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An Ultra-Wideband Capped Bow-Tie Multilayer-Stacked Yagi Antenna

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Abstract—An ultra-wideband multilayer-stacked Yagi antenna is presented in this article. The proposed design is based on a capped bow-tie antenna, on which a Yagi antenna is formed simply by capping several pieces of parasitic patches with equal lengths but unequal widths. Thus, the multilayer-stacked antenna attains a small footprint, compact size, customizable gain, and simple geometry, which make it promising for various applications. The prototype of this antenna is simulated, fabricated, and measured. Good agreement between simulation and measurement has been observed.

1. INTRODUCTION

Yagi antenna has, for decades, been popular for lots of applications such as TV, radio, and maritime communications, because of its simplicity as well as its customizable high gain by using different numbers of directors. Classical Yagi antenna, however, is very large in size to achieve high-gain performance due to many directors as well as space required between those elements. In recent years, attention has been attached upon Yagi antenna miniaturization for use in a few new applications, where high gain, small footprint, and compact size are particularly required.

As reported in scientific literature, two major approaches, planar and stacked configurations, are related to the design of a Yagi or quasi-Yagi antenna based on printed circuit board technology. In particular, stacked Yagi antennas have been more commonly found in monolithic packaging and compact footprint scenarios. For examples, stacked Yagi antenna can be used for 2.4 GHz wireless energy harvesting [1] and adaptive wireless communication systems [2], 5.8 GHz WiMAX [3] and local positioning systems [4], short-range communications at X-and E-band applications [5, 6], and portable imaging systems at 60 GHz [7, 8] and even at 340 GHz [9], etc. In addition to the dipoles and patches, various drive elements such as split-rings [10], loops [11], and slots [12] are found in stacked Yagi antennas.

A novel ultra-wideband (UWB) multilayer-stacked Yagi antenna is proposed in this article, according to the basic principles of UWB antennas and a previously developed so-called capped bow-tie antenna [13], which can achieve a roughly 3 : 1 band by simply adding a single piece of parasitic metal patch director above a planar bow-tie driver over a ground plane as reflector. This capped bow-tie idea can be easily extended to form a UWB 3D quasi-Yagi antenna by using multiple parasitic directors.

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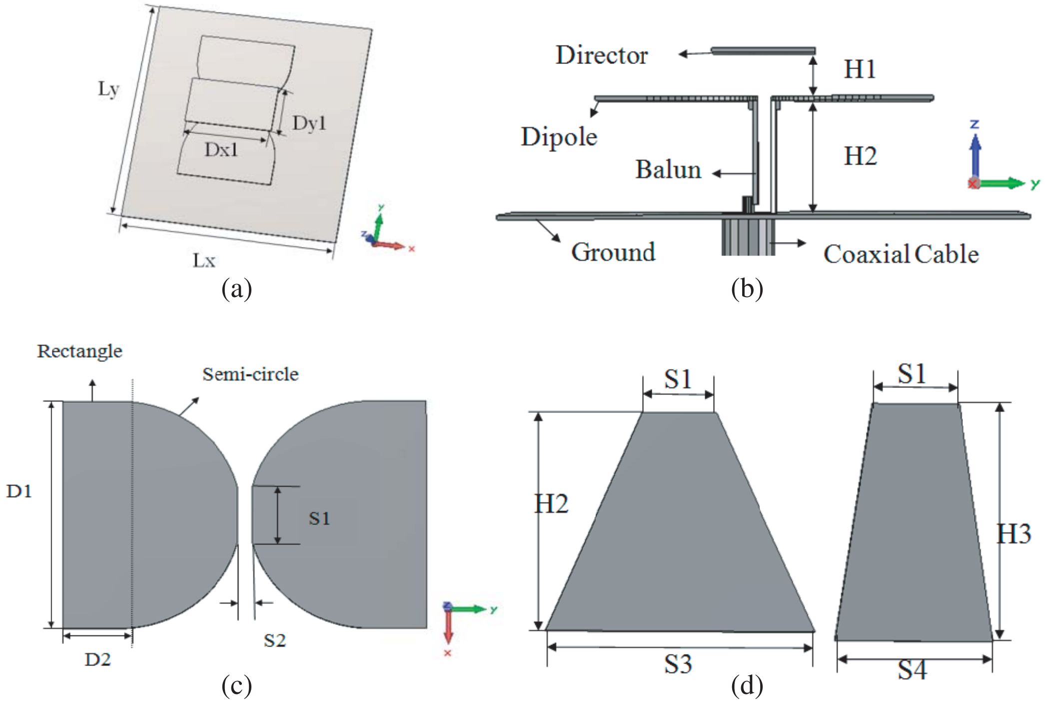
2. ANALYSIS AND SIMULATION

2.1. Basic 3-Layered Yagi Antenna

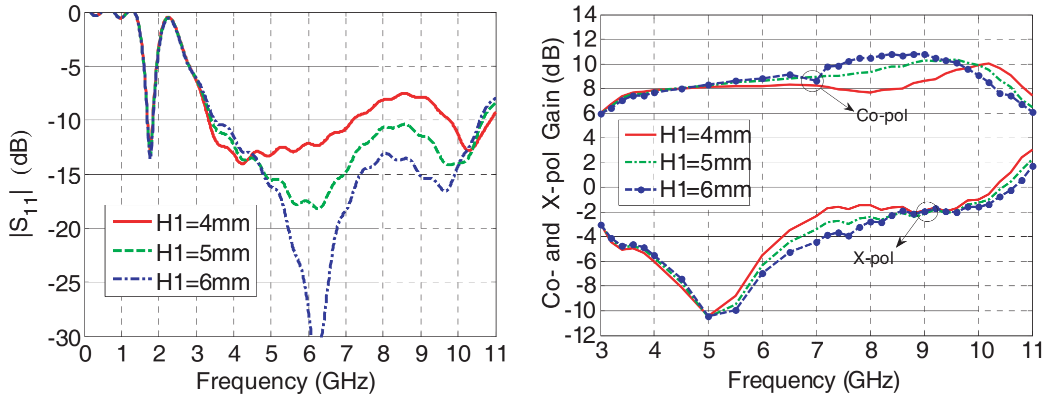
A fundamental capped bow-tie Yagi antenna, 3-layered stacked one, is illustrated in Fig. 1. It is primarily composed of a parasitic patch as the director, a planar bow-tie dipole as the driver, and a ground plane as the reflector, which are all made of copper plates with a thickness 0.5 mm. The bow-tie dipole petal is constructed by a rectangular and a semicircular patch, while the center of the dipole is cut into straight edges for connecting an air-substrated balun that is connected with a coaxial cable penetrating the ground plane from beneath.



(a) (b)

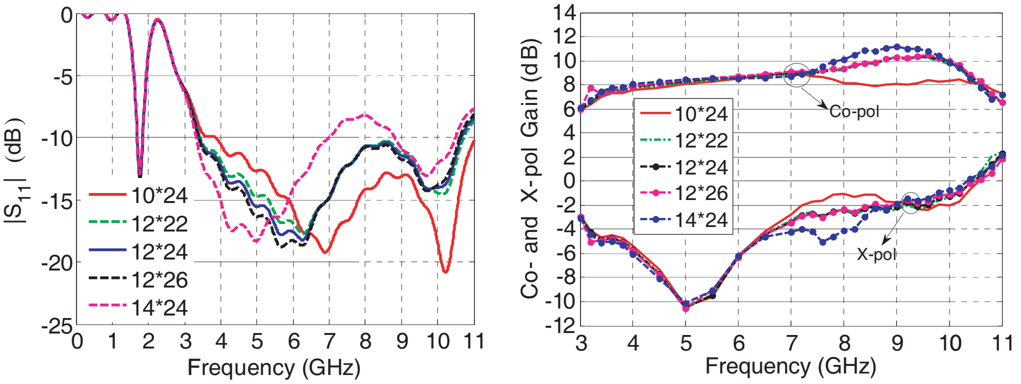
(c) (d)

Figure 1. Geometry of the 3-layered UWB Yagi antenna: (a) 3D view, (b) side view, (c) source dipole, (d) balun.



(a) (b)

Figure 2. (a) S_{11} parameters and (b) Co- and X-pol. components vary with different size of the parameter $H1$ of the proposed 3-layered UWB antenna.



(a) (b)

Figure 3. (a) S_{11} parameters and (b) Co- and X-pol. components vary with different size (in mm^2) of the director of the proposed 3-layered UWB antenna.

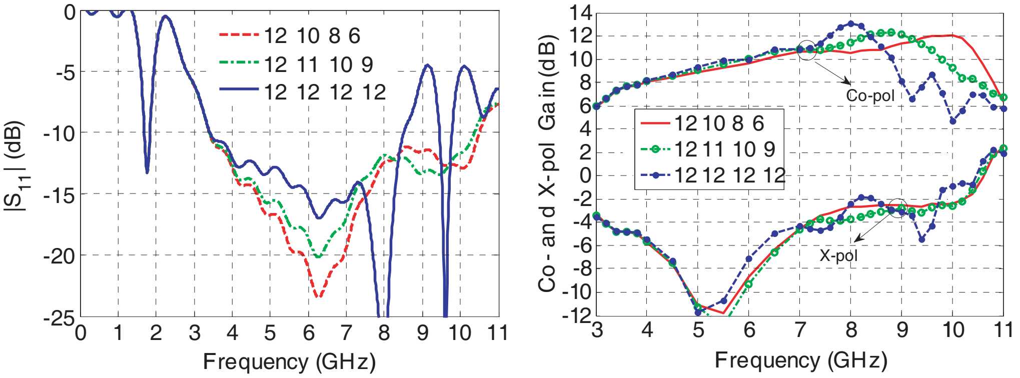
The antenna is modeled, simulated, and optimized by CST MWS. The parametric analysis has been performed with respect to critical parameters, including the height ($H1$) and size ($Dy1$ $Dx1$) of the patch director. Fig. 2(a) and Fig. 2(b) illustrate H1 sweep for S_{11} parameters and co- and cross-polar gains. Similarly, Fig. 3(a) and Fig. 3(b) illustrate director size sweep for S_{11} parameters and co- and cross-polar gains. The optimized dimensions of the 3-layered UWB Yagi antenna are given in Table 1.

Table 1. Parameters of prototype antenna.

Parameter	**Lx**	**Ly**	**Dx1**	**Dy1**	**H1**	**H2**
Value (mm)	60	60	24	12	5	13
Parameter	**H3**	**D1**	**S1**	**S2**	**S3**	**S4**
Value (mm)	12	26	4.4	1.6	16	8

2.2. 6-Layered Yagi Antenna

Aroused by the stacked patch idea, the 3-layered antenna can readily be extended to form a multi-layered Yagi antenna by simply capping one or more patch directors overhead. The spacing between



(a) (b)

Figure 4. (a) S_{11} parameters and (b) co-polar and cross-polar gains vs. different y-axis width directors. The marking of 12 10 8 6 means the width of the 1st (closest to the driver dipole), 2nd, 3rd and 4th director, respectively.

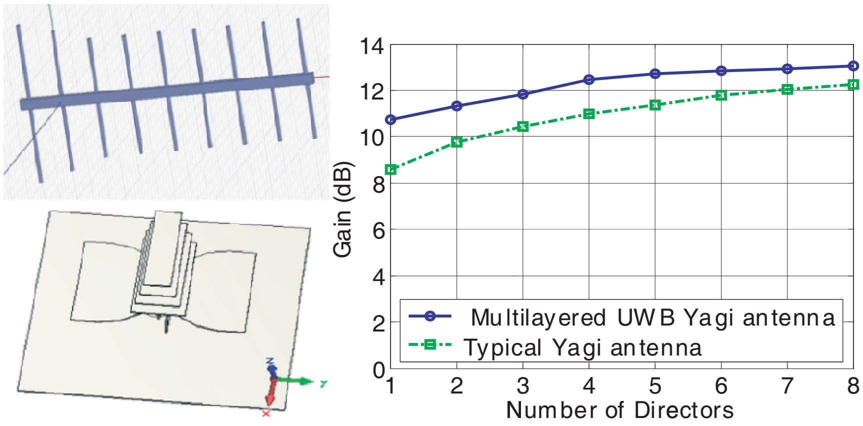


Figure 5. Simulated peak gain vs. the number of directors of Yagi antennas.

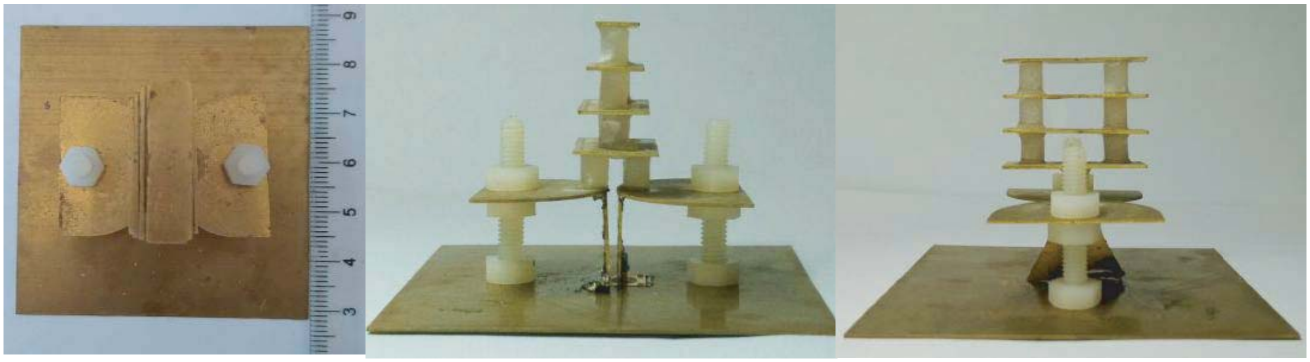
any two of extra directors is set same as $H1$, and the length of each extra director is set same as $Dx1$. The width of the extra director is investigated, as exhibited in Fig. 4. It can be observed that the multilayered Yagi antenna with decreased-width directors performs as well as the one with equal-width directors in the lower band, while the former greatly outperforms the latter in the upper band.

As shown in Fig. 5, the relationship between the peak gain in the operating ultra-wideband and the number of directors is investigated and compared with a typical linear Yagi antenna [14] (Fig. 5, upper left). A very similar trend can be found on the two Yagi antennas that the gain curves rise with the increase of the director number, but for a saturation on the gains when the director number hits a certain value (8, in this case); meanwhile, the gain of the UWB Yagi model is $1 \sim 2\,\text{dB}$ greater than its counterpart when the two have equal numbers of directors.

3. MEASURED RESULTS

An antenna prototype is manufactured as demonstrated in Fig. 6, where all conductors are copper flat with thickness of 0.5 mm. A linearly tapered air-substrate microstrip balun is designed to feed the dipole by a $50\,\Omega$ coaxial cable soldered under the ground plane through an SMA connector. White insulative PFTE screws and posts are used to fix and support the bow-tie dipole and directors.

The measurement is performed in a 6 m × 8 m × 10 m anechoic chamber using an antenna measurement platform based on a vector network analyzer (Agilent N5230C), a test table, and a motor controller, etc. The simulated and measured S_{11} parameters are compared in Fig. 7, where good agreement between the simulated and measured curves can be observed, and a 10 dB return



(a) (b) (c)

Figure 6. The fabricated model in (a) top view, (b) front view and (c) side view.

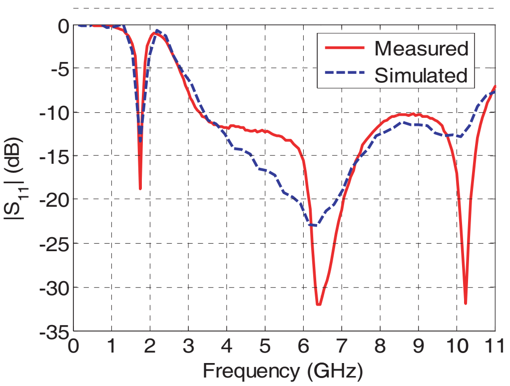
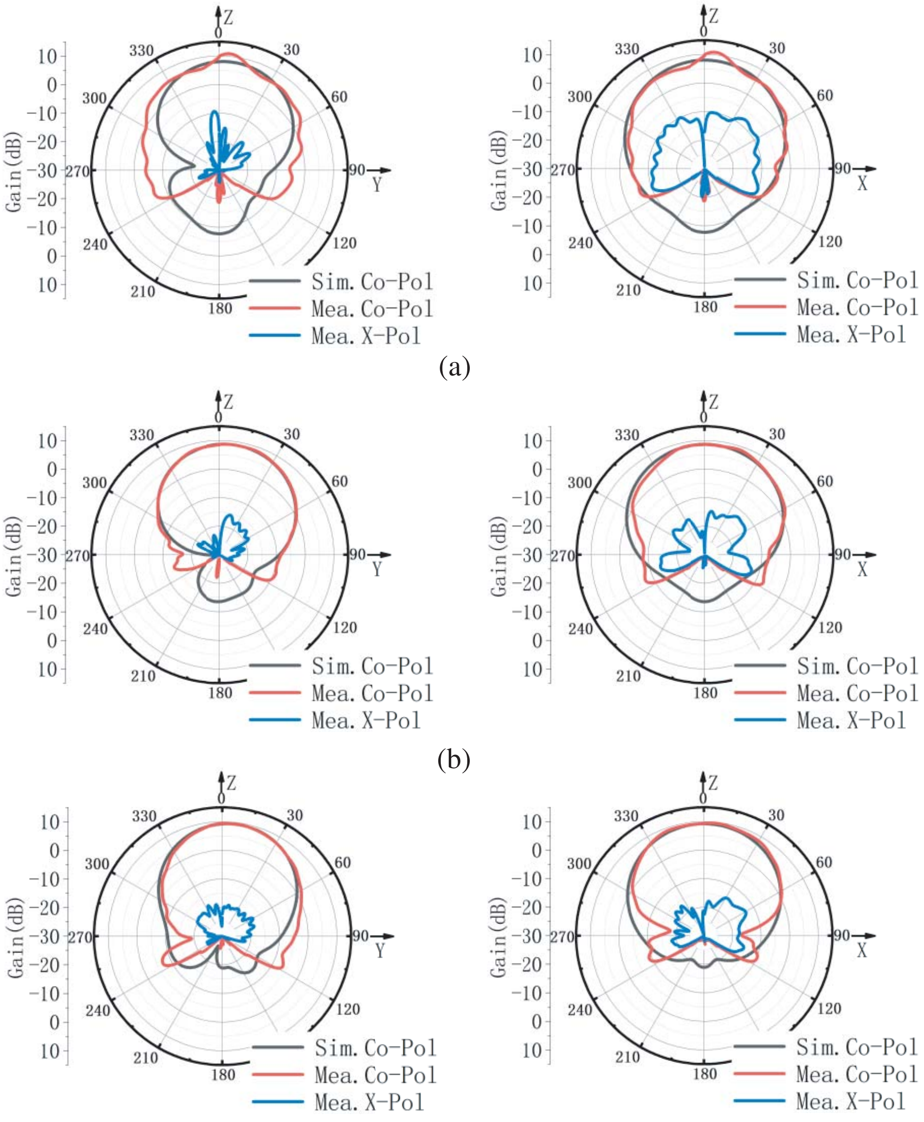


Figure 7. Simulated and measured S_{11} parameter of the proposed antenna.

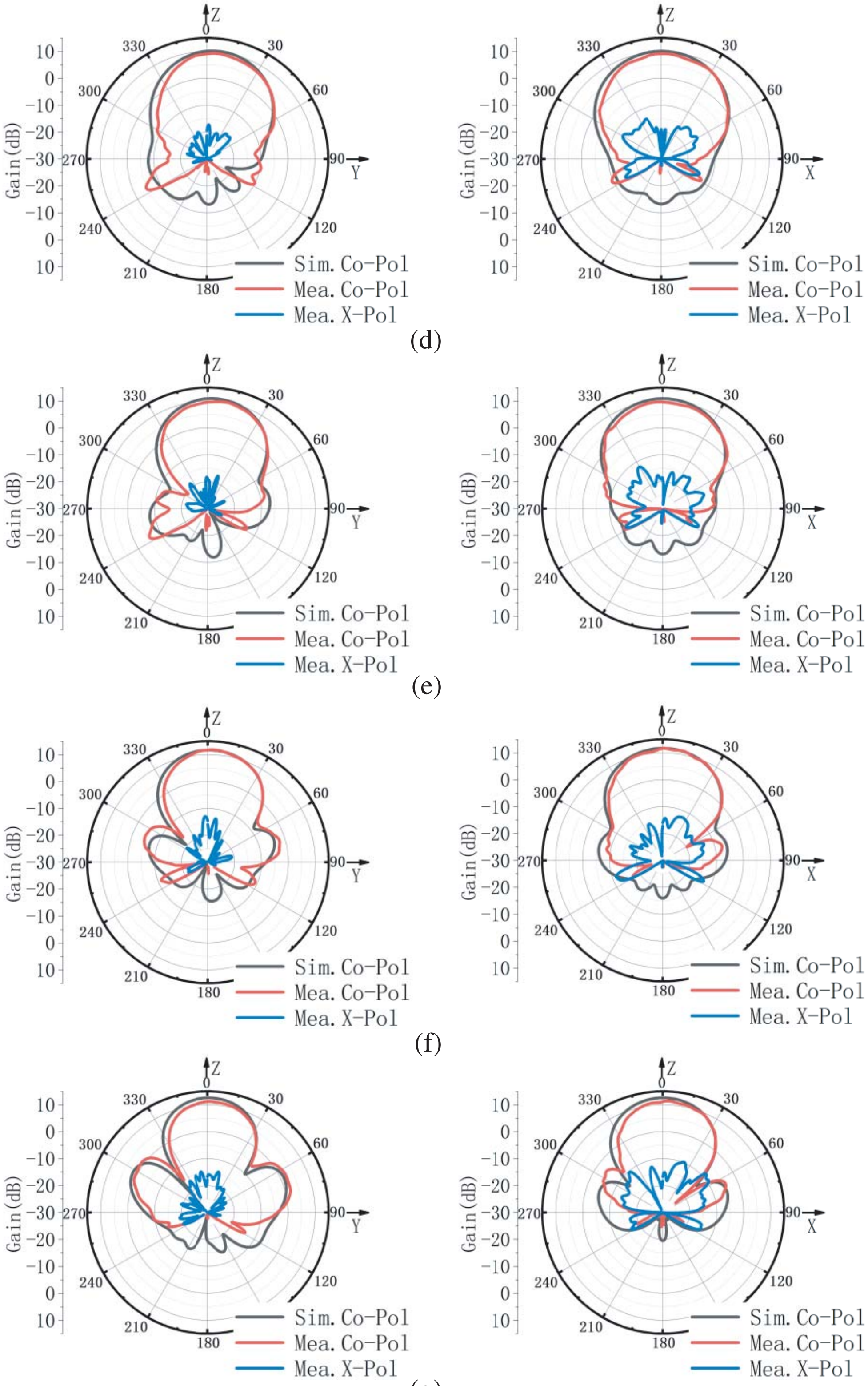
loss bandwidth over 3.4 ∼ 10.6 GHz can then be found. The discrepancy between the simulated and measured S_{11} parameters is mostly due to the tolerance error of antenna prototype geometry and the dielectric constant error of the real plastic materials.



(a)

(b)

(c)

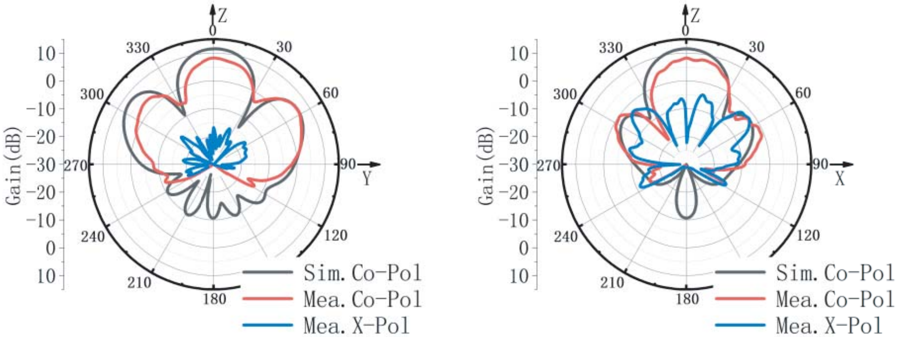

Z
0
30
60
90
120
180
210
240
270
300
330
Y
X
Gain (dB)
10
0
-10
-20
-30
Sim. Co-Pol
Mea. Co-Pol
Mea. X-Pol

(d)

(e)

(f)

(g)



(h)

Figure 8. Simulated and measured co- and cross-polar patterns of the proposed antenna in E-plane (left) and H-plane (right) at different in-band frequencies. (a) $f = 3.5\,\text{GHz}$. (b) $f = 4.5\,\text{GHz}$. (c) $f = 5.5\,\text{GHz}$. (d) $f = 6.5\,\text{GHz}$. (e) $f = 7.5\,\text{GHz}$. (f) $f = 8.5\,\text{GHz}$. (g) $f = 9.5\,\text{GHz}$. (h) $f = 10.5\,\text{GHz}$.

The simulated and measured co-polar and cross-polar patterns in the E-plane (yz-plane) and H-plane (xz-plane) at 8 in-band points are exhibited in Fig. 8. It is noted that the co-polar direction is along the Y-axis, and the maximum radiation direction is along the Z-axis. It is observed that stable directional radiation patterns, low cross-polarization, and narrow half-power beamwidth are attained over the entire bandwidth; the simulated and measured patterns almost coincide over most part of the whole band, but some slight discrepancies are primarily due to fabrication tolerances and uncertainty of material parameters. The relative cross-polar levels are better than $-15\,\text{dB}$ over $3.4 \sim 10.6\,\text{GHz}$ and especially better than $-20\,\text{dB}$ over most band. The discrepancy between the simulated and measured E-plane and H-plane patterns is mostly due to the antenna tolerance errors, and the influence of the test table and accessory tools in the anechoic chamber.

The simulated and measured peak gains are shown in Fig. 9. It can be found that good agreement exists over most band except for the lower and upper ends; the peak gains vary between about $8 \sim 12\,\text{dB}$ over $3.4 \sim 10.6\,\text{GHz}$, and the peak gains drop at upper frequencies because of the increase of sidelobes due to main beam split.

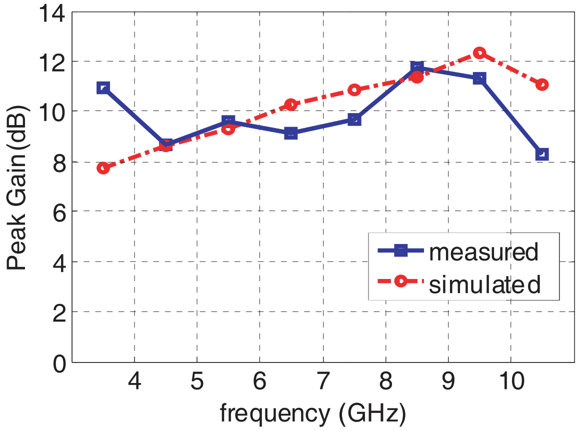


Figure 9. Simulated and measured peak gains of the proposed antenna.

4. CONCLUSION

A new UWB capped bow-tie multilayered-stacked Yagi antenna is studied in this article. It consists of a bow-tie dipole, a balun, a ground plane, and multiple patch directors. The 6-layered Yagi antenna, where the bow-tie is capped by four patch directors with equal lengths but decreasing widths, is investigated through simulation and measurement. The good agreement demonstrates that the proposed antenna achieves an impedance bandwidth 3.4 ∼ 10.6 GHz with return loss better than 10 dB, peak gains varying from 8 ∼ 12 dB, relative cross-polar levels better than −15 dB over the whole band (better than −20 dB over most band), in addition to a small footprint ($60 \times 60\,\mathrm{mm}^2$) and low cost. Further studies could explore this capped bowtie idea with respect to small footprint antenna arrays for use in wireless communications or electric power applications.

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REFERENCES

1. Soboll, P., V. Wienstroer, and R. Kronberger, "Stacked Yagi-Uda array for 2.45-GHz wireless energy harvesting," *IEEE Microwave Magazine*, Vol. 16, No. 1, 67-73, Feb. 2015.
2. Choe, H. and S. Lim, "Directivity and diversity dual-mode stacked antenna array using directors of Yagi-Uda antenna as monopole antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, No. 1, 575–578, 2014.
3. Roopan, R. B. and E. Sidhu, "High gain stacked microstrip folded dipole Yagi antenna configuration for WiMAX applications," *IEEE International Conference on Wireless Communications, Signal Processing and Networking*, 1013–1017, 2016.
4. Kramer, O., T. Djerafi, and K. Wu, "Vertically multilayer-stacked Yagi antenna with single and dual polarizations," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 4, 1022–1030, Apr. 2010.
5. Jun, S. and K. Chang, "A simple broadband stacked quasi-Yagi antenna," *IEEE Antennas and Propagation Society International Symposium*, Vol. 58, No. 4, 1804–1805, 2014.
6. Zarghooni, B. and K. Wu, "Circularly polarized stacked Yagi antenna with logarithmic spiral elements for E-band applications," *General Assembly and Scientific Symposium of the International Union of Radio Science*, 1–3, Aug. 2017.
7. Briqech, Z., A. R. Sebak, and T. A. Denidni, "High-efficiency 60-GHz printed Yagi antenna array," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, No. 3, 1224–1227, 2013.
8. Kramer, O., T. Djerafi, and K. Wu, "Very small footprint 60 GHz stacked Yagi antenna array," *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 9, 3204–3210, Sep. 2011.
9. Deng, X.-D., Y. Li, C. Liu, W. Wu, and Y. Z. Xiong, "340 GHz on-chip 3-D antenna with 10 dBi gain and 80% radiation efficiency," *IEEE Transactions on Terahertz Science and Technology*, Vol. 5, No. 4, 619–627, Jul. 2015.
10. Aguila, P., S. Zuffanelli, G. Zamora, F. Paredes, F. Martin, and J. Bonache, "Planar Yagi-Uda antenna array based on Split Ring Resonators (SRRs)," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, 1233–1236, 2017.
11. Korekado, T., K. Okuno, and S. Kurazono, "Design method of Yagi-Uda two-stacked circular loop array antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 8, 1112–1118, Aug. 1991.
12. Liu, Y., H. Liu, M. Wei, and S. Gong, "A novel slot Yagi-like multilayered antenna with high gain and large bandwidth," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 790–793, 2014.
13. Xie, C., J. Yin, X. Li, et al., "An ultra-wideband dipole with a director as a feed for reflector antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, 1341–1344, 2017.
14. Stutzman, W. L. and G. A. Thiele, *Antenna Theory and Design*, 2nd Edition, John Wiley & Sons, Inc., 1998.