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NOVEL WIDE-SLOT ANTENNA WITH TRAVELING-WAVE EXCITATION FOR BAND-NOTCHED ULTRA-WIDEBAND APPLICATIONS

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Abstract—In this paper, a novel band-notched wide slot antenna for UWB applications has been proposed. The antenna consists of a circularly slotted square ground, two wide-slots separated by a conductive ring, and an equiangular spiral feed line, which excites the antenna through traveling-wave. Experimental prototypes are fabricated and tested. The obtained results indicate that the proposed antenna has a small size and offers a broad bandwidth from 3.1 to 12 GHz, with a band notch from 3.4 to 3.9 GHz. The radiation patterns display nearly omnidirectional performance and the measured group delays are within ±1 nanosecond except for the notch band.

1. INTRODUCTION

Being low in power consumption and high in data rate, the ultra-wideband (UWB) technology has drawn more and more attention in wireless communication systems, particularly in wireless multimedia system [1]. As significant components in receiving and transmitting systems, UWB antennas are in great demand. And band-notched UWB antennas are widely used to avoid possible interferences [2]. Many antenna configurations including planar monopoles, dipoles, and slot antennas have been developed to realize the ultra wideband performance [1–9]. It is found that some of them are of tapered structures [3, 4], and many others are wide slotted with modified feed lines [1, 6–9]. Wide slot antennas have the advantages of small sizes, ease of fabrication, low cost and compatibility with active devices. Furthermore, wide slot antennas are much wider in bandwidth than

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the narrow slotted ones [9]. Besides, different kinds of tuning stubs such as H shaped [1], taper [6], fork-like [7], and rectangular [8] stubs, etc. are added to the feed lines of the wide-slotted antennas to further broaden the impedance bandwidth. However, they complicate the design process to a certain extent.

In this article, we have advanced a novel wide slot band-notched UWB antenna with a 0.5-turn equiangular spiral as feed line. As one kind of the frequency independent structures [10], the equiangular spirals have inherent broadband characteristics. The conductive ring in conjunction with the slotted ground is introduced to generate a band notch at the 3.5 GHz WiMAX band. This design provides a small size ($28 \times 28\,\mathrm{mm}^2$) and ultra-wideband performance from 3.1 to 12 GHz, except for the 3.5 GHz WiMAX band, covering the band range $3.1 \sim 10.6$ GHz released by the Federal Communication Commission (FCC) in 2002.

2. ANTENNA DESIGN

Figure 1 shows the geometry and configuration of the proposed antenna. As shown, the antenna is etched on both sides of an inexpensive substrate (FR4) with thickness of 1.6 mm, relative dielectric constant of 4.6, and loss tangent equivalent to 0.02. The total size of the antenna is $28 \times 28\,\mathrm{mm}^2$.

An essential broadband feed line-0.5 turn equiangular spiral is applied in this design to achieve the UWB characteristic. The spiral is derived from a curve that satisfies the property that a scaling equals to a rotation. The expression of the curve can be written in polar coordinate $(\rho_{1,2}, \varphi)$ as [11]: $\rho_1 = \rho_0 e^{\alpha\varphi}$, $\rho_2 = \rho_0 e^{\alpha(\varphi-\delta)}$, where ρ_1 and ρ_2 are the inner and outer radii that make up a spiral arm. Parameter ρ_0 is the initial radius of the equiangular spiral antenna, δ is the angular width of the spiral arm, and φ is the independent variable in polar coordinate $(\rho_{1,2}, \varphi)$. Parameter α corresponds to the tightness of the spiral; a smaller α gives a tighter wrap. Formulation of self-complementary antennas, where the conductive area is the same shape and size as the open area, requires that the angular width δ, be equal to $pi/2$. Here we chose the classical values: $\alpha = 0.22$, $\rho_0 = 1$, and $\delta = pi/2$.

The square ground with two apertures is the basis of the presented

Table 1. Dimensions of the two antennas (unit: mm).

antenna	W_g	L_g	R_1	R_2	R_3	h
proposed (with band notch)	28	28	12.8	7.6	7.2	1.6
reference (without band notch)	28	28	12.4	4	3.2	1.6

antenna. The inner conductive ring connecting to the square ground is placed in the center of the circular slot to achieve a band notch for the 3.5 GHz WiMAX band. A reference antenna (without band notch performance), which has the same configuration as but different slot dimensions from the proposed antenna, is also manufactured. Ansoft HFSS v11, a commercial electromagnetic simulator based on finite element method (FEM), is utilized to facilitate the design and optimization process of the antenna. The detailed dimensions of both the proposed and reference antenna are presented in Table 1.

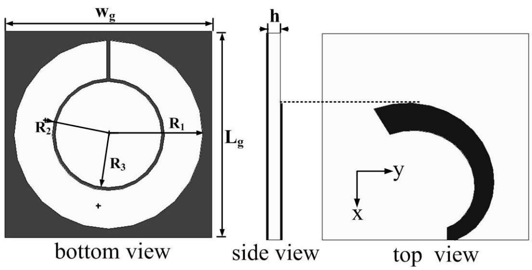

Figure 1. Geometry and configuration of the proposed antenna.

Figure 2. Photograph of the manufactured band-notched UWB antenna.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

To verify the proposed design, experimental prototypes were fabricated and measured. The photograph of the manufactured band-notched UWB antenna is shown in Figure 2. The Voltage Standing Wave Ratio (VSWR) is measured using a WILTRON-37269A vector network analyzer. The curves depicted in Figure 3 show reasonable agreements between the measured and simulated results. Results of a reference antenna without notched characteristic are also shown for comparison. A very broad operating band with VSWR less than 2.0 ranging from 3.1 to 12 GHz is achieved, except for a notch from 3.4 GHz to 3.9 GHz, which satisfies the requirement of band-notched UWB antennas. Also, there are slight differences between the simulated and measured results,

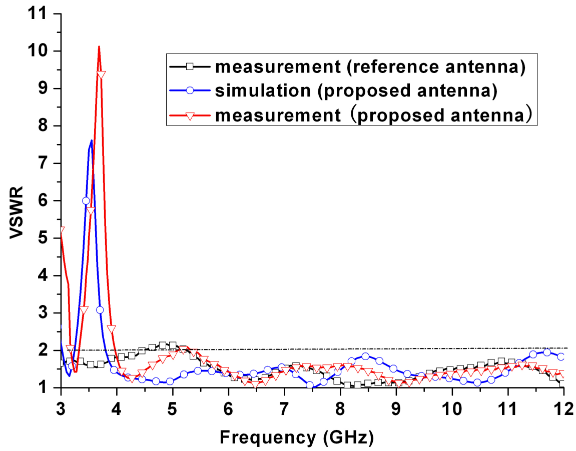

Figure 3. Measured and simulated VSWRs of the proposed antenna.

which due mainly to the effect of the inhomogeneous of the employed substrate and the measurement environment.

The current distributions can be investigated to confirm the band-notched characteristic. Figure 4 shows the simulated current distribution at 3.1, 3.5, 5, and 7.5 GHz for the proposed antenna. It is seen that the current concentrates mainly along the circular ring and does not radiate efficiently at 3.5 GHz, leading to a band notch. Figure 5 gives an enlarged view at the impact of the R_1 on the resonant frequency of the band notch. It can be found that the larger R_1 is, the

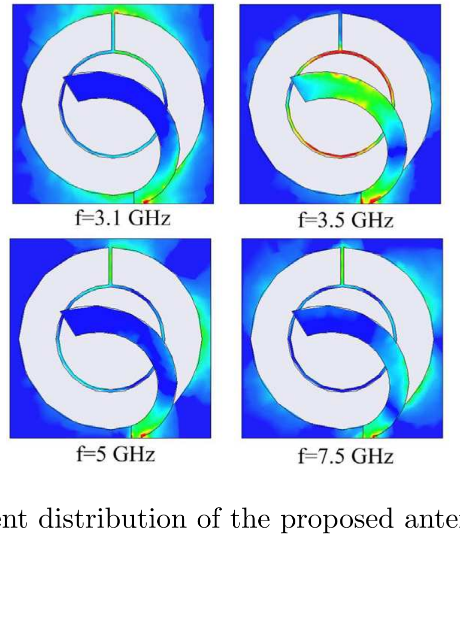

Figure 4. Current distribution of the proposed antenna.

lower the resonant frequency is.

Far field radiation performances of the proposed band-notched antenna are also studied. The normalized radiation patterns in *xoz*, *yoz*, and *xoy* plane for frequencies at 3.1, 5 and 7.5 GHz, have been given in Figure 6. As shown in the figure, the patterns are similar to those of dipole antennas although there is some fluctuation. The major reason for the fluctuation could be the asymmetrical of the feed line. Figure 7 illustrates the measured peak gains of the proposed band-notched antenna and reference antenna over the operating band. As expected, sharp gain decrease occurs in the vicinity of 3.5 GHz. All of the above demonstrate the band-notched function of the proposed antenna.

Group delays of the prototypes of the proposed antennas are also measured with the WILTRON-37269A vector network analyzer. The measurement is performed with the antennas placed face to face at a distance of 30 cm. The results, exhibited in Figure 8, of the proposed antenna display much larger delays for the notched band than those of other operating frequencies. There is a group delay within ±1 ns through almost the entire frequency band, which satisfies the requirements of high data rate systems.

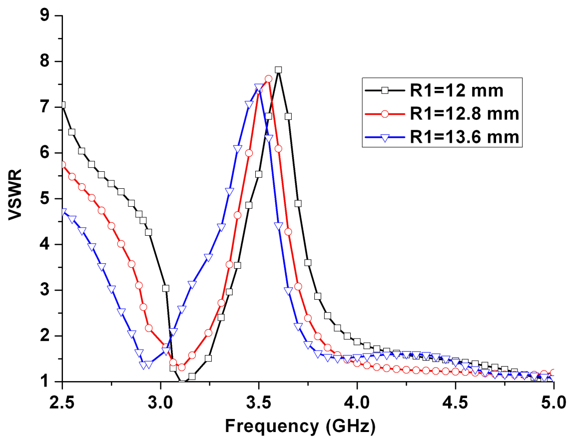

Figure 5. Simulated VSWRs for the proposed antenna with various R_1 (other parameters fixed in optimized dimension).

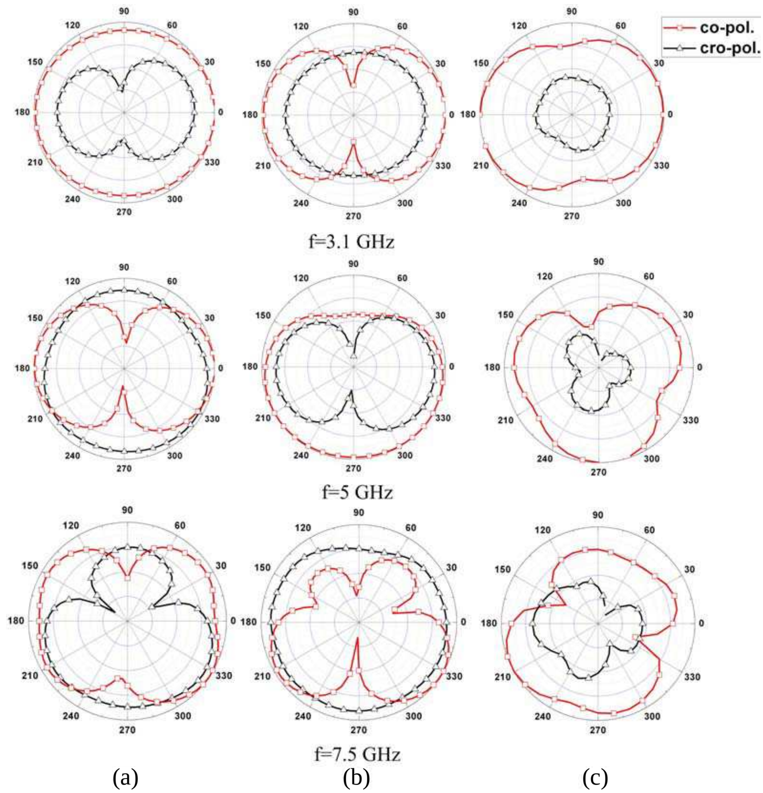

Figure 6. Radiation patterns of the proposed UWB antenna. (a) *xoz* plane, (b) *yoz* plane, (c) *xoy* plane.

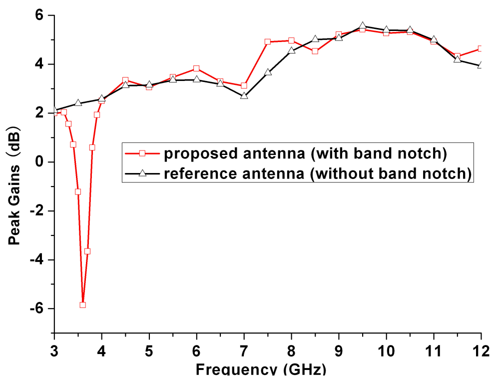

Figure 7. Peak gains of the proposed UWB antenna.

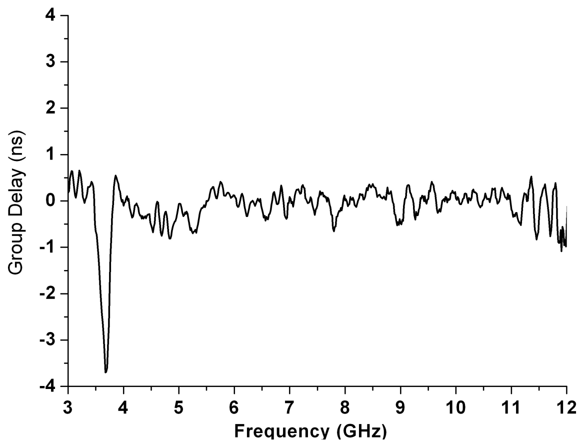

Figure 8. Group delay of the proposed antenna.

4. CONCLUSION

A novel band-notched ultra-wideband antenna has been put forward, which utilizes traveling-wave excitation as the design concept. This antenna mainly comprises a circularly slotted ground, a conductive ring connecting to the ground, and a 0.5-turn equiangular spiral. Operating with a traveling wave excitation, the proposed antenna has inherent broadband characteristic in impedance performance. The application of the conductive ring results in a band notch for the 3.5 GHz WiMAX band. The obtained results indicate that the proposed antenna has a small size and offers a broad bandwidth from 3.1 to 12 GHz, with a band notch from 3.4 to 3.9 GHz. The radiation patterns display nearly omnidirectional performance and the measured group delays are within ± 1 nanosecond except for the notch band. These features make it a promising candidate for ultra wideband wireless applications.

REFERENCES

1. Sadat, S., S. D. S. Javan, and M. houshmand, "Design of a microstrip square-ring slot antenna filled by an H-shape slot for UWB applications," *Antennas and Propagation Society International Symposium*, 705–708, 2007.
2. Yang, Y.-B., F.-S. Zhang, L. Zhang, S. Gai, and J.-G. Gong, "Design of a dual band-notched ultrawideband antenna," *Journal*

of Electromagnetic Waves and Applications, Vol. 23, No. 17–18, 2279–2287, 2009.

3. Yin, K. and J. P. Xu, "Compact ultra-wideband monopole antenna with band-stop characteristic," *International Conference on Microwave and Millimeter Wave Technology*, Vol. 3, 1174–1176, 2008.
4. Zhao, Y. H., J. P. Xu, and K. Yin, "A miniature coplanar waveguide-fed ultra-wideband antenna," *International Conference on Microwave and Millimeter Wave Technology*, Vol. 4, 1671–1674, 2008.
5. Lin, S. Y. and S. A. Yeh, "A double-sided printed double-T-shaped dipole antenna for UWB communications," *TENCON 2007 IEEE Region 10 Conference*, 1–3, 2007.
6. Cheng, S., P. Hallbjörner, and A. Rydberg, "Printed slot planar inverted cone antenna for ultrawideband applications," *Antennas and Wireless Propagation Letters*, Vol. 7, 18–21, 2008.
7. Sadat, S., M. Fardis, F. Geran, G. Dadashzadeh, N. Hojjat, and M. Roshandel, "A compact microstrip square-ring slot antenna for UWB applications," *Antennas and Propagation Society International Symposium*, 4629–4632, 2006.
8. Chen, H. D., "Broadband CPW-Fed square slot antennas with a widened tuning stub," *IEEE Transactions Antennas and Propagation*, Vol. 51, 1982–1986, 2003.
9. Qu, S. W., C. L. Ruan, and B. Z. Wang, "Bandwidth enhancement of wide-slot antenna fed by CPW and microstrip line," *Antennas and Wireless Propagation Letters*, Vol. 5, 15–17, 2006.
10. Dyson, J. D., "The equiangular spiral antenna," *Antennas and Propagation on IRE Transactions*, Vol. 7, 181–187, 1959.
11. Wentworth, S. M. and S. M. Rao, "Analysis of equiangular spiral antennas," *International Journal of Microwave and Millimeter-wave Computer-aided Engineering*, Vol. 6, 92–99, 1996.