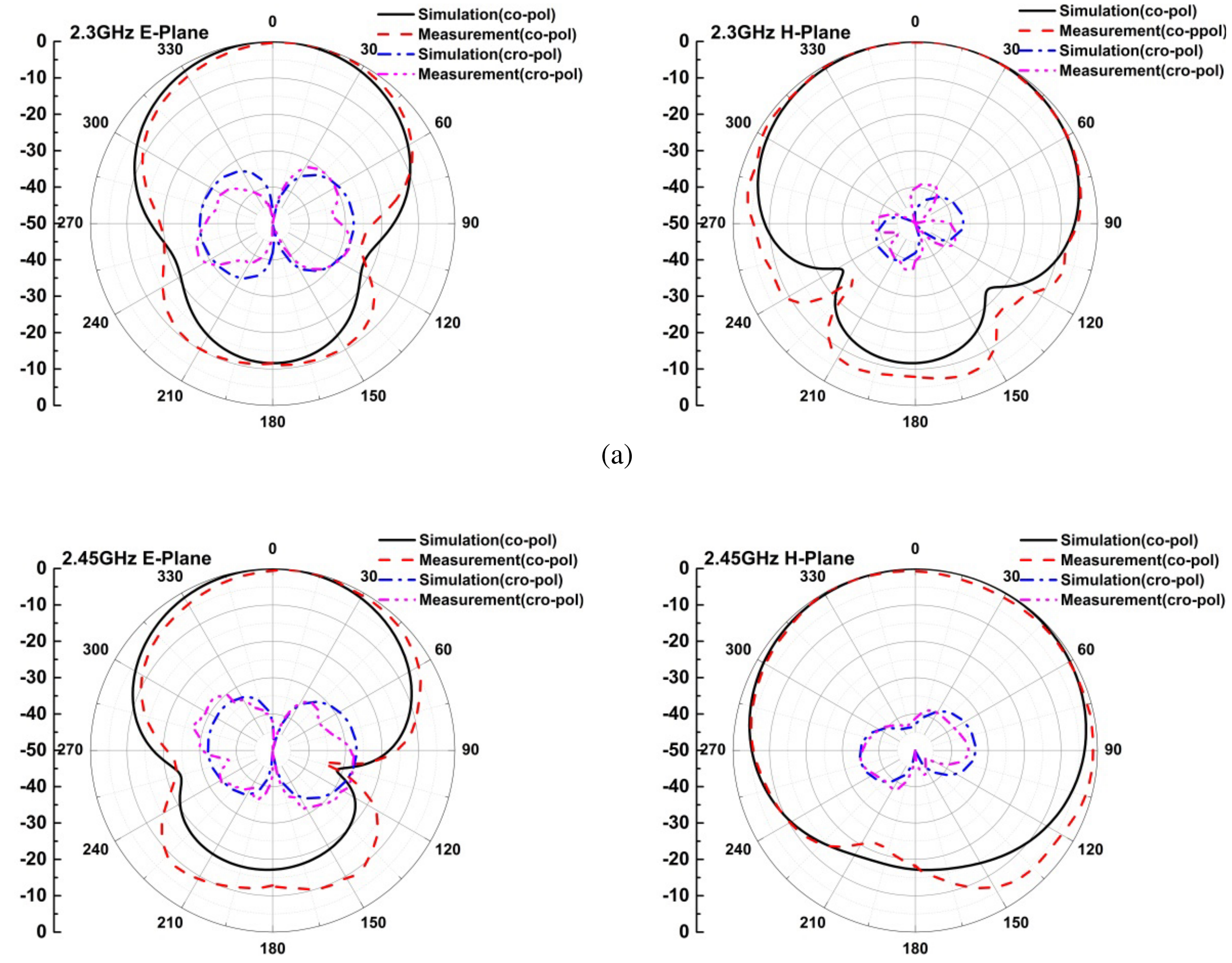
The proposed antennas can be divided into three parts: feeding line, CPS and radiation structure. The CPS is located between feeding line and radiation structure and can be regarded as a matching network to the radiation structure. The width ds and length Wk of CPS are key parameters for antenna reflection coefficient. The simulation results with ds and Wk are shown in Figure 5. By optimizing these parameters, $ds = 0.6\,\text{mm}$ and $Wk = 1.4\,\text{mm}$ are selected, and other parameters after optimization are listed in Table 1.

The measurement results of the antenna's reflection coefficient and gain agree well with the simulations as illustrated in Figure 6. The antenna achieves wide bandwidth where the reflection coefficient is less than −10 dB at 2.27–3.35 GHz and below −15 dB at 2.32–2.85 GHz band. The gain is more than 4 dBi at the operation band. Meanwhile, it reaches about 5 dBi at the interesting frequencies of 2.3 GHz, 2.45 GHz and 2.6 GHz.



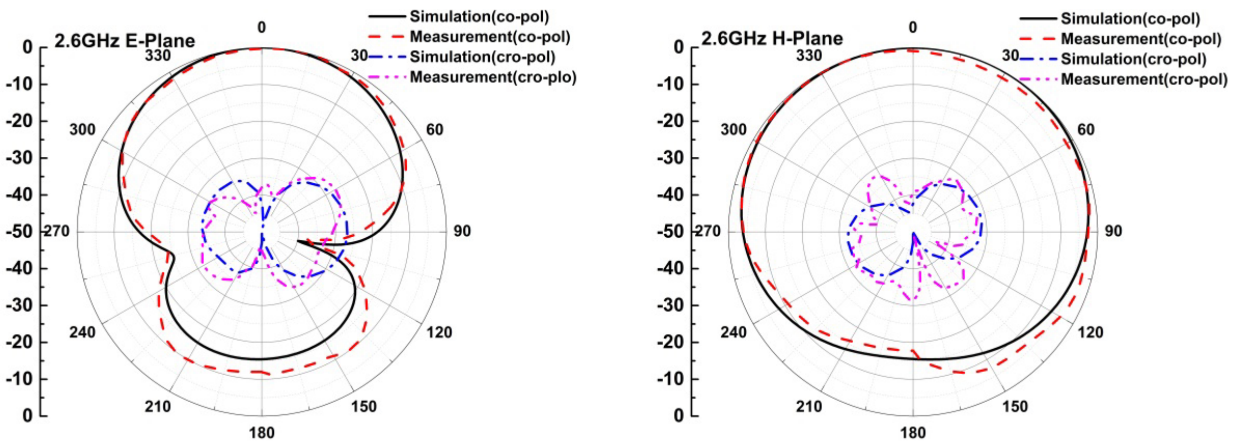
(a) (b)

Figure 6. (a) Measured and simulated reflection coefficients of antenna 1; (b) Measured and simulated gain of antenna 1.



(a)

(b)



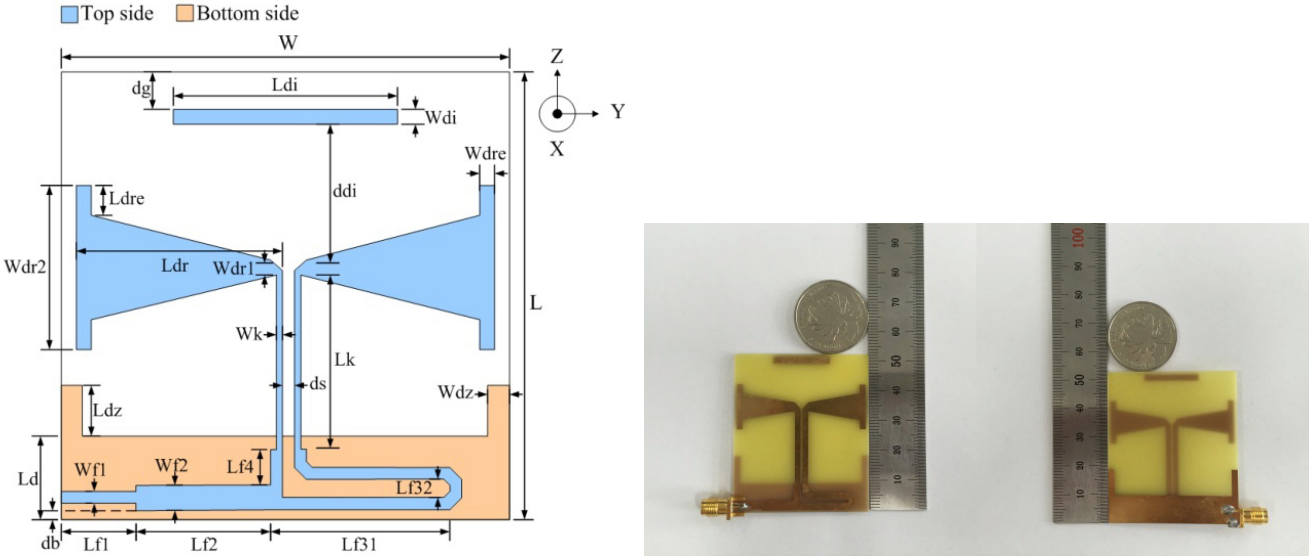
(c)

Figure 7. Measured and simulated normalized radiation patterns of antenna 1 in the *E*-plane and *H*-plane at (a) 2.3 GHz, (b) 2.45 GHz, (c) 2.6 GHz.

Figure 7 shows the simulation and measurement about the normalized radiation patterns in the *E*-plane and *H*-plane at 2.3 GHz, 2.45 GHz and 2.6 GHz. It indicates that antenna #1 has 82° beam widths in *E*-plane and 157° in *H*-plane. Its front-to-back ratio is better than 12 dB, and the level cross polarization is less than −26 dB. The radiation patterns are stable and similar to each other in *E*-plane at all interested frequencies, while a little difference occurs in *H*-plane.

3.2. Design and Measure of Antenna #2

An improved antenna which has a similar structure to antenna #1 is designed, where a whole bowtie acts as the driven dipole. To maintain a small size and symmetry, the loading strips are prolonged, which are longer than the two sides of the driver. The antenna sketch is shown in Figure 8 with its size 45 mm × 52.75 mm ($0.39\lambda_0 \times 0.47\lambda_0$). Figure 9 compares the reflection coefficients of four different



(a) (b)

Figure 8. (a) Geometry of the antenna 2; (b) Photograph of the antenna #2.

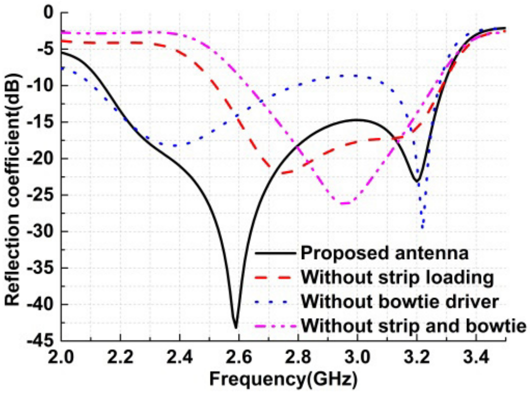
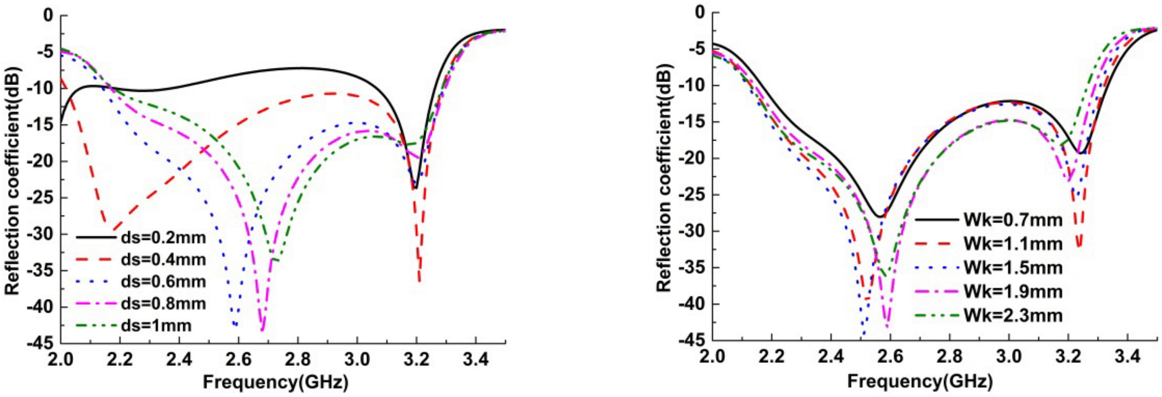


Figure 9. Simulated reflection coefficients of different structures.



(a) (b)

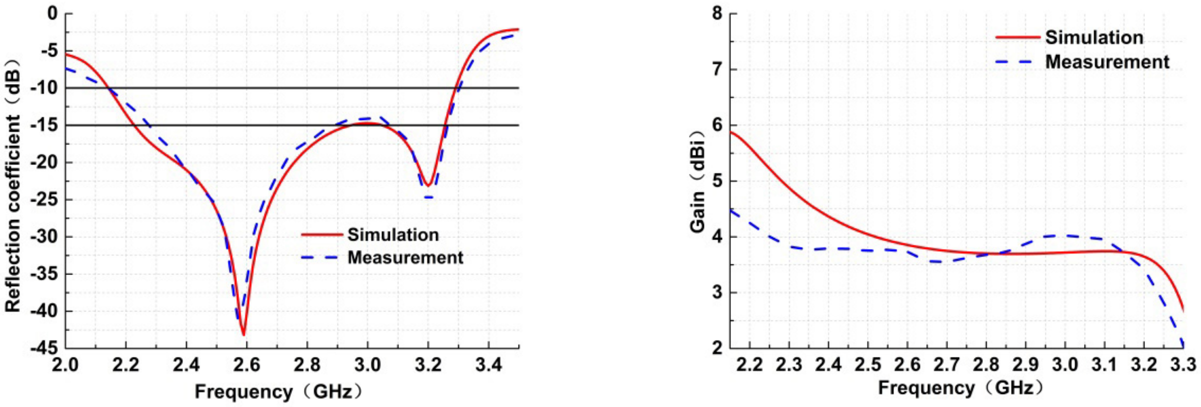
Figure 10. (a) Simulated reflection coefficient of antenna #2 with different ds; (b) Simulated reflection coefficient of antenna #2 with different Wk.

Table 2. Final parameters of antenna #2 (unit: mm).

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
W	45	$Lf31$	20.6	Wdz	2.3	$Wdr2$	15
L	52.75	$Lf32$	1.2	ds	0.6	$Wdre$	2
$Wf1$	2.3	$Lf4$	3.6	Wk	1.9	$Ldre$	3
$Lf1$	9.5	db	0.7	Lk	26.2	ddi	13.35
$Wf2$	3.3	Ld	9.6	Ldr	21.5	Ldi	19
$Lf2$	10.4	Ldz	9	$Wdr1 = Wdi$	2.3	dg	1

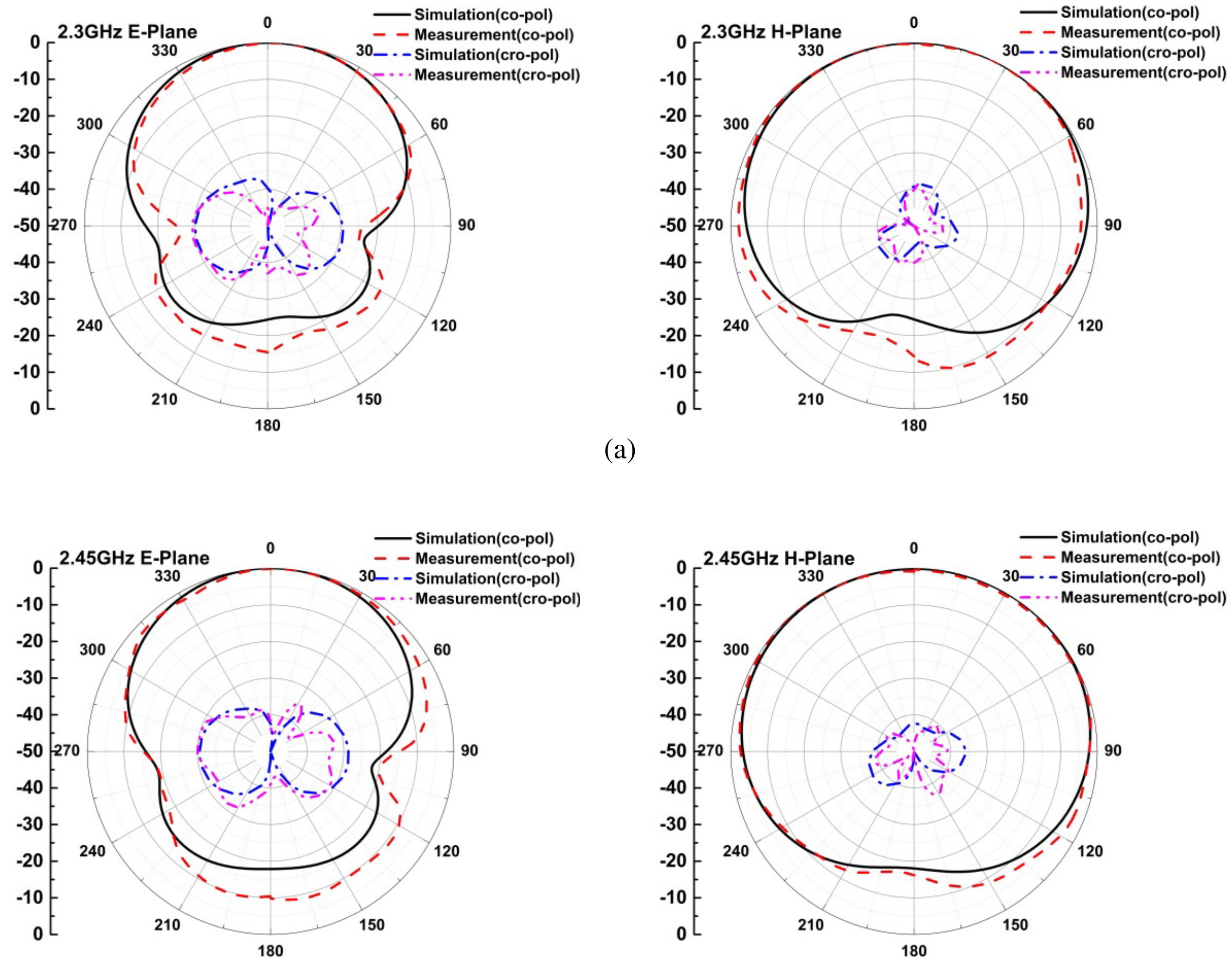
dipoles as mentioned above. The reflection coefficient distinctions among the four structures are more obvious than the results shown in Figure 4.

The reflection coefficients of antenna #2 with different ds and Wk are shown in Figure 10. By optimizing the two parameters, $ds = 0.6$ mm and $Wk = 1.9$ mm are the most suitable values, and the other determined parameters are listed in Table 2. Its reflection coefficient and gain are shown in Figure 11. Antenna #2 obtains a wide bandwidth from 2.14 GHz to 3.3 GHz for reflection coefficient



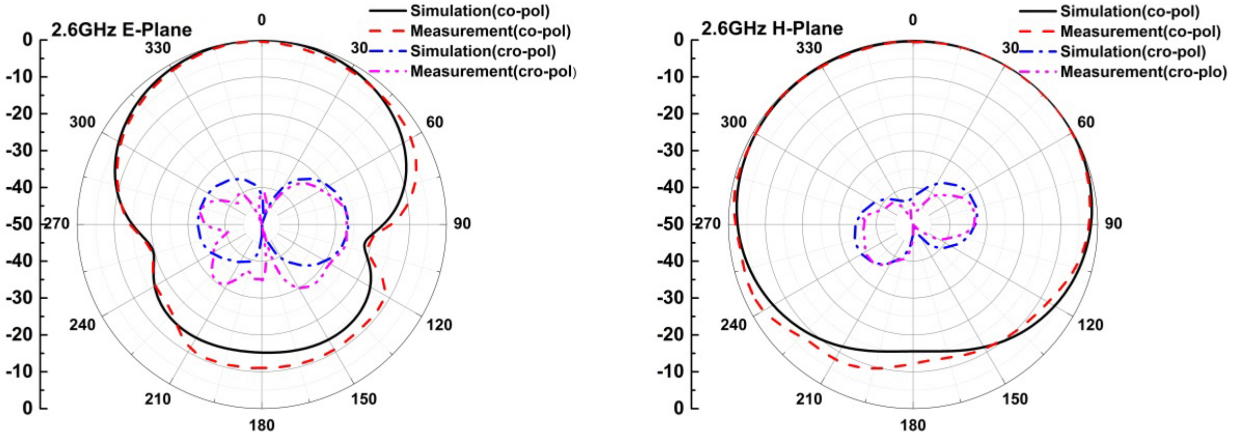
(a) (b)

Figure 11. (a) Measured and simulated reflection coefficients of antenna #2; (b) Measured and simulated gain of antenna #2.



(a)

(b)



(c)

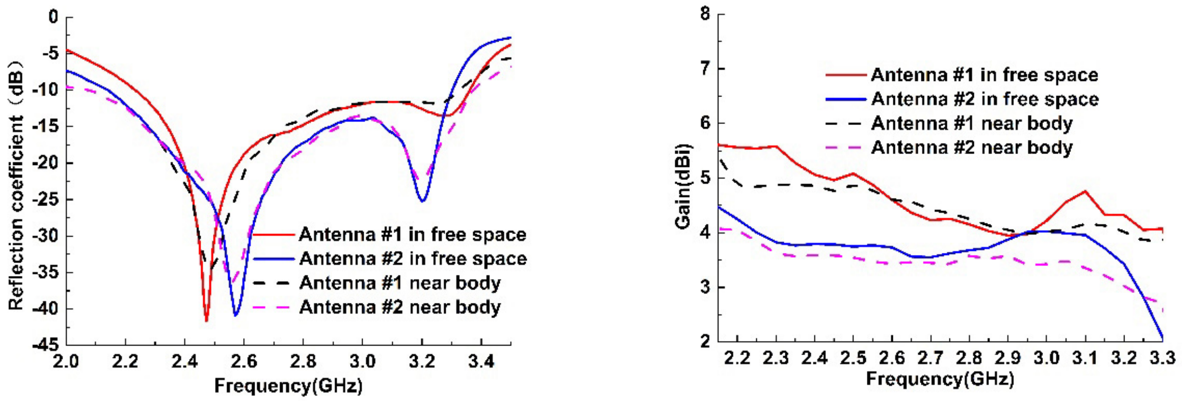
Figure 12. Measured and simulated normalized radiation patterns of antenna 2 in the *E*-plane and *H*-plane at (a) 2.3 GHz, (b) 2.45 GHz, (c) 2.6 GHz.

below −10 dB and a stable gain around 4 dBi. Especially, in the band of 2.23–3.25 GHz, its reflection coefficient is below −15 dB. The measured reflection coefficient and the gain match perfectly to the simulation, except that the measured gain is a little lower than simulation at the two edges of the band.

Figure 12 shows the normalized radiation patterns of antenna #2 in the *E*-plane and *H*-plane at 2.3 GHz, 2.45 GHz and 2.6 GHz. The radiation patterns of antenna #2 are stable in both *E*-plane and *H*-plane at all frequencies. It achieves wider 3 dB beamwidths which are 90° in *E*-plane and 180° in *H*-plane. This antenna has a better front-to-back ratio above 14 dB and a level cross polarization below −26 dB.

3.3. Performance near Human Body

It is possible that the antenna is placed in compound environment in the practical application. In order to verify the antenna performance, we assume that the antenna acts as a wearable antenna and measure the reflection coefficient and gain when the antenna is placed near the human body, as shown in Figure 14. The measurement result is shown in Figure 13, and there is little difference between near human body and in free space except that the gain is decreased about 0.3 dBi as being close to human



(a) (b)

Figure 13. Measured performance of the two proposed antennas in free space and near human body include (a) reflection coefficient, (b) gain.

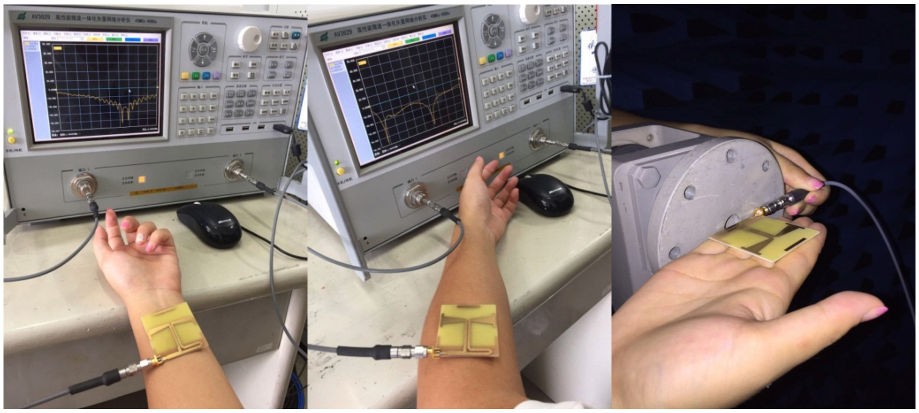


Figure 14. Measured environment of the two proposed antennas near the human body.

body. The performances of the two proposed antennas just have little attenuation when they are placed near the human body. It indicates that the antennas can be operated normally near human body and used as the wearable antenna.

3.4. Comparison between Antennas #1 and #2

From the result in Figures 7, 12 and 13, it is found that their radiation patterns are almost the same except that the back lobe level of antenna #2 is a little lower than antenna #1. Meanwhile, the reflection coefficient band of antenna #2 is broader than antenna #1, while the first antenna's gain is obviously higher than antenna #2. For the property of higher gain of antenna #1, it has better performance in the need of further transmission distance. On the other hand, if wide bandwidth is necessary, antenna #2 will be more suitable.

4. CONCLUSIONS

Two novel miniature broadband Quasi-Yagi antennas are presented in this paper. By rearranging the layout and the strips loading technology, the antennas' sizes are $0.39\lambda_0 \times 0.42\lambda_0$ and $0.39\lambda_0 \times 0.47\lambda_0$, respectively. Their bandwidths for reflection coefficient below -10 dB are over 2.27–3.35 GHz (relative bandwidth 38.4%) and 2.14–3.3 GHz (relative bandwidth 42.6%). At the same time, their gains are both around 4 dBi. Especially, antenna #2 exhibits a good performance in 2.23–3.25 GHz (relative bandwidth 37.5%) with reflection coefficient below -15 dB. The antennas have more than 12 dB front-to-back ratios and less than -26 dB cross-polarizations, which are suitable for wireless communication and recognition applications, such as 2.4 GHz WLAN, 2.45 GHz RFID, 2.3 GHz and 2.5 GHz WiMAX, and 2.6 GHz LTE. Moreover, the antennas will still maintain good performance when being placed near human body, and they could act as wearable antennas.

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