Progress In Electromagnetics Research C, Vol. 71, 17–23, 2017

Compact UWB MIMO Ground Linearly Tapered Slot Antenna Decoupled by a Stepped Slot

Hui-Fen Huang* and Shu-Guang Xiao

Abstract—A very compact ultra-wideband (UWB) multiple-input-multiple-output (MIMO) ground linearly tapered slot Antenna (LTSA) is presented in this paper. On a cost-effective FR4 substrate, it consists of a ground plane and two microstrip feedlines. Its overall dimension is only $22 \times 26\,\mathrm{mm}^2$. To miniaturize the dimension of the antenna, two linearly tapered slots on the ground plane act as the main radiator. Then it does not need extra large radiation patch. In particular, a simple embedded three-level stepped slot on the central ground, brings high isolation in the whole UWB band. In addition, two rectangular slots cut in the feedlines widen the impedance bandwidth. Simulated and measured results verify $S_{11} < -10\,\mathrm{dB}$ and $S_{12} < -18\,\mathrm{dB}$ at 3.1 GHz −12 GHz and good diversity performance. Therefore, the proposed MIMO antenna has potential for portable devices applications.

1. INTRODUCTION

Tapered Slot Antennas (TSA) [1–3], owing to broadband characteristics, are widely used in broadband phased array antennas. Multiple-input-multiple-output (MIMO) technique [4], utilizing the antenna array scheme in the very limited space, can obtain higher channel capacity and data transfer rate. Recently, MIMO technology has been incorporated with ultra-wideband (UWB) [5] to complement each other's advantages [6]. In other words, MIMO technology has been incorporated with UWB to combat multipath fading in the scattering environment. Nevertheless, introducing TSA into compact UWB MIMO antennas and designing corresponding efficient decoupling structures further are very scant in the literature.

Various decoupling methods for UWB MIMO antennas to improve performance in multi-path fading channels have been previously reported, for example, double-layer electromagnetic band-gap (EBG) structures for reducing the electromagnetic coupling on a common ground [7], taking the inherent advantage of the self-complementary structure to decouple [8], vertical feeding placement without using any extra decoupling structures [9], introducing reflective units such as parasitic components [10] or protruding ground stubs [11, 12], using defected ground structure (DGS) [13] to suppress surface wave, adding neutralization lines (NL) to reduce the coupling current flowing [14]. Overall, most of the previously published decoupling structures are complex and then make them difficult for mass production. Meanwhile, the dimensions are large because today's portable devices do not leave much room for antenna elements.

In this letter, a very compact UWB MIMO ground linearly tapered slot antenna (LTSA) with an overall dimension of $22 \times 26\,\mathrm{mm}^2$ is proposed. To miniaturize the dimension of the antenna, the main radiator is assigned to two linearly tapered slots on the ground plane, not extra large radiation patch. Specifically, a simple three-level stepped slot embedded in the central ground improves the isolation of the whole UWB band. Besides, two rectangular slots cut in the feedlines bring a wider impedance bandwidth. Detailed explanation follows below.

Received 25 November 2016, Accepted 30 December 2016, Scheduled 18 January 2017

* Corresponding author: Hui-Fen Huang (jia.luyang@mail.scut.edu.cn).
The authors are with the School of Electronic and Information Engineering, South China University of Technology, Guangzhou, China.

2. ANTENNA DESIGN

Figure 1 shows the proposed UWB MIMO ground LTSA. It includes a shared ground plane loaded with two linearly tapered slots and two 50 Ohm microstrip feedlines, which are printed on both sides of an FR4 substrate (thickness 1.6 mm, relative permittivity 4.4 and loss tangent 0.02). Moreover, a three-level stepped slot is cut in the ground to decouple the antenna. And two rectangular slots are cut in the feedlines to widen impedance bandwidth. Optimized parameters are (units: mm): $H = 1.6$, $d_f = 5.5$, $d_t = 8.6$, $d_r = 7$, $L = 22$, $L_{t1} = 6.3$, $L_{t2} = 0.5$, $L_f = 15$, $L_r = 7.7$, $L_{s1} = 3$, $L_{s2} = 4$, $L_{s3} = 1$, $W = 26$, $W_t = 10.7$, $W_r = 2$, $W_f = 3$, $W_{s1} = 4.8$, $W_{s2} = 2$, $W_{s3} = 8.8$. These final values of the antenna dimensions were obtained by parameter optimization using the commercial software Ansoft HFSS [15].

3. ANTENNA STRUCTURE ANALYSIS

3.1. Bandwidth Analysis

Figure 2 shows the S-parameters versus frequency with three different opening angles of the UWB antenna element. The bandwidth increases with the decrease of the opening angle of the tapered slot.

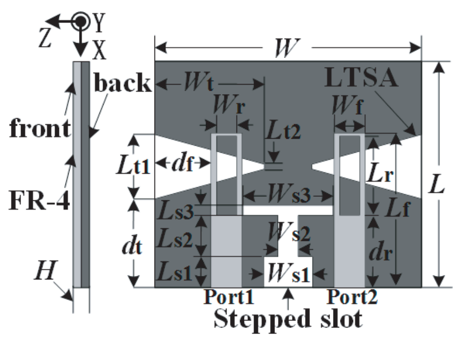

Figure 1. Geometry of the proposed antenna.

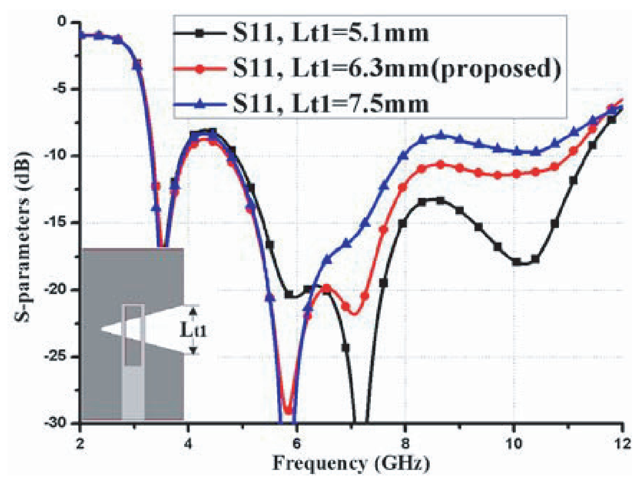

Figure 2. S-parameters of the antenna element vary with L_{t1}.

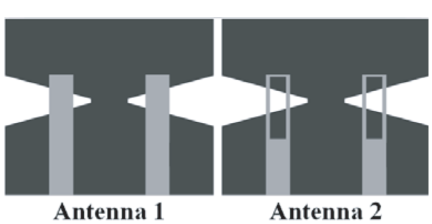

Figure 3. The feedlines: with/without slot.

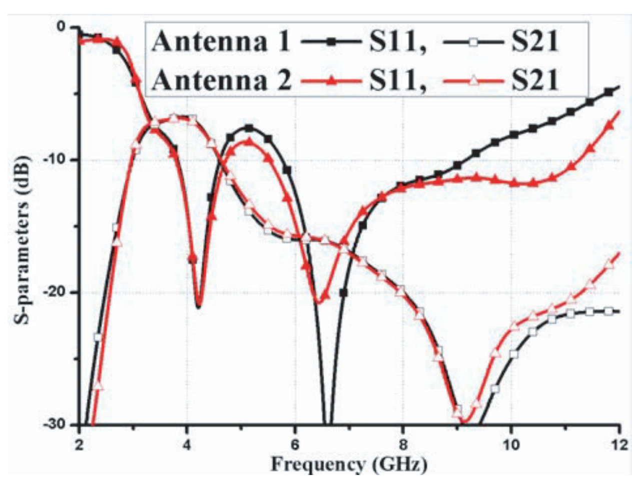

Figure 4. Comparison of the S-parameters for Fig. 3.

Hence, the opening angles of the linearly tapered slot on the ground mainly influence the reflection coefficient of the medium and high band of the UWB. We can adjust the structure of the linearly tapered slot on the ground to obtain a suitable antenna element.

Simulation on the S parameters of the MIMO antenna with and without the rectangular slot on the microstrip feedline, as shown in Fig. 3, has been performed, and the results are displayed in Fig. 4. It is observed that the rectangular slot in the feedline obviously improves the -10 dB impedance bandwidth, finally covering most frequency band of the UWB (3.1–10.6 GHz).

3.2. The Decoupling Effect of the Three-Level Stepped Slot

Figure 5 shows the structural evolution of the three-level slot. Fig. 6 shows that the first one-level slot (Antenna 3) achieves a good isolation at the high band of the UWB. Furthermore, the two-level slot (Antenna 4) enhances the decoupling at the medium and high band of the UWB. Finally, the three-level slot mainly improves the isolation of the low band of the UWB, and then we obtain the decoupling of the whole UWB frequency band.

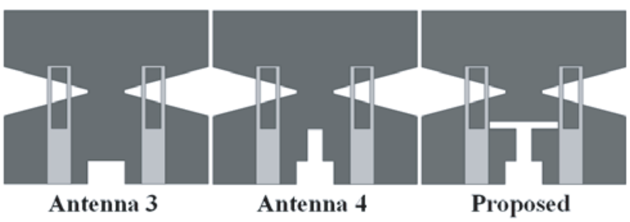

Figure 5. Evolution of the three-level slot.

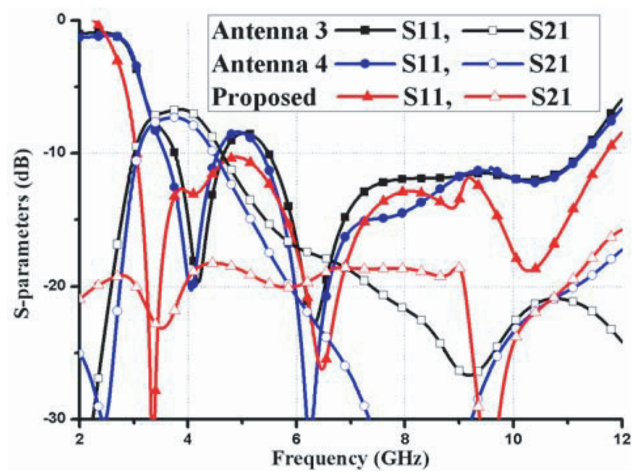

Figure 6. Comparison of the S-parameters for Fig. 5.

The parametric sweep analysis of the stepped slot is illustrated in Fig. 7, Fig. 8 and Fig. 9. The simulated S-parameters for different W_{s1}, W_{s2} and W_{s3} values are presented. As observed, W_{s1} mainly influences isolation of the low band of the UWB; W_{s2} influences isolation of the low and high bands of the UWB; W_{s3} influences isolation of the low, medium and high bands of the UWB.

The detailed explanation on why and how the tapered slot increases the decoupling is mainly as follows.

(1) From the view of equivalent-circuit model, each slot can be seen as a capacitor. Meanwhile, some inductance is introduced along the stepped slot. Therefore, we can consider that each slot is equivalent to a bandstop filter based on a parallel resonator. The different actual dimensions of each slot are equivalent to the different equivalent capacitances. The different equivalent capacitances lead to that the different bandstop filters resonate at different frequencies to decouple [16]. Finally, with the three-level stepped slot, we obtain a good isolation at the whole UWB frequency band.

(2) From the view of surface current, the surface current distributions with and without the three-level stepped slot are shown in Fig. 10, on condition that port 1 is excited while port 2 is terminated to a matching load. A large portion of surface current is confined by the stepped slot on the middle ground. Less current is propagating across. This demonstrates that the current flowing on the ground plane from port to port is dramatically reduced, which contributes to the improvement of the isolation between the two antennas [17].

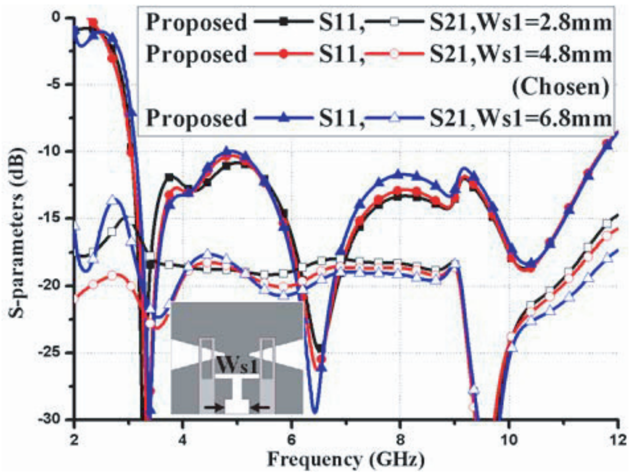

Figure 7. S-parameters with different width W_{s1}.

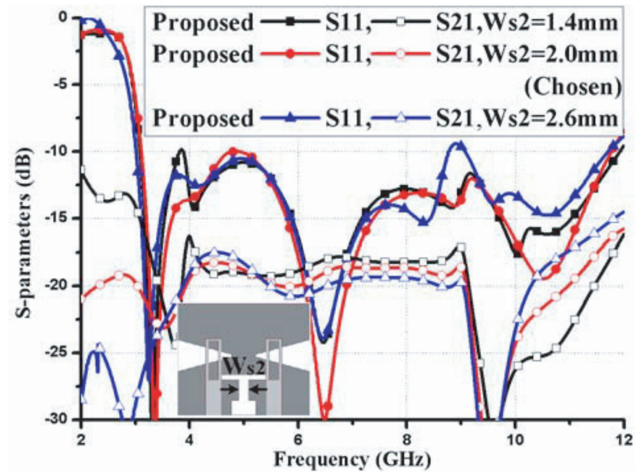

Figure 8. S-parameters with different width W_{s2}.

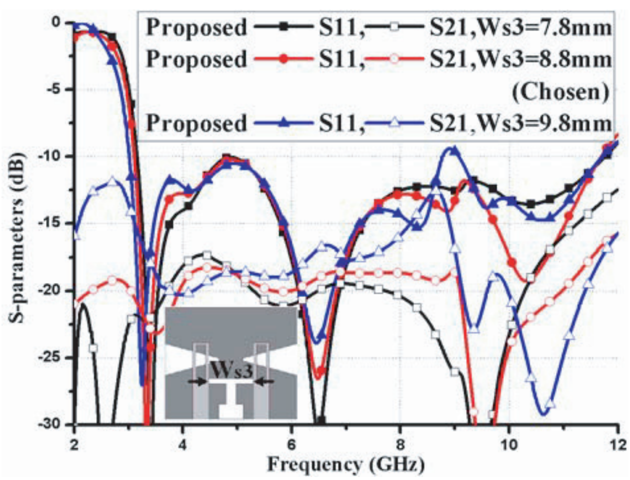

Figure 9. S-parameters with different width W_{s3}.

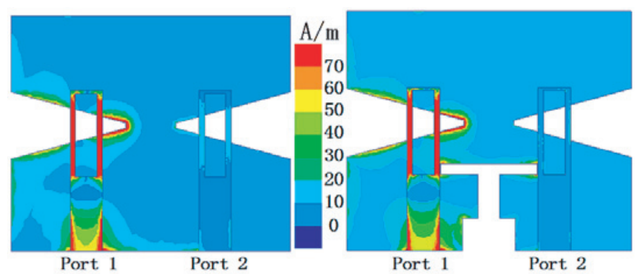

Figure 10. Current distribution at 7 GHz.

(3) From the view of bandgap, the stepped slot on the middle ground makes the resonant frequency of the proposed antenna fall inside the bandgap of the stepped slot. Consequently, surface waves are effectively suppressed, and the isolation between the two antennas is improved then [18].

4. FABRICATION AND MEASUREMENT

The manufactured antenna prototype is shown in Fig. 11. Simulated and measured results agree well as shown in Fig. 12. At 3.1 GHz–12 GHz, it is revealed that $S_{11} < -10$ dB and $S_{12} < -18$ dB. In Fig. 13, gain is at 1.5 dBi–4.1 dBi, and efficiency is above 70% in the UWB band. In Fig. 14, derived from the measured 3D E-field radiation patterns [19], the envelope correlation coefficient (ECC) is below 0.02, ensuring good diversity performance. Table 1 shows a comparison of this antenna with some other UWB MIMO works. Clearly, the proposed antenna has a smaller size with good performance by using ground antenna technique. In Fig. 15, the H-plane pattern is nearly omnidirectional [20]. About the testing Instruments, we use the Agilent R3770 vector network analyzer to measure S-parameters and use a

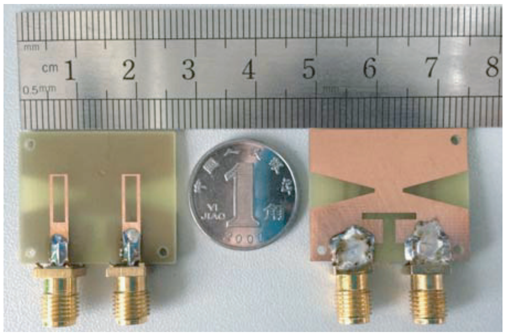

Figure 11. Photograph of a fabricated prototype.

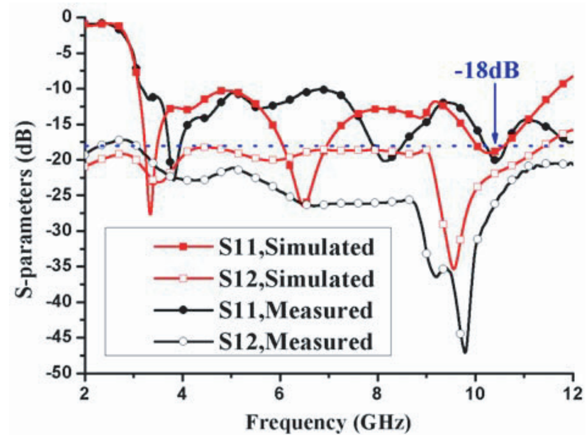

Figure 12. Simulated and measured S-parameters.

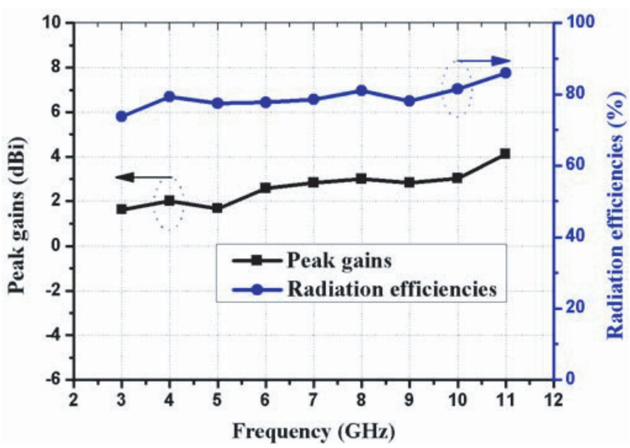

Figure 13. Measured gains and radiation efficiencies.

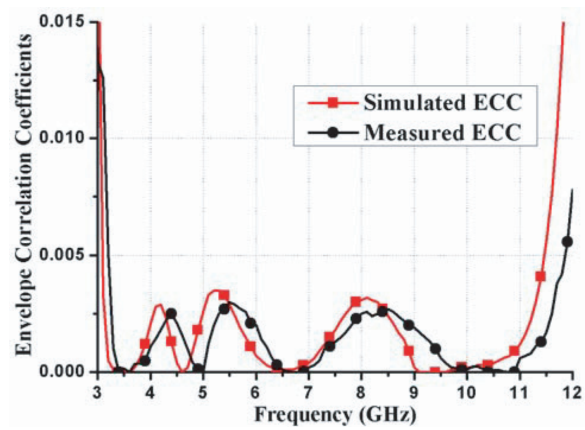

Figure 14. Simulated and measured ECC.

Table 1. Comparison with the recent compact UWB MIMO antennas.

Reference	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	**This**
Dimension (mm^2)	60×50	35×35	30×60	25×30	22×36	43.5×43.5	30×40	35×33	22×26
Min. Isolation (dB)	20	15	20	20	15	15	12	22	**18**
f_L–f_H (GHz)	3.4–6.1	3–12	2.8–11	3.1–11.3	3.1–11	3.1–11	2.4–10.6	3.1–5	**3.1–12**

Satimo chamber [21] to measure the radiation patterns, realized gains and efficiency. The discrepancy between the simulation and measurements still exists. This may be due to the SMA connector and environment of measurement.

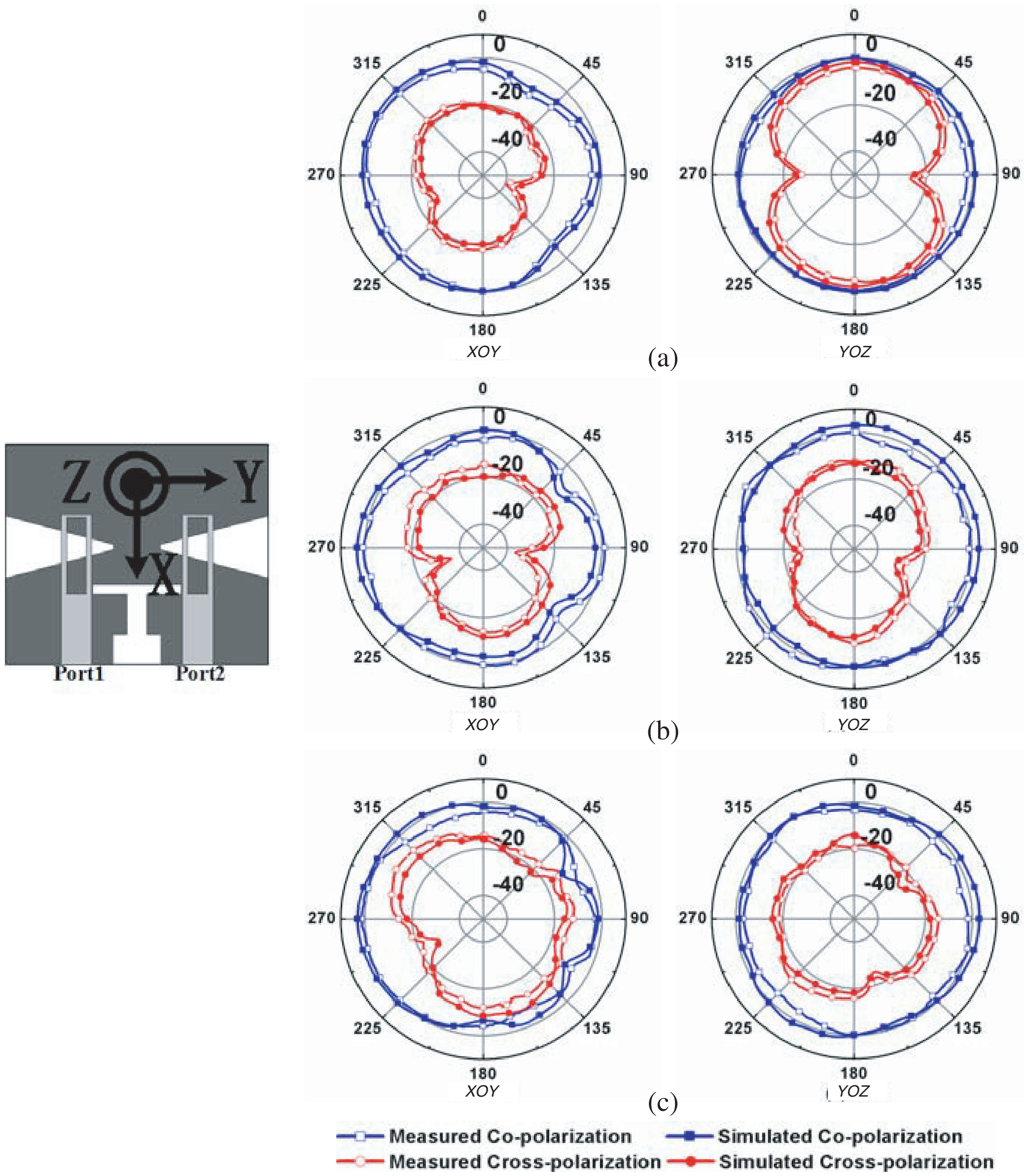

Figure 15. Radiation patterns of the *XOZ*, *YOZ* plane: at (a) 4.5 GHz; (b) 7.5 GHz; (c) 9.5 GHz.

5. CONCLUSION

In this paper, decoupled by a simple three-level stepped slot, a very compact UWB MIMO ground LTSA is proposed. Its size is only $22 \times 26\,\mathrm{mm}^2$, smaller than most recently published UWB MIMO antennas. At 3.1 GHz–12 GHz, it is revealed that $S_{12} < -18\,\mathrm{dB}$, $S_{11} < -10\,\mathrm{dB}$, $ECC < 0.02$. Hence, the proposed antenna has the advantage of small size, low cost, wide bandwidth, high isolation and good diversity performance.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China under Grant 61071056, Natural Science Foundation of Guangdong Province under Grant 2016A030313462 and Education of Guangdong Province Characteristic innovation Foundation under Grant 2014KTSCX017.

REFERENCES

1. Gibson, P. J., "The Vivaldi aerial," *1979 Ninth European Microwave Conference*, 101–105, IEEE, 1979.
2. Yngvesson, K. S., T. L. Korzeniowski, Y. S. Kim, E. L. Kollberg, and J. F. Johansson, "The tapered slot antenna — A new integrated element for millimeter-wave applications," *IEEE Trans. Microwave Theory Tech.*, Vol. 37, No. 2, 365–374, 1989.
3. Wu, C., L. Shen, G. Y. Deng, Y. Shen, and J. Litva, "Experimental study of a wide band LTSA which is fed by an inverted microstrip line (IML)," *1998 Antennas and Propagation Society (AP-S) International Symposium*, Vol. 4, 2328–2331, IEEE, 1998.
4. Zhao, N. and W.-P. Tian, "CPW-fed dual-band MIMO antenna with common radiating element," *Progress In Electromagnetics Research Letters*, Vol. 62, 71–75, 2016.
5. Lim, E. G., Z. Wang, C. U. Lei, Y. Wang, and K. Man, "Ultra wideband antennas — Past and present," *Iaeng International Journal of Computer Science*, Vol. 37, No. 3, 304–314, 2010.
6. Kaiser, T., F. Zheng, and E. Dimitrov, "An overview of ultra-wide-band systems with MIMO," *Proc. IEEE*, Vol. 97, No. 2, 285–312, 2009.
7. Li, Q., A. P. Feresidis, M. Mavridou, and P. S. Hall, "Miniaturized double-layer EBG structures for broadband mutual coupling reduction between UWB monopoles," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 3, 1168–1171, 2015.
8. Zhu, J. F., S. F. Li, B. T. Feng, L. Deng, and S. X. Yin,"Compact dual-polarized UWB quasi-self-complementary MIMO/diversity antenna with band-rejection capability," *IEEE Antennas Wireless Propag. Lett.*, Vol. 15, 905–908, 2016.
9. Huang, H., Y. Liu, S. S. Zhang, and S. X. Gong, "Compact polarization diversity ultrawideband MIMO antenna with triple band-notched characteristics," *Microwave Opt. Technol. Lett.*, Vol. 57, 946–953, 2015.
10. Roshna, T. K., U. Deepak, V. R. Sajitha, K. Vasudevan, and P. Mohanan, "A compact UWB MIMO antenna with reflector to enhance isolation, " *IEEE Trans. Antennas Propag.*, Vol. 63, No. 4, 1873–1877, 2015.
11. Liu, L., S. W. Cheung, and T. I. Yuk, "Compact MIMO antenna for portable UWB applications with band-notched characteristic," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 5, 1917–1924, 2015.
12. Qin, H. and Y. F. Liu, "Compact UWB MIMO antenna with ACS-fed structure," *Progress In Electromagnetics Research C*, Vol. 50, 29–37, 2014.
13. Deng, J. Y., L. X. Guo, and X. L. Liu, "An ultrawideband MIMO antenna with a high isolation," *IEEE Antennas Wireless Propag. Lett.*, Vol. 15, 182–185, 2016.
14. Zhang, S. and G. F. Pedersen, "Mutual coupling reduction for UWB MIMO antennas with a wideband neutralization line," *IEEE Antennas Wireless Propag. Lett.*, Vol. 15, 166–169, 2016.
15. http://www.ansoft.com/products/hf/hfss/.
16. Chiu, C. Y., C. H. Cheng, R. D. Murch, and C. R. Rowell, "Reduction of mutual coupling between closely-packed antenna elements," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 6, 1732–1738, 2007.
17. Addaci, R., et al., "Dual-band WLAN multi-antenna system and diversity/MIMO performance evaluation," *IEEE Trans. Antennas Propag.*, Vol. 62, No. 3, 1409–1415, 2014.
18. Zhu, F.-G., 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, 601–602, 2009.
19. Vaughan, R. G. and J. B. Andersen, "Antenna diversity in mobile communication," *IEEE Trans. Veh. Technol.*, Vol. 36, No. 4, 149–172, 1987.
20. Wong, K. L., *Planar Antennas for Wireless Communications*, Wiley-IEEE Press, 2003.
21. Satimo, [online] Available: http://www.satimo.com/.