Planar Dual-Band WLAN MIMO Antenna with High Isolation

Hui Li [*], Le Kang, Yuan Xu, and Ying-zeng Yin

Science and Technology on Antenna and Microwave Laboratory
Xidian University, Xi'an, Shaanxi, 710071, China
*huiyuezai@163.com

***Abstract* ─** In this paper, a dual-band multiple-input multiple-output (MIMO) antenna with a planar and rotational symmetric structure is presented. The proposed antenna comprises two via-fed monopole antennas arranged orthogonally in cross-pairs. When each monopole is excited, the other can be employed as a parasitic element. By properly adjusting the antenna dimensions, two resonant modes can be generated at about 2.45 and 5.6 GHz. Besides, the radiation patterns of two monopoles are orthogonal to each other, resulting in good pattern diversity and high isolation without using additional decoupling methods. Measured results show that two operating bands ranging from 2.3-2.75 and 5.09-6.16 GHz are obtained, which can cover the whole (2.4/5.2/5.8-GHz) wireless local area network (WLAN) bands. Port-to-port isolation is more than 24 and 22 dB at the lower and higher operating bands, respectively. Envelope correlation coefficient is studied as well.

***Index Terms* ─** Dual-band, high isolation, MIMO, via-fed monopole, WLAN.

I. INTRODUCTION

Nowadays, combining the existing wireless communication systems such as wireless local area networks (WLAN) with multiple-input multiple-output (MIMO) technology is a hot topic. Due to the limited space available in wireless terminals, multi-antennas are often closely packed in MIMO systems and strong mutual coupling is caused. In order to suppress the mutual coupling in MIMO antennas, various types of methods have been developed, which include the lumped decoupling circuit [1], parasitic element [2], neutralization line [3], defected ground structure [4], electromagnetic band gap [5] and ground stub [6]. However, all these methods require additional space for the decoupling structures and some of the structures are wavelength-related, which makes them difficult to be integrated in the portable devices. To achieve high isolation without the use of complex decoupling methods, MIMO antennas with orthogonal polarizations/modes could be a promising choice [7-9]. Though the antennas [7, 8] exhibit good isolation performance, the impedance matching and radiation characteristics are different between ports. Owing to the orthogonal and symmetrical placement of the antenna [9], identical matching characteristics and orthogonal radiation patterns with low correlation are realized at two ports. Nevertheless, this antenna with a single resonant mode at 2.4 GHz just covers the lower-band WLAN operation. The WLAN MIMO antenna [10] produces dual-band matching as well as a built-in decoupling mechanism. However, the antenna exhibits an isolation level less than 15 dB.

In this work, a small and planar MIMO antenna is proposed for the 2.4/5.2/5.8-GHz WLAN applications. The antenna consists of a cross-pair of via-fed monopole elements. When each antenna port is excited, two resonances at 2.45 and 5.6 GHz are generated by the excited antenna element and the other parasitic element, respectively. Parasitic dipole antenna has also been adopted in [11] to excite an additional resonance and thus extend the impedance bandwidth. Compared with the design in [11], the proposed antenna with via-fed monopole elements has planar and simple feeding structures. Since the two ports are orthogonally fed, the radiation patterns appear rotated by 90° and produce low mutual coupling between antenna elements. Without using any extra decoupling methods, the antenna achieves isolation of above 24 and 22 dB at the 2.4- and 5-GHz band, respectively. Moreover, the antenna maintains a total size of 43×43×0.8 mm^3 and a full planar structure.

II. ANTENNA DESIGN AND ANALYSIS

A. Antenna structure

Geometry of the proposed antenna is shown in Fig. 1. The antenna is implemented with a low-cost FR4 substrate with a relative permittivity of 4.4 and a thickness of 0.8 mm. The MIMO antenna is composed of two perpendicularly crossed via-fed monopole elements, which are identical in configuration and arranged on both sides of the substrate without physical overlaps.

For each monopole, a 50-Ω transmission line is printed on one side of the substrate and connected to the tapered radiator on the other side through a shorting via. Each monopole itself is capable of generating a lower resonance at around 2.45 GHz. Then a higher resonant

Submitted On: May 15, 2016
Accepted On: September 28, 2016

mode at about 5.6 GHz is excited by the other perpendicular monopole. By appropriately designing the detailed dimensions of the MIMO antenna, dual-band operation can be realized for WLAN applications. In addition, since one monopole element is horizontally polarized and the other is vertically polarized, orthogonal radiation patterns are obtained inherently at two ports and this weakens the coupling between antenna elements without additional decoupling structures. Based on the above analysis, the final parameters are optimized as follows (in millimetres): $W = L = 43$, $W_1 = 10$, $W_2 = 1.5$, $W_3 = 2$, $L_1 = 26.8$, $L_2 = 16.5$, $L_3 = 20.5$, $D = 5.7$, and $H = 0.8$.

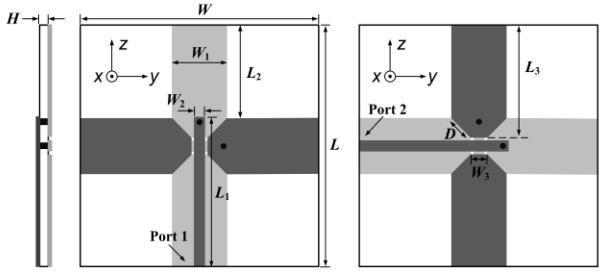

Fig. 1. Geometry of the proposed MIMO antenna.

B. Working mechanism

To clarify the dual-band excitation mechanism, the simulated current distributions of the proposed antenna are illustrated in Fig. 2. At 2.45 GHz, when only Port 1 is excited, most surface current is concentrated on the radiator as well as the ground plane of the vertically oriented monopole element. It is noted that the electrical length of the radiator is close to a quarter-wavelength at 2.45 GHz. It also can be seen that at 5.6 GHz, larger current is distributed along the tapered edges of the two crossed monopoles, and strong induced currents can be observed on the horizontally arranged monopole. It is revealed that the horizontal monopole can be viewed as a parasitic element, which leads to the appearance of an additional resonance. This resonant mode is sensitive to the electromagnetic coupling between the monopoles at the two sides of the substrate, which is controlled by adjusting the coupled length.

Figure 3 displays the simulated 3-D radiation patterns of the proposed antenna. It can be found from Figs. 3 (a) and (b) that, orthogonal radiation patterns are obtained at 2.45 GHz when different ports are excited. The two patterns have little influence on each other, which consequently leads to coupling reduction. Similar results are observed at 5.6 GHz, as indicated in Figs. 3 (c) and (d). The antenna provides two different radiation patterns to receive signals from different directions, hence ensuring pattern diversity with good isolation.

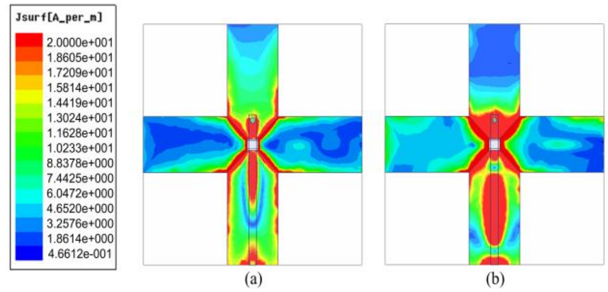

Fig. 2. Surface current distributions at: (a) 2.45 and (b) 5.6 GHz.

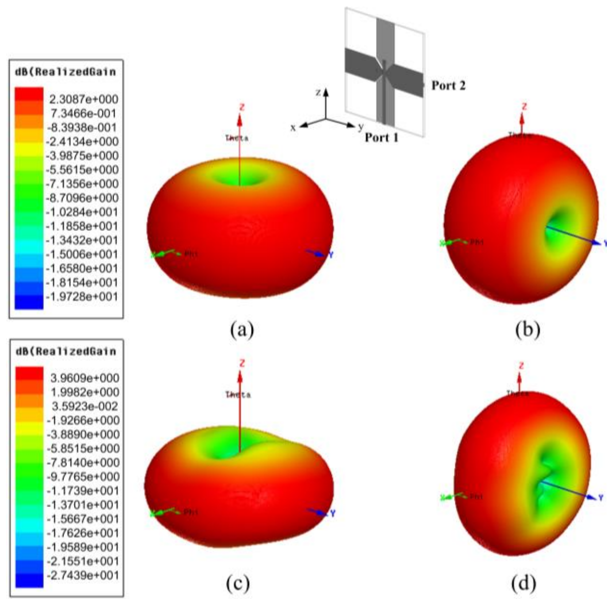

Fig. 3. Simulated 3-D radiation patterns at: (a), (b) 2.45 GHz, and (c), (d) 5.6 GHz.

The effects of the important design parameters on antenna performance are investigated through simulation, as presented in Fig. 4. It can be found from Fig. 4 (a) that, both the resonant bands at about 2.45 and 5.6 GHz shift towards lower frequencies when L_3 are influenced by increasing the total length of the tapered radiator (L_3). The change of the mutual coupling with the variation of L_3 is slight. In Fig. 4 (b), with the increase of D, the higher resonant band shifts to lower frequencies while the lower band almost remains unchanged. Meanwhile, the mutual coupling remains below -25 and -20 dB at the two bands, respectively. It is demonstrated that the coupled length (D) significantly affects the higher resonant band.

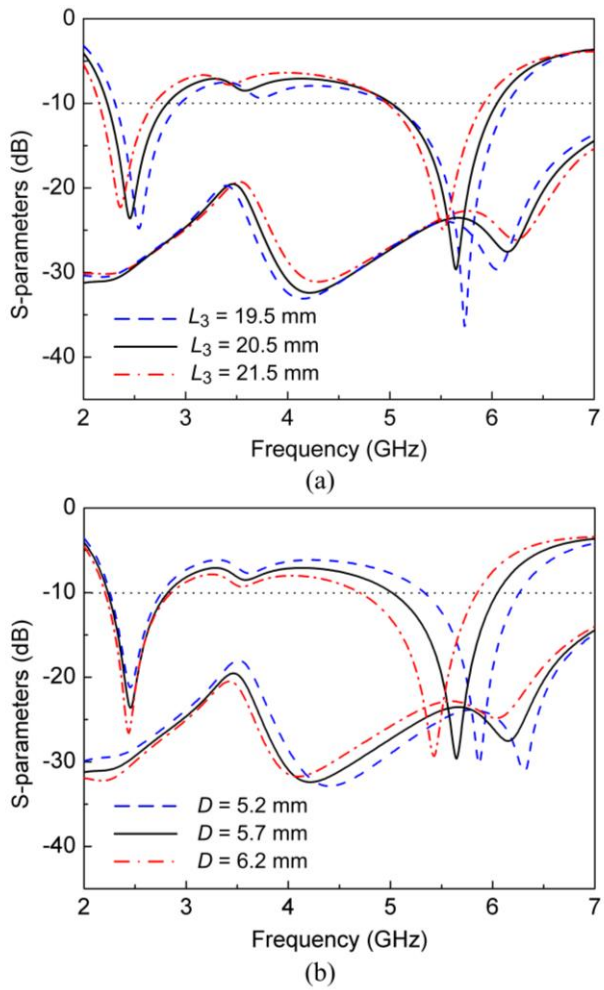

Fig. 4. Parametric study with different values of: (a) L_3 and (b) D.

III. RESULTS AND DISCUSSION

A. S-parameters

In order to examine the design above, an antenna prototype is fabricated and shown in Fig. 5. The reflection coefficient (S_{11} & S_{22}) and mutual coupling (S_{12} & S_{21}) are displayed in Figs. 6 (a) and (b), respectively. As can be observed, the discrepancies between measurement and simulation are very slight, which proves the design structure has a good and stable performance. The measured bandwidths with -10 dB reflection coefficient are 450 MHz (2.3-2.75 GHz) and 1070 MHz (5.09-6.16 GHz), which can cover the entire WLAN operating bands. It is also shown that the measured port isolation is more than 24 dB at the 2.4-GHz band and 22 dB at the 5.2/5.8-GHz band.

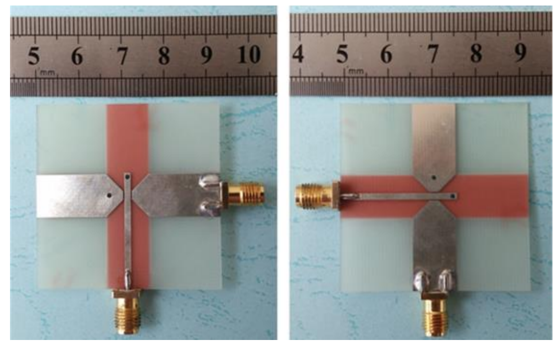

Fig. 5. Photographs of the fabricated antenna.

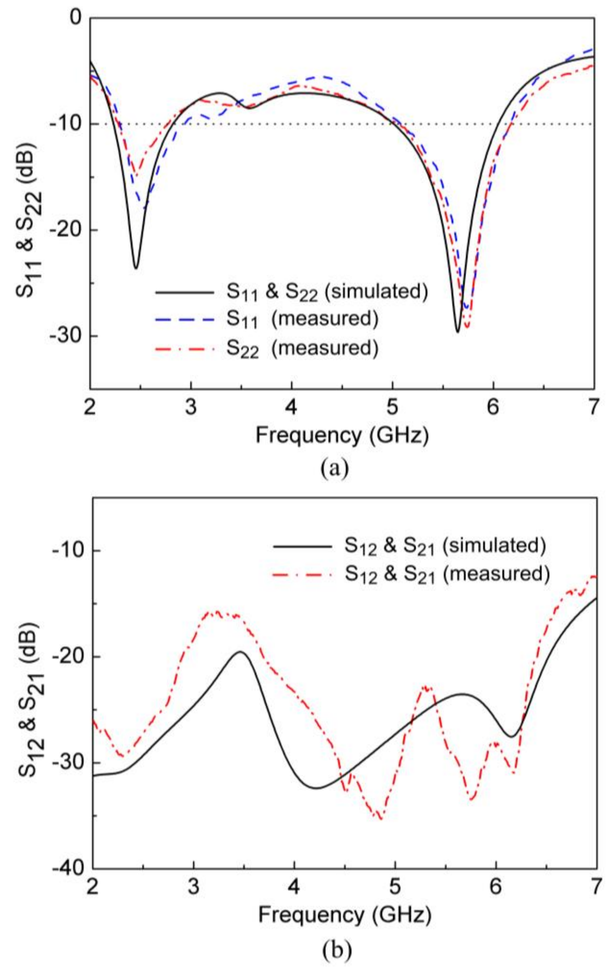

Fig. 6. Measured and simulated S-parameters.

B. Radiation characteristics

Since the antenna has a planar and rotational symmetric configuration, the radiation characteristics are measured with a single port excited. The normalized radiation patterns are depicted in Fig. 7. It is observed that the radiation patterns are quasi-omnidirectional in the *H*-plane (*xoy*-plane of Port 1 and *xoz*-plane of Port 2) and nearly dumb-bell shaped in the *E*-plane (*xoz*-plane of Port 1 and *xoy*-plane of Port 2). In the *yoz*-plane, the patterns at two ports exhibit good complementary properties.

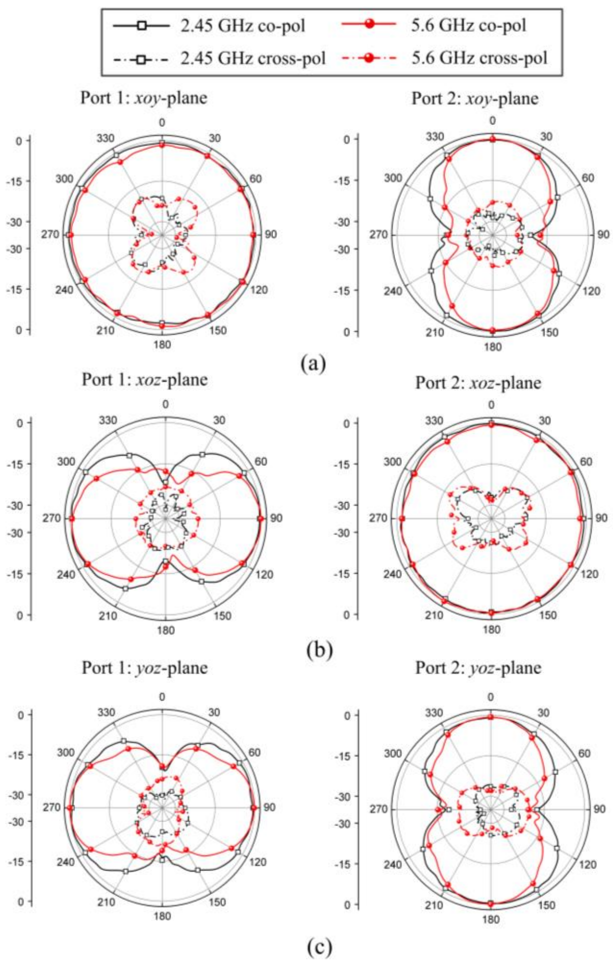

Fig. 7. Measured far-filed radiation patterns at 2.45 and 5.6 GHz: (a) *xoy*-plane, (b) *xoz*-plane, and (c) *yoz*-plane.

The measured results agree well with the simulation in Fig. 3. Therefore, the antenna produces both orthogonal and complementary patterns, which weaken the channel correlation and strengthen the power of the reception.

As shown in Fig. 8, the peak gain varies from 1.93 to 2.28 and 3.07 to 3.94 dBi at the lower and higher bands, respectively. Besides, the antenna provides radiation efficiency better than 80% at low-frequency range. At higher frequencies, the efficiency deceases to around 73%.

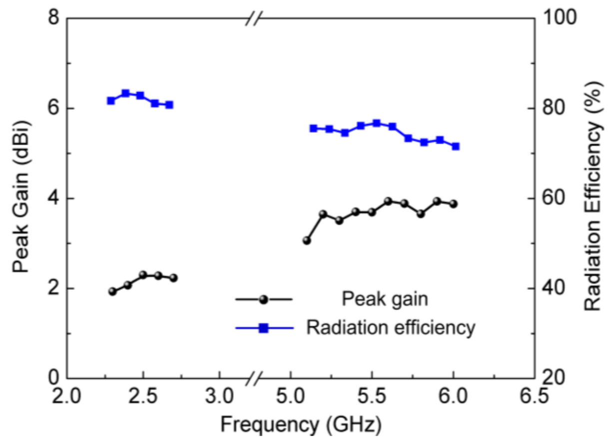

Fig. 8. Measured gain and radiation efficiency.

C. Diversity performance

An envelope correlation coefficient (ECC) level of below 0.5 is set as a widely accepted limit for diversity conditions [12]. Assuming that the antenna operates in a uniform multipath environment, the ECC value (denoted by ρ_e) is calculated from the measured results [13]:

$$\rho_e = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^2}{(1-(\left|S_{11}\right|^2+\left|S_{21}\right|^2))\,(1-(\left|S_{22}\right|^2+\left|S_{12}\right|^2))\eta_{\mathrm{rad1}}\eta_{\mathrm{rad2}}}. \quad (1)$$

As observed in Fig. 9, the ECC value between ports is found to be below 0.01 at the two bands of interest, which is much less than 0.5.

To estimate the loss of channel capacity in MIMO antenna systems, the capacity loss (C_{loss}) is obtained using the correlation matrix of the receiving antenna [14]:

$$C_{\mathrm{loss}} = -\log_2 \det(\Psi^{R}), \quad (2)$$

where

$$\Psi^R = \begin{bmatrix} \rho_{11} & \rho_{12} \\ \rho_{21} & \rho_{22} \end{bmatrix}, \quad (3)$$

and

$$\rho_{ii} = 1-(\left|S_{ii}\right|^2+\left|S_{ij}\right|^2),\ \rho_{ij} = -(S_{ii}^{*}S_{ij}+S_{ji}^{*}S_{ij}),\ \text{for } i, j = 1 \text{ or } 2. \quad (4)$$

It also can be seen from Fig. 9 that the C_{loss} is less than 0.28 b/s/Hz, and it is well below the threshold value of 0.4 b/s/Hz. Therefore, the results above indicate that good diversity performance can be achieved

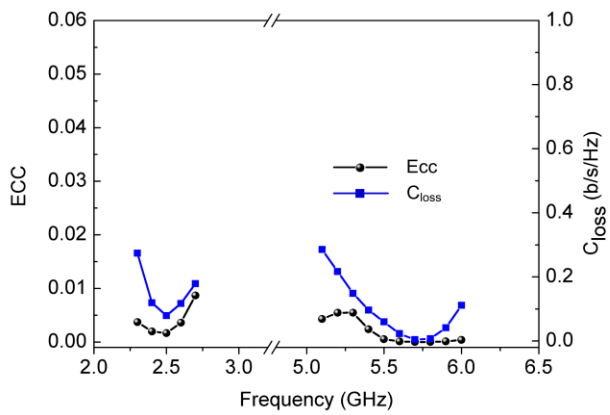

Fig. 9. Measured envelope correlation coefficient and capacity loss.

IV. CONCLUSION

A dual-port MIMO antenna using a planar rotational symmetric structure has been proposed and investigated. By employing a cross-pair of via-fed monopole elements, dual-band resonant characteristics can be obtained. Meanwhile, orthogonal radiation patterns are achieved when feeding different ports, which leads to low correlation in reception. According to the measured data, the antenna operates from 2.3 to 2.75 and 5.09 to 6.16 GHz, along with port isolation of better than 24 and 22 dB at the lower and higher working bands. The envelop correlation coefficient and capacity loss are better than 0.01 and 0.28 b/s/Hz, respectively. Furthermore, the planar structure and simple configuration make the antenna easy to be manufactured and integrated.

REFERENCES

[1] S. C. Chen, Y. S. Wang, and S. J. Chung, "A decoupling technique for increasing the port isolation between two strongly coupled antennas," *IEEE Trans. Antennas Propag.*, vol. 56, no. 12, pp. 3650-3658, Dec. 2008.

[2] A. C. K. Mak, C. R. Rowell, and R. D. Murch, "Isolation enhancement between two closely packed antennas," *IEEE Trans. Antennas Propag.*, vol. 56, no. 11, pp. 3411-3419, Nov. 2008.

[3] A. Chebihi, C. Luxey, A. Diallo, P. L. Thuc, and R. Staraj, "A novel isolation technique for closely spaced PIFAs for UMTS mobile phones," *IEEE Antennas Wireless Propag. Lett.*, vol. 7, pp. 665-668, 2008.

[4] F. G. Zhu, J. D. Xu, and Q. Xu, "Reduction of mutual coupling between closely-packed antenna elements using defected ground structure," *Electron. Lett.*, vol. 45, no. 12, pp. 601-602, June 2009.

[5] C. C. Hsu, K. H. Lin, and H. L. Su, "Implementation of broadband isolator using metamaterial-inspired resonators and T-shaped branch for MIMO antennas," *IEEE Trans. Antennas Propag.*, vol. 59, no. 10, pp. 3936-3939, Oct. 2011.

[6] L. Liu, S. W. Cheung, and T. I. Yuk, "Compact MIMO antenna for portable devices in UWB applications," *IEEE Trans. Antennas Propag.*, vol. 61, no. 8, pp. 4257-4264, Aug. 2013.

[7] J. Malik, A. Patnaik, and M. V. Kartikeyan, "Novel printed MIMO antenna with pattern and polarization diversity," *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 739-742, 2015.

[8] W. W. Li, B. Zhang, J. H. Zhou, and B. Q. You, "High isolation dual-port MIMO antenna," *Electron. Lett.*, vol. 49, no. 15, pp. 919-921, July 2013.

[9] H. Wang, Z. J. Zhang, and Z. H. Feng, "Dual-port planar MIMO antenna with ultra-high isolation and orthogonal radiation patterns," *Electron. Lett.*, vol. 51, no. 1, pp. 7-8, Jan. 2015.

[10] S. M. Wang, L. T. Hwang, C. J. Lee, C. Y. Hsu, and F. S. Chang, "MIMO antenna design with built-in decoupling mechanism for WLAN dual-band applications," *Electron. Lett.*, vol. 51, no. 13, pp. 966-968, June 2015.

[11] Q. X. Chu, D. L. Wen, and Y. Luo, "A broadband ±45° dual-polarized antenna with Y-shaped feeding lines," *IEEE Trans. Antennas Propag*., vol. 63, no. 2, pp. 483-490, Jan. 2015.

[12] R. G. Vaughan and J. B. Andersen, "Antenna diversity in mobile communications," *IEEE Trans. Veh. Technol.*, vol. 36, no. 4, pp. 149-172, Nov. 1987.

[13] H. Paul, "The significance of radiation efficiencies when using S-parameters to calculate the received signal correlation from two antennas," *IEEE Antennas Wirel. Propag. Lett.*, vol. 4, no. 1, pp. 97-99, Jan. 2005.

[14] Y. K. Choukiker, S. K. Sharma, and S. K. Behera, "Hybrid fractal shape planar monopole antenna covering multiband wireless communications with MIMO implementation for handheld mobile devices," *IEEE Trans. Antennas Propag*., vol. 62, no. 3, pp. 1483-1488, Mar. 2014.

Hui Li received the B.S. and M.S. degrees from Xidian University, Xi'an, China, in 2008 and 2012, respectively. She is currently pursuing the Ph.D. degree in Electromagnetic Field and Microwave Technology from the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, China

Her research interests include multiband antennas, ultra-wideband antennas, tightly coupled antennas and MIMO technologies.

Le Kang received the B.S. and M.S. degrees from Xidian University, Xi'an, China, in 2008 and 2011, respectively. He is currently pursuing the Ph.D. degree in Electromagnetic Field and Microwave Technology from the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, China.

His research interests include microstrip antennas, MIMO antennas, and phased array antennas.

Yuan Xu received the B.S. degrees from Xi`an University of Posts & Telecommunications, Xi'an, China, in 2014. She is currently pursuing the M.S. degree in Electromagnetic Field and Microwave Technology from the National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, China.

Her research interests include multiband antennas, UWB antennas, and wideband unidirectional antenna.

Ying-zeng Yin received the B.S. degree, M.S. degree and Ph.D. degree in Electromagnetic Wave and Microwave Technology from Xidian University, Xi'an, China, in 1987, 1990, and 2002, respectively. From 1990 to 1992, he was a Research Assistant and an Instructor at the Institute of Antennas and Electromagnetic Scattering, Xidian University. From 1992 to 1996, he was an Associate Professor in the Department of Electromagnetic Engineering, Xidian University. Since 2004, he has been a Professor at Xidian University.

His research interests include design of microstrip antennas, artificial magnetic conductors, phased array antennas, and computer aided design for antennas.