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Wideband Unidirectional Bowtie Antenna with Pattern Improvement

Jia-Yue Zhao*, Zhi-Ya Zhang, Neng-Wu Liu, Guang Fu, and Shu-Xi Gong

Abstract—A wideband unidirectional bowtie antenna with stable radiation patterns is proposed and investigated. It is fed by a wideband microstrip balun, using a coupling triangular structure to induce more balanced currents. Particularly, the corners of the conventional triangular bowtie dipole are rounded to achieve an impedance BW of 106.9% for $|S_{11}| \leq -10\,\mathrm{dB}$ ranging from 1.97 GHz to 6.49 GHz. Additionally, a special small circular reflector between the ground plane and the bowtie dipole is used to stabilize the radiation patterns. The antenna achieves a stable gain of around 9.5 dBi with a little variation of 1.4 dBi and unidirectional radiation patterns over the whole operating band.

1. INTRODUCTION

In recent years, with the expeditious development of modern wireless communication systems, wideband antennas become a critical component in these systems [1]. As far as the radiation patterns are concerned for wideband antennas, the wideband unidirectional antennas with small electrical dimensions and stable gain are more popular and needed in wireless communication now.

Microstrip patch antenna [2] is widely used in communication systems as it has major advantages of unidirectional radiation patterns, low profile and low fabrication cost but its impedance BW is generally smaller than 40% [3], not wide enough to enable stable unidirectional radiation patterns. The similar problems can also be found in the short backfire antenna (SBA) [4–6]. The backfire structure make it can achieve unidirectional pattern and high gain, but it limited by its narrow impedance BW and large profile. Log-periodic antenna [7] cannot be used for these applications for its large dimension. Cavity-backed bowtie antenna was proposed by S.-W. Qu [8], it has stable gain around 9.5 dBi and the impedance bandwidth is 92.2% for $|S_{11}| \leq -10\,\mathrm{dB}$. But the Cavity-backed structure is large and high in fabrication cost. The gain varies from 7.5 dBi to 10.9 dBi with variation of 3.4 dBi, which is not stable enough.

In this paper, a wideband unidirectional bowtie antenna is proposed. It is differentially fed by a wideband printed microstrip balun with triangular coupling feeding structure. The rounded bowtie dipole with slot load can make the antenna have a better impedance matching. Moreover, a circular reflector, which replaced the Cavity-backed structure is placed between the bowtie and the ground plane to stabilize the radiation patterns, especially in the high frequency band. With these improvements, the final designed antenna can achieve an impedance BW of 106.9% for $|S_{11}| \leq -10\,\mathrm{dB}$ and a stable gain about 9.5 dBi with unidirectional radiation patterns over the whole operating band.

2. ANTENNA DESIGN AND DISCUSSION

Figure 1 shows the geometry of the proposed antenna, consisting of a folded triangular bowtie dipole with slot load, a circular-backed plane, a small circular reflector, a wideband printed microstrip balun and an SMA connector which is placed under the circular-backed plane to feed the antenna.

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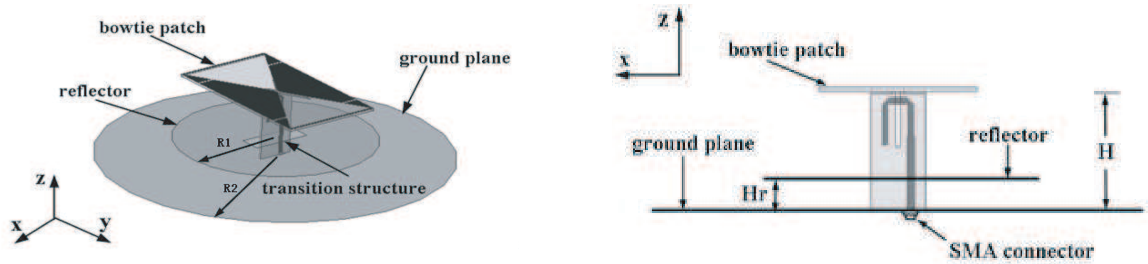

Figure 1. Geometry of the proposed bowtie antenna. (a) 3-D view, (b) side view.

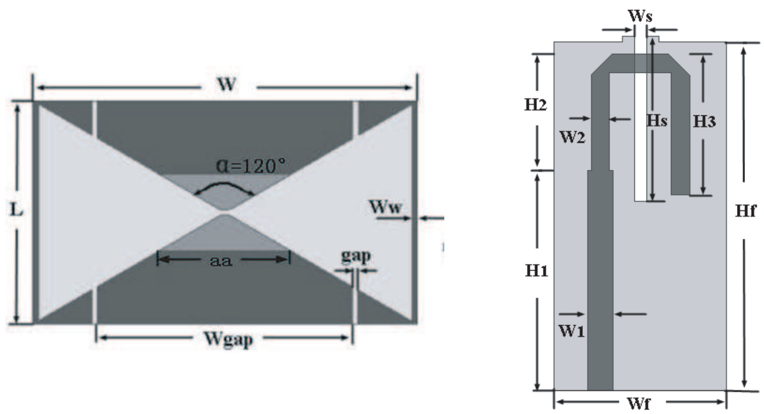

Figure 2. Geometry of the bowtie patch and feeding structure bowtie patch and feeding structure. (a) Top view of the bowtie patch, (b) side view of the feeding structure.

Figure 2(a) shows the geometry of the folded triangular bowtie dipole and its parameters in detail. It is built on a substrate with thickness of 1 mm and relative permittivity $\varepsilon_r = 2.65$ for easy fabrication and support, the deep color denotes its shape on the top side of the substrate and the light color shows that on the bottom side. The folded triangular bowtie dipole on the top side can provide flatter input impedance and the slot load on the bowtie patch can provide a resonance at 2 GHz, which can widen the impedance BW at low frequency. The smaller triangular coupling structure on the bottom side with two overlapping parts between the two layers acts as an important part of feeding structure and also a capacitive loading. The desired input reactance of the proposed bowtie dipole can be easily achieved. The geometry of the microstrip-to-DSL transition, with one dielectric and two metallic layers, is given in Fig. 2(b), which is built vertically on the ground plane and fabricated on a substrate with $\varepsilon = 2.65$ and a thickness of 1 mm. The Γ-shaped microstrip-to-DSL transition comprises three parts as shown in the Fig. 2(b). The first port can be treated as a microstrip line which act as an impendence transformerthe second portion is responsible to couple the electrical energy to the coupling smaller triangular feeding structure. The remaining coupling strip can be adjusted for impedance matching by selecting appropriate length. The transition and the coupling smaller triangular feeding structure can induce more balanced currents on the bowtie antenna than that used in [8, 9]. The impedance matching is much easier by turning the width and length of the microstrip line.

The patterns of bowtie antenna without reflector are split and the main beam is shifted away from the broadside direction when it work at high frequency. That is due to the distance between the bowtie patch and the ground is too larger than $\lambda/4$ when the antenna work at high frequency band, so a reflector is added to improve the radiation patterns at high frequency band and make the gain of the antenna more stable.

The function of the reflector can be seen from Fig. 3, comparisons of the co-polarizations radiation patterns of the between the proposed antenna with and without are given in this figure. It can be seen that the E-plane and H-plane patterns of the two antennas are almost identical in lower frequency band. When frequency increases up to 4 GHz, the gain of the bowtie antenna without reflector in the normal direction is reduced. Particularly, at 5 GHz the patterns of the bowtie antenna without reflector are seriously distorted and its main beam is also shifted away from the normal direction. The antenna designed with a reflector can achieve a stable gain over the whole band. It can be clearly seen from the Fig. 4 that the gain of the bowtie antenna without reflector reduce tempestuously from 3.5 GHz. The difference of the gain between two antenna is 19 dB at 5 GHz. Parameters for the final optimal antenna are shown in Table 1.

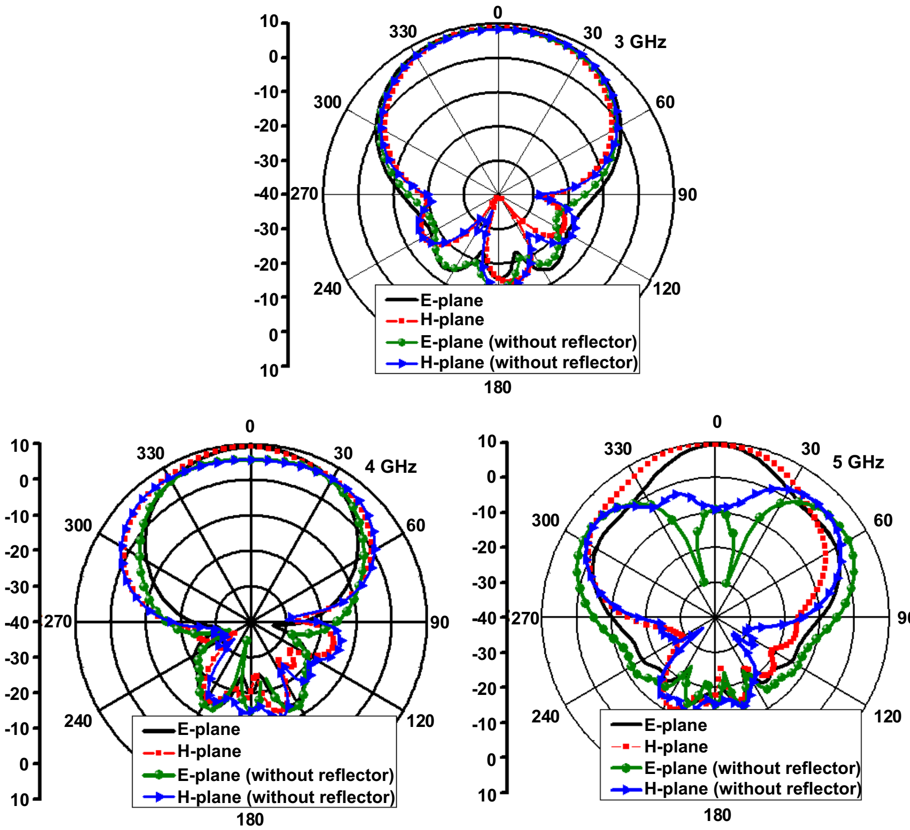

Figure 3. Simulated co-polarizations radiation patterns of the bowtie antennas with/without reflector at 3, 4, and 5 GHz.

Table 1. Dimensions of proposed antenna.

Parameters	**H**	$\mathbf{H_1}$	$\mathbf{H_2}$	$\mathbf{H_3}$	$\mathbf{H_f}$	$\mathbf{H_s}$	$\mathbf{H_r}$	$\mathbf{R_1}$	$\mathbf{R_2}$	**aa**
Values/mm	29	18	9.5	11.5	28	13.5	11	60	100	24.2
Parameters	**W**	$\mathbf{W_1}$	$\mathbf{W_2}$	$\mathbf{W_{gap}}$	$\mathbf{W_f}$	$\mathbf{W_w}$	$\mathbf{W_s}$	**L**	**gap**	
Values/mm	70	10	1.6	23	14	1	1	40	1	

3. EXPERIMENTAL RESULTS

All simulations in this paper were performed by AnsysEM High Frequency Structure Simulation (HFSS). Its optimized parameters are shown in the Section 2. The $|S_{11}|$ was measured using an Agilent E8363B PNA network analyzer. The simulated and measured $|S_{11}|$ against frequency for the designed antenna

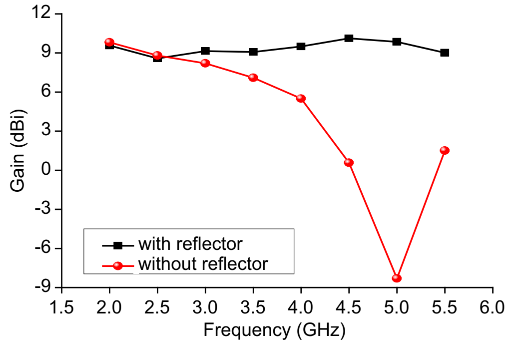

Figure 4. Simulated gains in broadside direction of the proposed antenna with/without reflector.

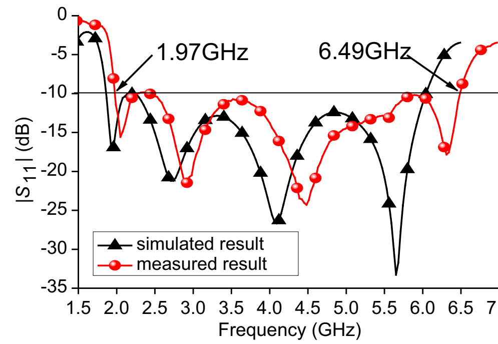

Figure 5. Measured and simulated $|S_{11}|$ of the proposed antenna.

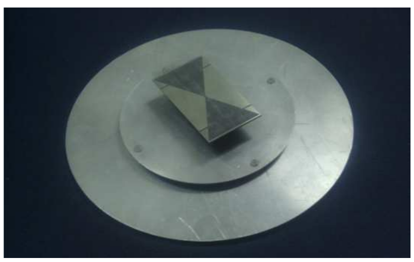

Figure 6. Photograph of the fabricated antenna.

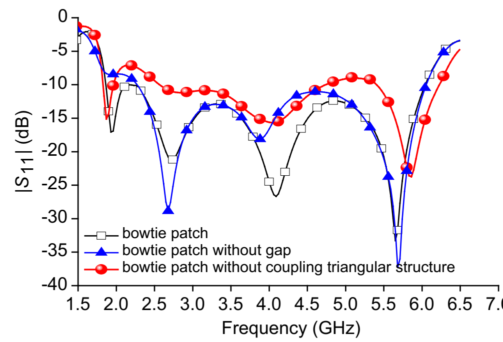

Figure 7. Simulated $|S_{11}|$ of three kinds of bowtie antenna.

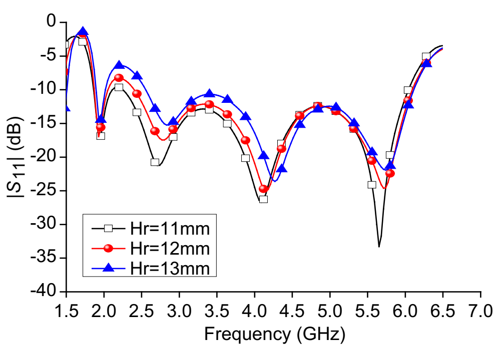

Figure 8. Simulated $|S_{11}|$ of the proposed antenna versus H_r.

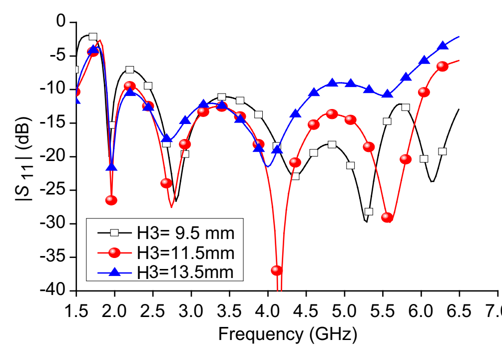

Figure 9. Simulated $|S_{11}|$ of the proposed antenna versus H_3.

are shown in Fig. 5. It can be observed from the figure that measured results reasonably agree with the simulated results with an acceptable frequency discrepancy. For $|S_{11}| \leq -10\,\text{dB}$, the measured impedance bandwidths are about 106.9%, ranging from 1.97 GHz to 6.49 GHz. A prototype of the proposed antenna fabricated according to these design parameters is shown in Fig. 6.

Simulated $|S_{11}|$ of the three kinds of bowtie antenna is shown in Fig. 7. It can be observed that the bowtie patch with a gap load can offer a resonance at 2.0 GHz, which broaden the impedance bandwidths in the lower frequency band. The triangular coupling feeding structure at bottom layer make the antenna has a better impedance matching over the whole working band.

Figure 8 shows the simulated $|S_{11}|$ versus H_r. It can be seen that the higher the reflector, the worse is the return loss $|S_{11}|$, especially in the lower frequency band, that because of the larger fluctuation of input impedance as H_r increases. However, the gain varies with H_r obviously as the electric field is sensitive to the change of H_r. Considered both the $|S_{11}|$ and the gain of antenna, $H_r = 11\,\mathrm{mm}$ is chosen for the final design to make the antenna has a better impedance matching in the lower frequency band.

Simulated $|S_{11}|$ versus different H_3 are given in Fig. 9. H_3 is an important parameter of the Microstrip-to-DSL transition, by selecting appropriate length of which, a better impedance matching can be achieved. It can be seen from this figure that the $|S_{11}|$ is slightly influenced by H_3 in the lower frequency band, but in higher frequency band, especially from 4 to 6 GHz, when H_3 increases, the $|S_{11}|$ show a worse matching. Finally, we chose $H_3 = 11.5\,\mathrm{mm}$ as the final dimensions of the proposed antenna.

The measured and simulated radiation patterns for the designed antenna in the E- and H-planes are shown in Fig. 10 for 3, 4, 5 GHz. Good agreements between them can further prove the validity of simulations over the whole band. It can be observed that the measured front-to-back ratios (FBR) of the proposed antenna are over 25 dB and the co-polarization is around 25 dB higher than the cross-

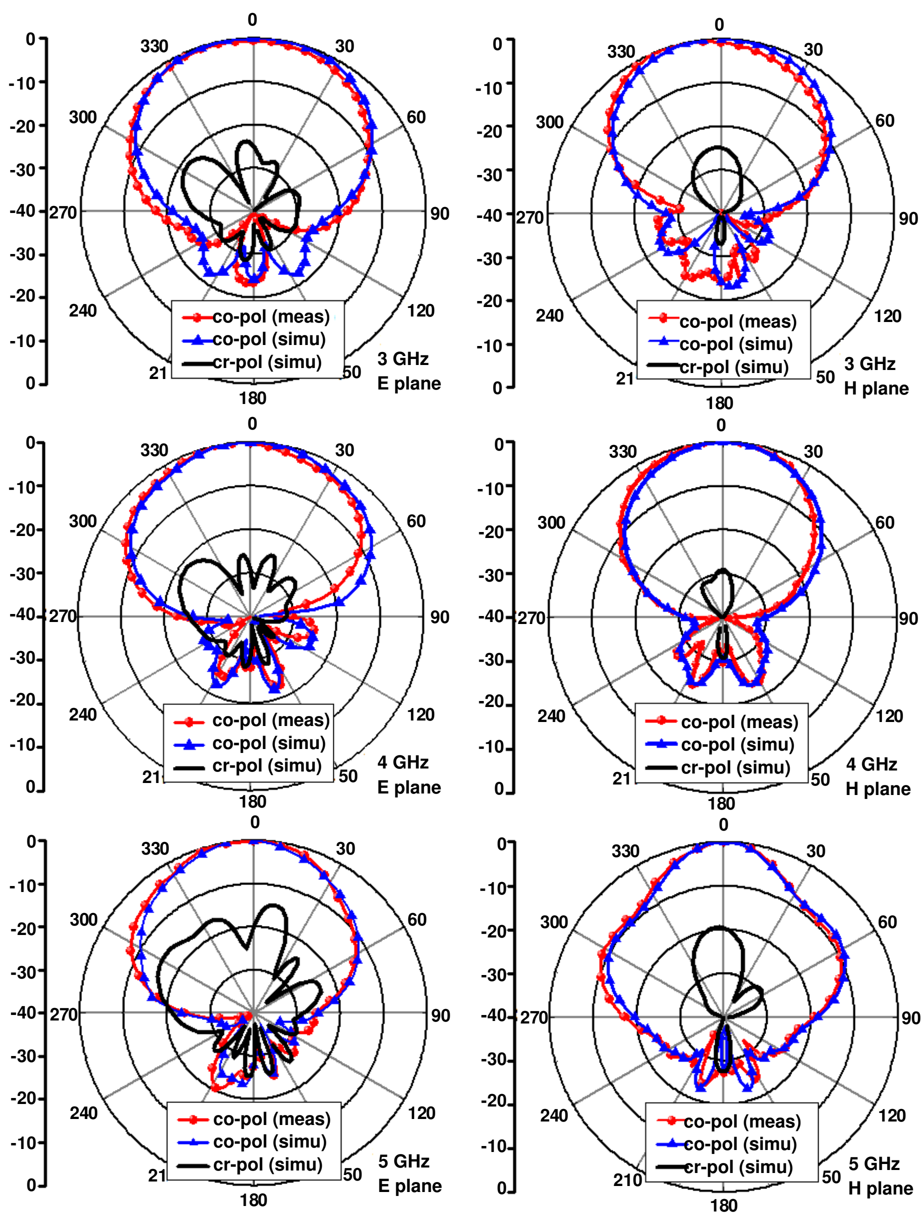

Figure 10. Measured and simulated radiation patterns of the proposed antenna at 3, 4, and 5 GHz.

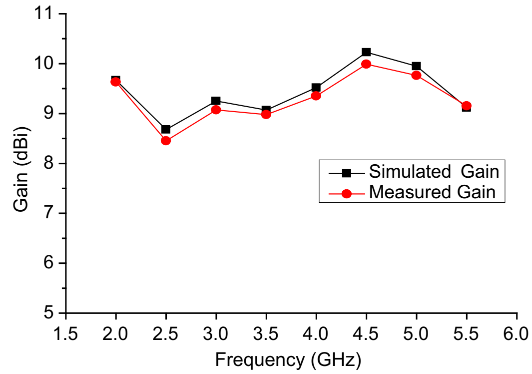

Figure 11. Simulated and measured gain of proposed antenna.

polarization with unidirectional and symmetrical radiation patterns in both E- and H-planes across the whole operating band.

Figure 11 shows the antenna gain variation against frequency. The measured results match well with the simulation results. Over the whole band, the measured antenna gain varies from about 8.5 dBi to 9.9 dBi with a 1.4 dBi variation, show a stable gain around 9.5 dBi.

4. CONCLUSIONS

A wideband unidirectional antenna with a reflector and triangular coupling feeding structure has been designed, simulated, fabricated and tested. Measurements show that the final design features an impedance BW of 106.9%, a stable gain of around 9.5 dBi with unidirectional and symmetrical radiation patterns in both E- and H-planes across the whole operating band. Because of these characteristics, the antenna has wide and potential applications for wireless communication applications.

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