

Wideband Quasi-Yagi Antenna Design and Its Usage in MIMO/Diversity Applications

Li Gu*, Yan-Wen Zhao, Qiang Ming Cai, and Zhi-Peng Zhang

Abstract—In this paper, a novel wideband quasi-Yagi antenna is proposed and investigated for multiple-input multiple-output (MIMO)/diversity antennas applications. An aperture-coupled balun is adopted with a curved Yagi radiator for the antenna to realize wideband property. The proposed quasi-Yagi antenna has high radiation efficiency and stable end-fire radiation patterns, operating in a wide bandwidth from 7 to 13.8 GHz. Then a pattern diversity antenna is developed using two elements, which are overlapped partly and placed in opposite orientations. The measured 10-dB bandwidth of the MIMO antenna is from 6.3 to 13.6 GHz. Meanwhile, isolation between the two ports is better than -26 dB. The radiation patterns and envelope correlation coefficients are also presented. The proposed pattern diversity antenna is validated to perform stable behaviours over a wide bandwidth, and it will find applications in wireless communications and radars systems.

1. INTRODUCTION

Yagi antennas have been widely used in modern communication systems due to their features of simple structures, moderate gain and stable unidirectional radiation. Quasi-Yagi antennas have attracted considerable attentions as they conquer the difficulties for planar implementation. They also have the merits of compact size, light weight, low profile and ease of installation. With the rapid development of wireless communication systems, there are urgent demands for wideband quasi-Yagi antennas. Various technologies have been developed to broaden the bandwidth of quasi-Yagi antennas [1–9]. Coplanar waveguide (CPW)-to-slotline transitions [1, 2] are convenient to be used to improve the bandwidth of quasi-Yagi antennas. Microstrip-to-coplanar stripline (CPS) structure combined with truncated ground plane contributes to the compact size and stable radiation patterns of wideband quasi-Yagi antenna [3]. Artificial transmission line has been used to design broadband microstrip-to-coplanar stripline (CPS) balun [4]. However, the antenna bandwidths in [3] and [4] are limited below 50% mainly due to the using of delay lines. On the other hand, much attention have been drawn to avoid the bottleneck brought by the drivers. The bandwidth of quasi-Yagi antennas could be broadened by using folded dipole drivers [5, 6], tapered driver [7] or bowtie driver [8]. In addition, wideband quasi-Yagi antenna also could be achieved with the dual-resonant driver [9], though the use of capacitors and inductors could bring additional loss of energy.

In this work, a novel wideband quasi-Yagi antenna is presented using a aperture-coupled wideband balun and a curved Yagi radiator. With via holes at the edge of balun, the electromagnetic energy mostly flows to the Yagi radiator. Good front-to-back ratios are obtained using the aperture-coupled balun. Without long phase delay lines, the proposed antenna achieves high radiation efficiency and stable radiation patterns over the band. It will be good candidates in wideband phased arrays for multifunction radars, and also has potential use in wideband microwave imaging systems.

Received 14 November 2016, Accepted 30 December 2016, Scheduled 18 January 2017

* Corresponding author: Li Gu (guli9125@163.com).

The authors are with the School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China.

Further, the proposed wideband quasi-Yagi antenna is investigated to design a wideband pattern diversity antenna. Two antennas are placed in opposite orientations and isolated by common-used via holes. MIMO antennas or diversity antennas possibly form uncoupled parallel channels which increase the capacity of wireless links. The combination of the wideband and diversity technology enable the high data rate and good resolution in applications [10–12]. Then, a prototype of the diversity antenna is fabricated and measured to validate the design.

2. WIDEBAND QUASI-YAGI ANTENNA DESIGN

The configuration of the proposed wideband quasi-Yagi antenna is shown in Figure 1. The antenna consists of two Rogers RT/duroid 5880 ($\epsilon_r = 2.2$, $\tan \delta = 0.001$) substrates with thickness of 0.79 mm. As depicted in details in Figure 2, the antenna can be divided into a wideband balun and a curved Yagi radiator. The wideband balun is excited by a $50\ \Omega$ microstrip line through a coupling slot in the truncated ground plane. The basic microstrip mode is converted to the first higher order mode [13–15] through the slot. On the top layer, a rectangular patch is designed with width of $\lambda_l/2$ (λ_l is the lower operating wavelength in the medium). A row of via holes are set on the edge of the patch, and two “arms” on the other edge are designed for the feed of the radiator. The electric fields on the two sides of the coupling slot operate in opposite directions, which guarantees the 180° out-of-phase signals at the two “arms” of the balun. The shorting vias not only reduce the radiation losses but also play an important role in the impedance matching over the band. A leaf-shaped driver with a curved director is is

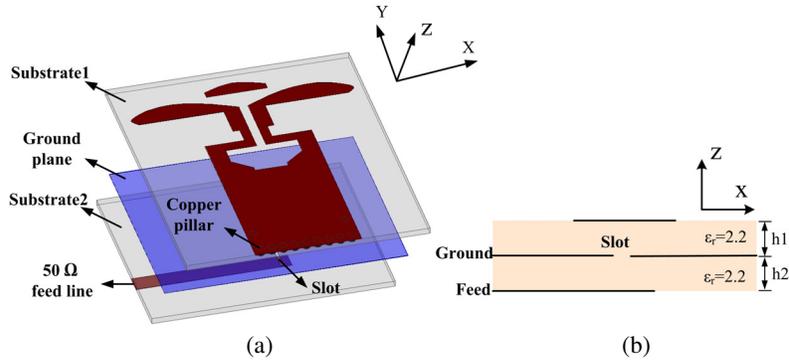


Figure 1. Proposed wideband quasi-Yagi antenna. (a) 3D view. (b) Side view.

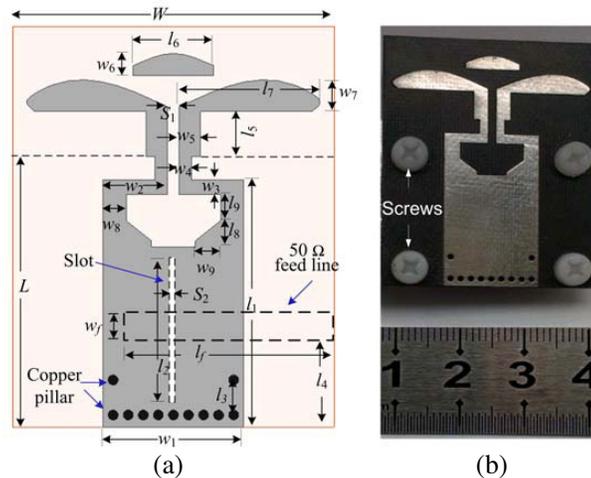


Figure 2. (a) Configuration of the quasi-Yagi antenna. (b) A photograph of the developed antenna.

designed to improve the impedance bandwidth of the antenna, and a comparison between the antennas with conventional dipole and the leaf-shaped dipole is conducted. As shown in Figure 3, $VSWR < 2$ is considered to guarantee good impedance matching during the optimization process. Therefore, the antenna with the curved dipole driver makes a little sacrifices of gain in the lower band, while it has better gain performance at high frequencies and achieves more stable and qualified VSWRs across the band. The truncated ground plane serves as a reflector. In order to further understand the operating principles of the antenna, the simulated current distributions of the proposed quasi-Yagi antenna at 8 GHz, 10 GHz and 12 GHz are shown in Figure 4. It is proved that the currents at the two “arms” of the balun have opposite directions over the band. The currents in the director get stronger as the frequency increases. This means that the effects of the director are improved in high frequency band.

The dimensions of the wideband quasi-Yagi antenna are optimized by using ANSYS HFSS. $VSWR < 2$ is a major consideration over the frequency band. The final design parameters of the antenna are summarized in Table 1. To verify the performance of the proposed design, an antenna prototype, as shown in Figure 2(b), was manufactured and measured. The truncated ground plane with a slot on the centre is fabricated on the same substrate board with the top layer circuits. The microstrip feed line is on the other board. Finally, these two substrate boards are stacked and fixed tightly by 4 plastic screws. The performance of the fabricated antenna is obtained by using an Agilent E8363B Programmable Network Analyzer (PNA).

The simulated and measured VSWRs of the designed quasi-Yagi antenna are plotted in Figure 5. Good agreements between the experimental measurements and simulations can be observed. The measured bandwidth defined by $VSWR < 2$ ranges from 7 to 13.8 GHz, which mostly covers the X-band. The simulated and measured antenna gain versus frequency plots of the antenna are shown in Figure 6. It can be seen that the measured gain of the antenna increases from 3.2 dBi to 7.8 dBi over the band and agrees well with the simulated result. It also can be found in Figure 6 that the simulated radiation efficiency of the proposed antenna exceeds 98% over the whole frequency band.

To demonstrate the radiation characteristics of the wideband quasi-Yagi antenna, its radiation patterns are also measured. The simulated and measured radiation patterns of the proposed antenna at

Table 1. Design parameters of the final antenna prototype (unit: mm).

| Para. | Value | Para. | Value | Para. | Value | Para. | Value |
|-------|-------|-------|-------|-------|-------|-------|-------|
| W | 37 | l_5 | 4.5 | w_2 | 6.4 | w_8 | 2.3 |
| L | 27 | l_6 | 8 | w_3 | 1.5 | w_9 | 2.5 |
| l_1 | 24.7 | l_7 | 14 | w_4 | 1.4 | w_f | 2.4 |
| l_2 | 14 | l_8 | 2.6 | w_5 | 2.1 | l_f | 20.5 |
| l_3 | 3.5 | l_9 | 2.6 | w_6 | 2.2 | S_1 | 1.2 |
| l_4 | 7.8 | w_1 | 14 | w_7 | 3.2 | S_2 | 0.4 |

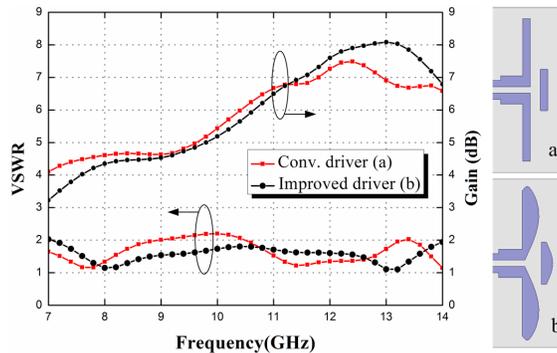


Figure 3. The comparison of using the leaf-shaped driver and conventional driver.

Table 2. Far field radiation properties.

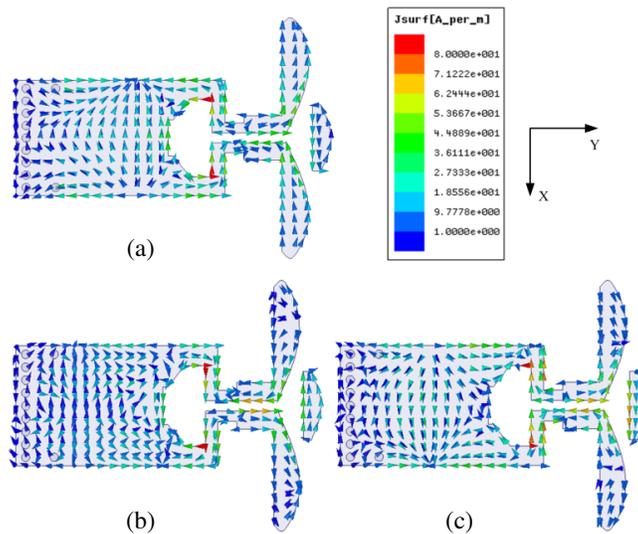
| Frequency (GHz) | 3 dB beam width | | F-to-B ratio (dB) | Gain (dB) |
|--------------------|-----------------|-----------------|----------------------|--------------|
| | <i>E</i> -plane | <i>H</i> -plane | | |
| 8 | 80° | 133° | 11.8 | 4.4 |
| 9 | 68° | 106° | 17.9 | 5.0 |
| 10 | 49° | 80° | 12.6 | 5.5 |
| 11 | 46° | 74° | 11.5 | 6.3 |
| 12 | 45° | 91° | 15.8 | 7.1 |
| 13 | 32° | 72° | 12.6 | 7.6 |

8, 10 and 12 GHz in the *E*-plane (*xoy*-plane) and *H*-plane (*yo_z*-plane) are shown in Figure 7, respectively. It can be observed from the figures that the measured results are in good agreement with the numerical simulations. The proposed antenna exhibits unidirectional radiation characteristics and stable patterns over the frequency band. The radiation properties of the antenna are further summarized in Table 2. The proposed antenna achieves narrower 3-dB beamwidth in *E*-plane which ranges from 32° to 80° over the band from 8 to 13 GHz, while the maximum beamwidth in *H*-plane is up to 133°. The front-to-back ratios of the proposed antenna are also presented in Table 2, which are better than 10 dB across the band.

3. DESIGN OF PATTERN DIVERSITY ANTENNA

As shown in Figure 8(a), a MIMO antenna is designed by employing two of the developed wideband quasi-Yagi antennas which are placed back-to-back in opposite orientations, and the two feed ports are fixed on different sides of the antenna. Take advantage of the good unidirectionality of the balun, the elements are overlapped by sharing the via holes in the centre of the plate to achieve compact size.

A prototype of the proposed MIMO antenna has been fabricated and tested to validate the design. The measurement of the *S*-parameters is conducted in a spacious laboratory using an Agilent E8363B PNA. The measured *S*-parameters are presented in Figure 8(b), compared with the simulated results. When port 1 is excited, port 2 is terminated with a 50 Ω load. The simulated results indicate that the

**Figure 4.** Current distributions of the proposed quasi-Yagi antenna at 8 GHz, 10 GHz and 12 GHz, respectively.

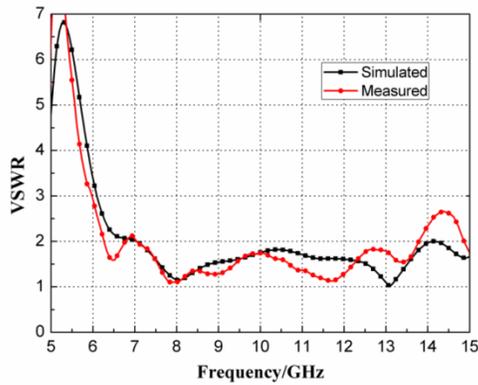


Figure 5. Simulated and measured VSWRs of the quasi-Yagi antenna.

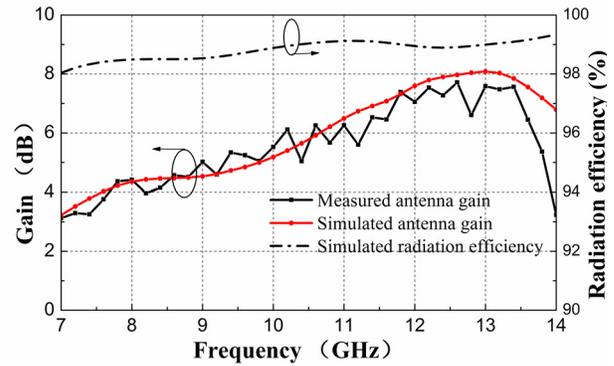


Figure 6. Radiation gain and efficiency of the quasi-Yagi antenna.

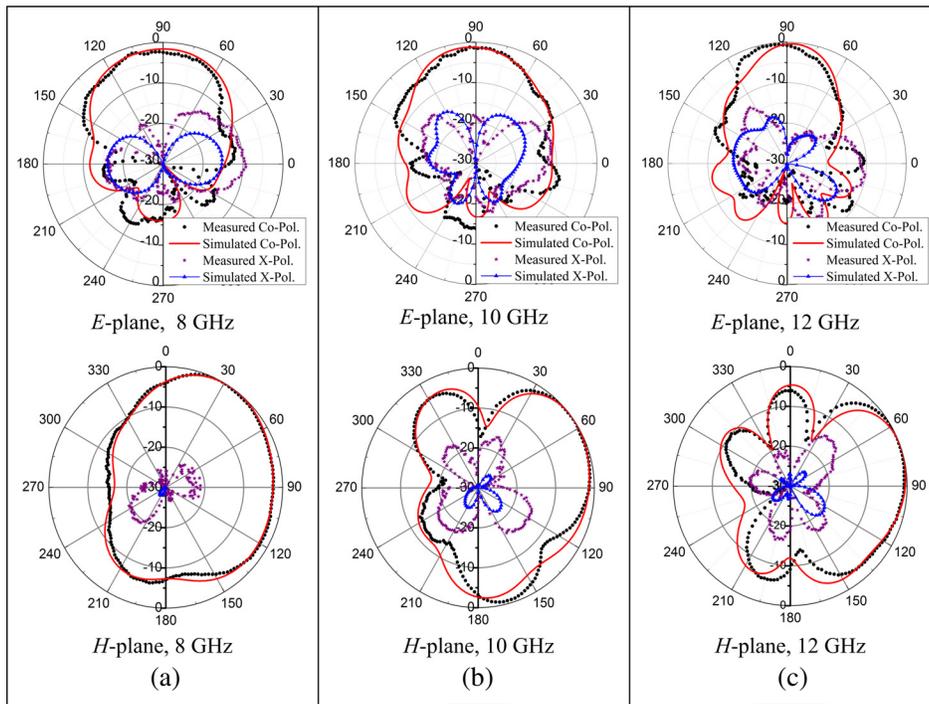


Figure 7. *E*-plane and *H*-plane Radiation patterns of the proposed antenna at (a) 8 GHz, (b) 10 GHz and (c) 12 GHz, respectively.

MIMO antenna achieves an impedance bandwidth from 7 to 13.8 GHz, whereas the measure impedance bandwidth ranges from 6.3 to 13.6 GHz. The isolation between the two ports is better than -26 dB over the whole frequency band.

In order to illustrate the pattern diversity property of the antenna, the radiation patterns of the simulation model are presented in Figure 9. When port 1 is excited, port 2 is terminated with a $50\ \Omega$ load, and the *E*-plane and *H*-plane radiation patterns across the frequency band are shown in Figure 9(a). When port 2 is excited and the other port is terminated with a $50\ \Omega$ load, the results are shown in Figure 9(b). It can be observed that the radiation patterns of the MIMO antenna cover the complementary regions of the space when either port is excited. The proposed MIMO antenna proves

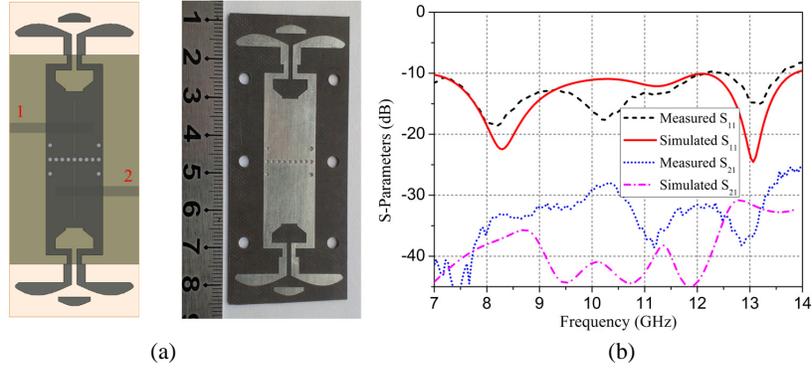


Figure 8. (a) Configuration of the proposed diversity antenna. (b) Simulated and measured S -parameters of the diversity antenna.

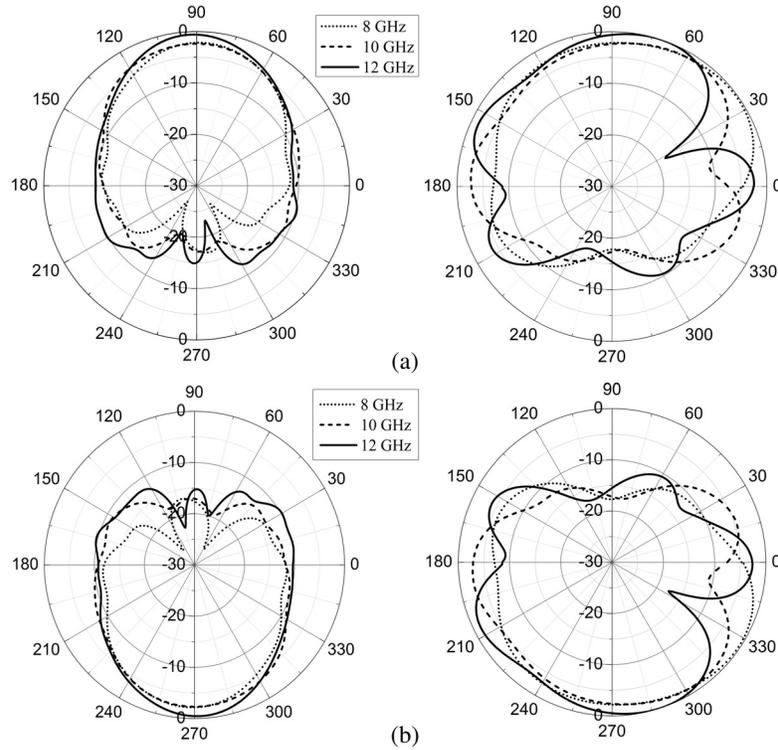


Figure 9. Simulated radiation patterns of the diversity antenna. (a) Port 1 is excited. (b) Port 2 is excited.

to achieve stable pattern diversity property over the frequency band.

In order to further evaluate the performance of the proposed wideband pattern diversity antenna, the envelop correlation coefficient ρ_e is calculated by using the S -parameters [16]

$$\rho_e = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}. \quad (1)$$

As shown in Figure 10, the measured envelop correlation coefficient, obtained from the measured S -parameters using (1), is below 0.01 across the whole frequency band. Which benefits from the good impedance matching and high isolation between the two ports of the MIMO antenna.

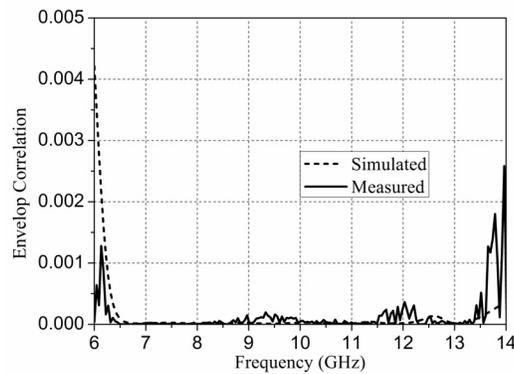


Figure 10. Simulated and measured envelop correlation coefficients of the diversity antenna.

4. CONCLUSION

A novel wideband quasi-Yagi antenna is presented and used to develop a pattern diversity antenna. The quasi-Yagi antenna achieves a measured bandwidth from 7 GHz to 13.8 GHz and a maximum gain of 7.8 dBi with a total profile of $0.55\lambda_0$. By using the aperture-coupled balun, good front-to-back ratios and high radiation efficiency are obtained. By sharing the via holes in the center, the diversity antenna achieves compact size and good isolation better than -26 dB. Stable radiation patterns with low cross-polarization levels are obtained over the frequency band. The envelop correlation coefficient between the antenna elements is less than 0.01. The MIMO quasi-Yagi antenna performs good diversity properties over the wide frequency bandwidth. It will find applications in wireless communication, satellite, and radar systems.

ACKNOWLEDGMENT

This work is supported in part by the National Natural Science Foundation of China (No. 61371050).

REFERENCES

1. Sor, J., Y. Qian, and T. Itoh, "Coplanar waveguide fed quasi-Yagi antenna," *Electron. Lett.*, Vol. 36, No. 1, 1–2, Jan. 2000.
2. Kan, H., R. Waterhouse, A. Abbosh, et al., "Simple broadband planar CPW-fed quasi-Yagi antenna," *IEEE Antennas Wireless Propag. Lett.*, Vol. 6, 18–20, 2007.
3. Deal, W. R., N. Kaneda, J. Sor, Y. Qian, and T. Itoh, "A new quasi-Yagi antenna for planar active antenna arrays," *IEEE Trans. Microw. Theory Tech.*, Vol. 48, No. 6, 910–918, Jun. 2000.
4. Ma, T.-G., C.-W. Wang, R.-C. Hua, and J.-W. Tsai, "A modified quasi-Yagi antenna with a new compact microstrip-to-coplanar strip transition using artificial transmission lines," *IEEE Trans. Antennas Propag.*, Vol. 57, No. 8, 2469–2474, Aug. 2009.
5. Nikolic, N. and A. Weily, "Compact E-band planar quasi-Yagi antenna with folded dipole driver," *IET microwaves, Antennas Propag.*, Vol. 4, No. 11, 1728–1734, 2010.
6. Wang, Z., X. L. Liu, Y.-Z. Yin, et al., "A novel design of folded dipole for broadband printed Yagi-Uda antenna," *Progress In Electromagnetics Research C*, Vol. 46, 23–30, 2014.
7. Nguyen, P. T., A. Abbosh, and S. Crozier, "Wideband quasi-Yagi antenna with tapered driver," *Proc. Asia-Pacific Conf. Antennas Propag.*, Singapore, 138–139, Aug. 2012.
8. Jiang, K., Q. G. Guo, and K. M. Huang, "Design of a wideband quasi-Yagi microstrip antenna with bowtie active elements," *Proc. Int. Conf. on Microwave and Millimeter Wave Technology (ICMMT)*, 1122–1124, 2010.

9. Abbosh, A., "Ultra-wideband quasi-Yagi antenna using dual-resonant driver and integrated balun of stepped impedance coupled structure," *IEEE Trans. Antennas Propag.*, Vol. 61, No. 7, 3885–3888, Jul. 2013.
10. Mattheijssen, P., M. H. A. J. Herben, G. Dolmans, and L. Leyten, "Antenna-pattern diversity versus space diversity for use at handhelds," *IEEE Trans. Vehicular Technol.*, Vol. 53, No. 4, 1035–1042, Jul. 2004.
11. Waldschmidt, C. and W. Wiesbeck, "Compact wide-band multimode antennas for MIMO and diversity," *IEEE Trans. Antennas Propag.*, Vol. 52, No. 8, 1963–1969, Aug. 2004.
12. Zhang, S., Z. Ying, J. Xiong, and S. He, "Ultrawideband MIMO/diversity antennas with a tree-like structure to enhance wideband isolation," *IEEE Antennas Wireless Propag. Lett.*, Vol. 8, 1279–1282, 2009.
13. Luxey, C. and J.-M. Laheurte, "Dual-beam array of microstrip leaky-wave antennas," *Inst. Elect. Eng. Electron. Lett.*, Vol. 34, 1041–1042, May 1998.
14. Hu, C. C., C. F. Jou, and J. J. Wu, "An aperture-coupled linear microstrip leaky-wave antenna with two-dimensional dual-beam scanning capability," *IEEE Trans. Antennas Propag.*, Vol. 48, No. 6, 909–913, Jun. 2000.
15. Wu, P. and Q. Xue, "A wideband microstrip balun structure," *2014 IEEE Microwave Symposium (IMS)*, 1–3, Florida, Jun. 2014.
16. Blanch, S., J. Romeu, and I. Corbella. "Exact representation of antenna system diversity performance from input parameter description," *Electron. Lett.*, Vol. 39, No. 9, 705–707, May 2003.