Progress In Electromagnetics Research Letters, Vol. 22, 39–45, 2011

BANDWIDTH ENHANCEMENT DESIGN OF COMPACT UWB STEP-SLOT ANTENNA WITH ROTATED PATCH

K. Song, Y.-Z. Yin, B. Chen, and S.-T. Fan

National Key Laboratory of Science and Technology
on Antennas and Microwaves
Xidian University, Xi'an, Shaanxi 710071, China

F. Gao

China Mobile Group, Design Institute Co., Ltd.
Beijing, China

Abstract—In this paper, a novel compact microstrip-fed ultra-wideband (UWB) step-slot antenna with a rotated patch is demonstrated and experimentally studied. With an effective combination of the step-slot and rotated patch and proper dimensions bandwidth enhancement for UWB operation is obtained. From the simulated and measured results, the enhanced impedance bandwidth is brought up to about 117.5% from 2.88 to 11.08 GHz defined by 10 dB return loss. Details of the proposed antenna are described, and experimental results are presented and discussed.

1. INTRODUCTION

In UWB communication systems, one of the key issues is the design of a compact antenna with a wideband characteristic over the whole operating band. Recently, a variety of slot antennas become very attractive candidates [1–6] due to their low profile, wide bandwidth, compact size, low cost, ease of fabrication, etc. In these designations, number of slot antennas have been experimentally investigated and reported with different geometries such as wide rectangular slot [1], a square-ring slot [2], E-slot [3], quasi-self complementary semicircular

Received 1 March 2011, Accepted 21 March 2011, Scheduled 23 March 2011
Corresponding author: Kun Song (songkun@mail.xidian.edu.cn).

structure [4], a rectangular notch [5], and multi-inverted cone slot [6] to realize broadband and ultra-wideband operation characteristics. Besides the above-mentioned UWB antennas, some open slot antennas with open L- and T-slot [7, 8] are introduced and designed with wide fractional bandwidths about 87% [7] and 94% [8], respectively. There is an apparent contradiction between the reduced antenna size and wider bandwidth in practice. In other words, these inchoate investigations on the ultra-wideband operation and size reduction are not solved well because that the narrow bandwidths in [1, 5, 7, 8] are not enough for ultra-wideband requirement and the sizes in [2–6] are too large for the portable systems.

For a good UWB characteristic, some novel configurations and techniques such as a rectangular aperture [9], multi via holes [10], a fractal-shaped slot [11], a self-similar slot [12], and multiple resonant slots [13] can be used to control and enhance the operation bandwidths for wideband and UWB applications. Unfortunately, these investigations on sizes are large for the portable systems. How to design UWB slot antenna with smaller size is still a significant and challenging subject.

In this article, a novel UWB step-slot antenna with a rotated rectangular patch is demonstrated and investigated. By properly adjusting the dimensions of the step-slot and rotating the radiation patch to a suitable position, the poor impedance matching condition at a wider frequency range is improved greatly, and an enhanced fractional bandwidth is brought up to 117.5% from 2.88 to 11.08 GHz. In addition, the small over-size of $25 \times 25\,\text{mm}^2$ makes it an excellent candidate for portable UWB applications. The details of the proposed antenna are also illustrated.

2. ANTENNA ARCHITECTURE DESIGN

The geometry of the proposed antenna is depicted in Figure 1. The proposed antenna is fabricated on a low-cost FR4 substrate with the relative permittivity of 4.6, thickness of 0.8 mm, loss tangent of 0.02, and total dimension of $25 \times 25\,\text{mm}^2$. The step-slot etched on the ground plane is comprised of L-slot and a square notch with a side l. Furthermore, a rotated rectangular patch with a size of $L \times W$ and a rotated angle of α is fed by $50\,\Omega$ microstrip line with a width of 1.5 mm. In our design, the notch and rotated patch technique are adopted to improve the poor impedance match at upper frequency range. By adjusting the parameters (l, α) carefully, the whole UWB band can be obtained. The required numerical analysis and proper geometrical parameters of the proposed antenna are studied with the aid of Ansoft's high frequency structure simulator (HFSS) software, and the optimum design parameters of the rectangular patch are as follows: $L = 9\,\text{mm}$, $W = 9\,\text{mm}$, $l = 5\,\text{mm}$, and $\alpha = 7.75°$. A prototype of the proposed antenna with the aforementioned results is fabricated and measured in Figure 2.

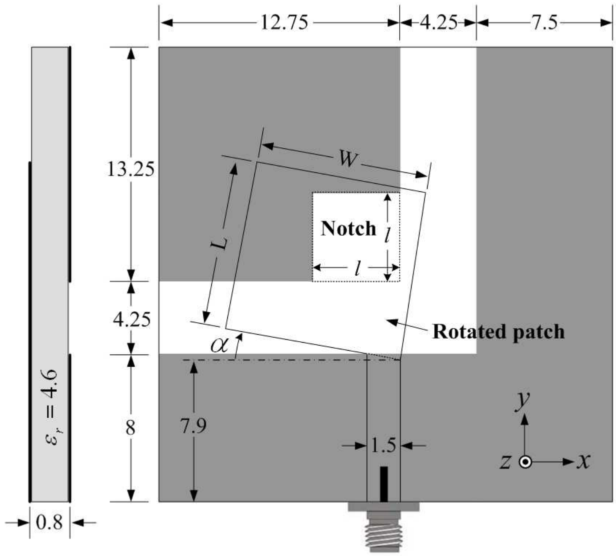

Figure 1. Geometry of the proposed antenna (units: mm).

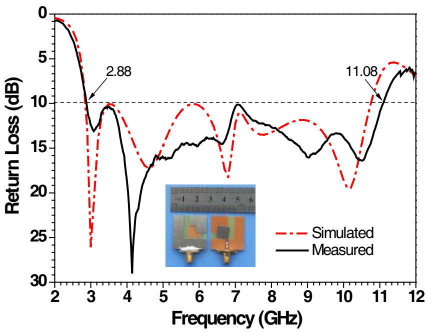

Figure 2. Simulated and measured return losses of the proposed antenna with $L = 9\,\text{mm}$, $W = 9\,\text{mm}$, $\alpha = 7.75°$, and $l = 5\,\text{mm}$.

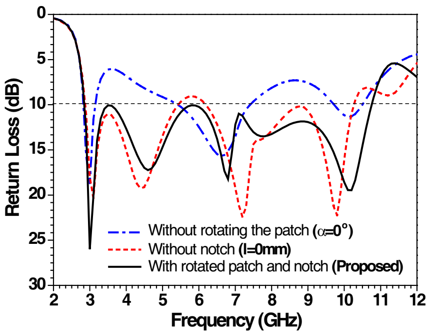

Figure 3. Simulated return losses of the proposed antenna with and without rotated patch and notch.

3. RESULTS AND DISCUSSION

With the help of the HFSS and WILTRON37269A vector network analyzer, the proposed antenna has been constructed and measured in Figure 2. It is obvious that the proposed UWB step-slot antenna with rotated patch can reach a wider operating bandwidth of about 117.5% from 2.88 to 11.08 GHz, which is completely adequate for the UWB applications.

In order to widen the impedance bandwidth of the proposed antenna, the expected performance can be thoroughly investigated. Some different corresponding antenna structures (with and without rotated patch and notch) and their return losses are presented in Figure 3. It is obvious that a wider bandwidth can be achieved with a proper corner notch and rotating the patch to a suitable angle. For a better understanding of their effects on bandwidth enhancement, more different resonant frequencies (m1, m2, m3, m4, m5) can be excited and more resonant loops are close to the center of the Smith chart in Figure 4. So, it is easy to form an enhanced bandwidth for UWB applications with these resonant frequencies and tightest loops. The simulated return losses of the proposed antenna with the vital parameters are presented in Figures 5(a) and (b). From these simulated results, the impedance match over a wider frequency range will be improved with the optimal values of $\alpha = 7.75^{\circ}$ and $l = 5$ mm, and it is also obvious that α and l have a strong effect on bandwidth enhancement of the proposed antenna.

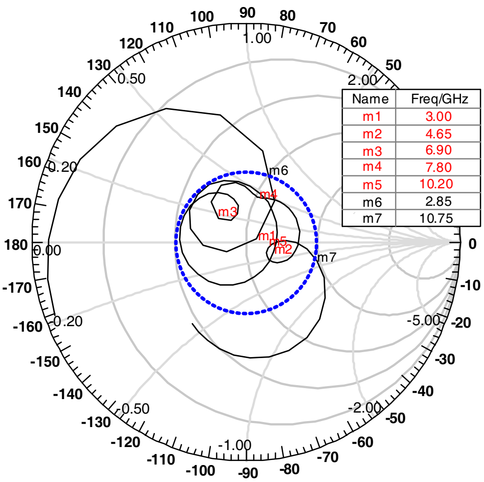

Figure 4. Widen impedance match of the proposed step-slot antenna in Smith chart.

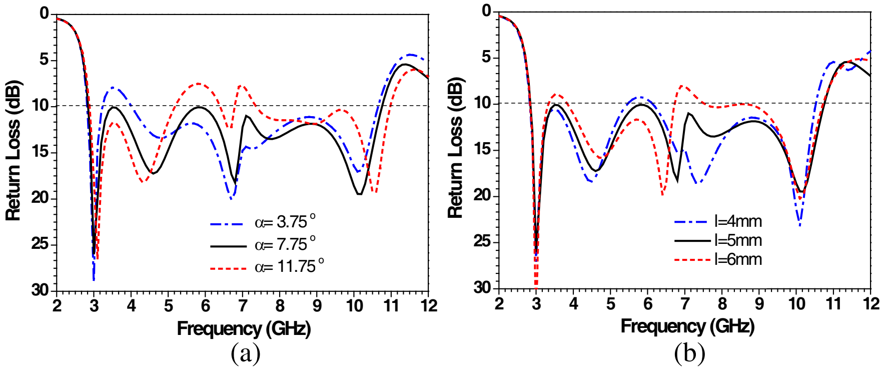

Figure 5. Vital parameters effect on bandwidth enhancement of proposed step-slot antenna. (a) Simulated return losses of different vales of α. ($l = 5\,\mathrm{mm}$). (b) Simulated return losses of different vales of d. ($\alpha = 7.75°$).

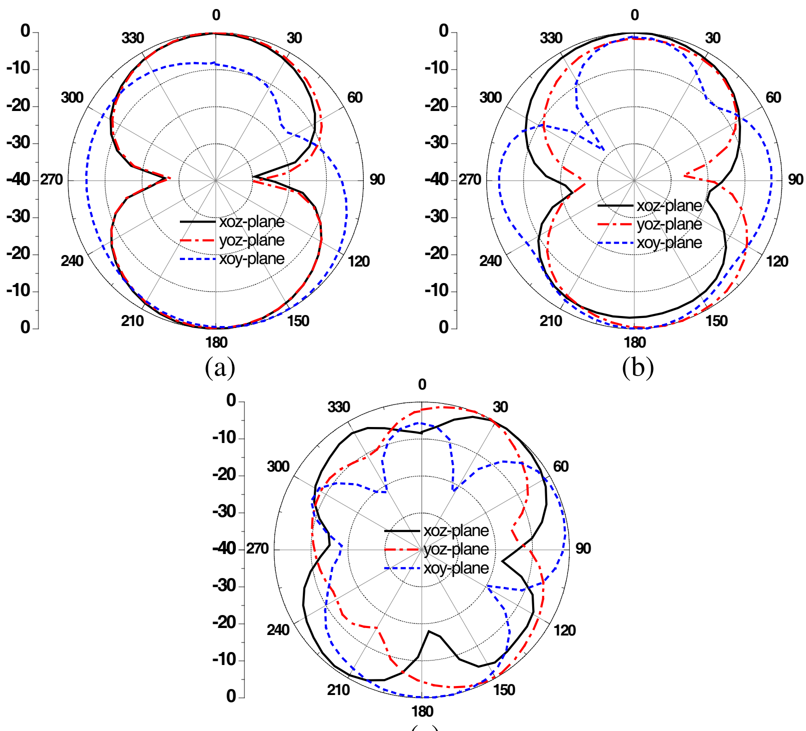

Figure 6. Radiation far-field patterns of the proposed step-slot antenna operation at (a) 3.5 GHz, (b) 6 GHz, and (c) 9 GHz, respectively.

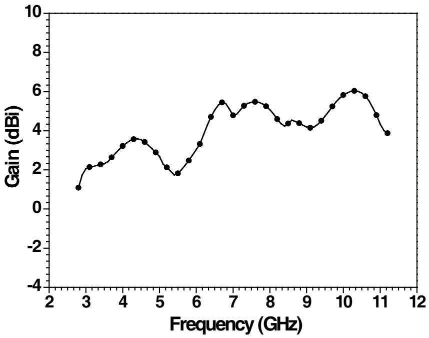

Figure 7. Peak gain of the proposed step-slot antenna.

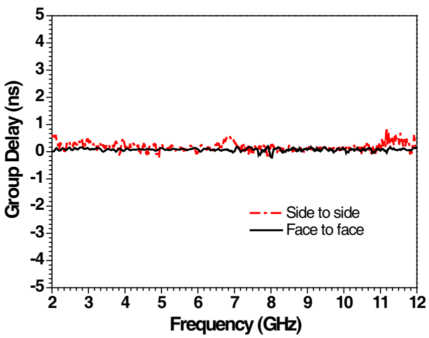

Figure 8. Group delay of the proposed step-slot antennas.

Figures 6(a), (b), and (c) show the simulated far-filed radiation characteristics of the proposed antenna operating at 3.5, 6, and 9 GHz, respectively. It can be seen that the proposed antenna has an asymmetric radiation characteristics at H-plane (xoy-plane) mainly because of its inherent asymmetric structure. Figure 7 shows the simulated peak gain of the proposed antenna against frequency, which demonstrates a variation from 2.05 to 6 dBi in the UWB band Finally, the group delay of the proposed UWB antenna system is presented with a distance of 15 cm in Figure 8, which proves that the antenna has a good time-domain characteristic with a small pulse distortion from -0.2 to 0.9 ns.

4. CONCLUSION

A novel UWB step-slot antenna with a rotated rectangular patch is proposed and investigated. By using the step-slot structure and the rotated patch, the impedance bandwidth of the proposed antenna is greatly brought up to 117.5% from 2.88 to 11.08 GHz, while it is adequate for the UWB systems and portable applications with a small dimension of about $25 \times 25\,\mathrm{mm}^2$.

REFERENCES

1. Chair, R., A. A. Kishk, K. F. Lee, C. E. Smith, and D. Kajfez, "Microstrip line and CPW fed ultra wideband slot antennas with U-shaped tuning stub and reflector," *Progress In Electromagnetics Research*, Vol. 56, 163–182, 2006.

2. Sadat, S., M. Fardis, F. Geran, and G. Dadashzadeh, "A compact microstrip square-ring slot antenna for UWB applications," *Progress In Electromagnetics Research*, Vol. 67, 173–179, 2007.
3. Dastranj, A., A. Imani, and M. Naser-Moghaddasi, "Printed wide-slot antenna for wideband applications," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 10, 3097–3102, 2008.
4. Guo, L., S. Wang, Y. Gao, Z. Wang, X. Chen, and C. G. Parini, "Study of printed quasi-self-complementary antenna for ultra-wideband systems," *Electronics Letters*, Vol. 44, No. 8, 511–512, 2008.
5. Lin, S.-Y. and B.-J. Ke, "Ultrawideband printed patch antenna in notch," *Microwave and Optical Technology Letters*, Vol. 51, No. 9, 2080–2084, 2009.
6. Wang, H., H. Zhang, X. Liu, and K. Huang, "A CPW-fed ultra-wideband planar inverted cone antenna," *Progress In Electromagnetics Research C*, Vol. 12, 101–112, 2010.
7. Latif, S. I., L. Shafai, and S. K. Sharma, "Bandwidth enhancement and size reduction of microstrip slot antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 53, No. 3, 994–1003, 2005.
8. Chen, W. S. and K. Y. Ku, "Broadband design of non-symmetric ground $\lambda/4$ open slot antenna with small size," *Microwave Journal*, Vol. 50, 110–121, 2007.
9. Lin, Y.-C. and K.-J. Hung, "Compact ultra-wideband rectangular aperture antenna and band-notched designs," *IEEE Transactions on Antennas Propagation*, Vol. 54, No. 11, 3075–3081, 2006.
10. Chen, D. and C. H. Cheng, "A novel compact ultra-wideband (UWB) wide slot antenna with via holes," *Progress In Electromagnetics Research*, Vol. 94, 343–349, 2009.
11. Chen, W. L., G. M. Wang, and C. X. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," *IEEE Transactions on Antennas Propagation*, Vol. 57, No. 7, 2176–2179, 2009.
12. Song, K., Y.-Z. Yin, and L. Zhang, "A novel monopole antenna with a self-similar slot for wideband applications," *Microwave and Optical Technology Letters*, Vol. 52, No. 1, 95–97, 2010.
13. Kim, H. and C.-W. Jung, "Bandwidth enhancement of CPW fed tapered slot antenna with multi-transformation characteristics," *Electronics Letters*, Vol. 46, No. 15, 1050–1051, 2010.