

A HEXAGONAL RING ANTENNA WITH DUAL TUNABLE BAND-NOTCHES FOR ULTRA-WIDEBAND APPLICATIONS

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Abstract—An ultra-wideband hexagonal ring antenna with dual tunable band-notches is presented in this paper. The proposed antenna achieves a good impedance match ($VSWR \leq 2$) covering the range of 2.5–10.6 GHz, except for the bandwidths of 3.1–3.8 GHz for WiMAX and 5.15–6 GHz for WLAN. The band-notch function is evolved by a stub and two pairs of parasitic elements for WiMAX and WLAN, respectively. The experimental results show that the band-notched characteristics can be tuned by adjusting the lengths of the stub and the two pairs of parasitic elements.

1. INTRODUCTION

UWB antennas have received an increasing research interest since the US Federal Communication Commission (FCC) released the frequency band for its application in 2002 [1]. However, in the range of 3.1 GHz to 10.6 GHz, there are many narrow-band interferences such as WLAN (Wireless Local Area Network) which operates in the band of 5.15 GHz to 5.825 GHz, and WiMAX (Worldwide Interoperability for Microwave Access) that works in the band of 3.4 GHz to 3.69 GHz. Therefore, it is necessary to design an ultra-wideband antenna with band-notched characteristics to avoid the potential interferences without complicating the system by additional components. Many techniques have already been proposed, such as various shaped slots [2–6], embedded resonant cells [7, 8], and half mode substrate integrated waveguide cavity technology [9]. Resonant stubs [10] and parasitic elements [11] are also two effective methods to generate frequency

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band-notched functions. However, the designs mentioned above either have only one frequency band notch or the notched bands can not be easily tuned. The half mode substrate integrated waveguide cavity technology [9] has been utilized to generate multi-band notches, but it is too complex for a simple and small antenna.

In this paper, we propose an ultra-wideband hexagonal ring antenna with dual tunable band-notches at 3.5 GHz and 5.5 GHz. A resonant stub is employed to generate the 3.5 GHz notch, while two mirror pairs of parasitic elements are applied to create the 5.5 GHz notch. By adjustment of the dimensions of the stub and parasitic elements, two tunable band-notches are easily achieved. To verify the proposed antenna, an experimental prototype was designed, fabricated, and measured. In the following sections, details of the antenna are described; both simulated and measured results are presented and discussed.

2. ANTENNA DESIGN

The dimensions of the investigated planar UWB antenna with the capability of rejecting frequencies over dual bands are shown in Fig. 1. Experimental results are obtained by application of commercial software HFSSTM V.11. The proposed antenna is printed on a low-cost FR-4 substrate with dielectric constant $\epsilon_r = 4.4$, loss tangent $\tan \delta = 0.02$, and thickness $h = 1.6$ mm. Provided that the lowest operation frequency is $f_a = 3$ GHz, the entire width (w) and length (l) of the proposed antenna is calculated by Equation (1) [11, 12] for the given thickness and relative dielectric constant of the substrate, and then optimized by the simulation software HFSSTM V.11. Finally, $w \times l$ is selected as 30×33 mm², approximately half an effective wavelength of the lowest operating frequency.

$$w = l = \frac{c}{2f_a \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

The radiating structure is a hexagonal ring of length $PL = 8$ mm each edge, rounded by a pair of parasitic elements. The ground plane is located at the reverse side of the substrate, in the shape of a rectangle with two triangular chamfers whose dimensions are $W_S \times L_S$. They are employed to obtain a better impedance match, seen in Fig. 3. Placed on the ground layer in mirror of the upper pair, another pair of parasitic elements is totally the same size as the upper one, and directly underneath. The antenna is fed by a tapered microstrip line, the width of which equals 2.64 mm according to the equations (Eq. (2-9-10) and Eq. (2-9-11)) in [13], while the computed value by

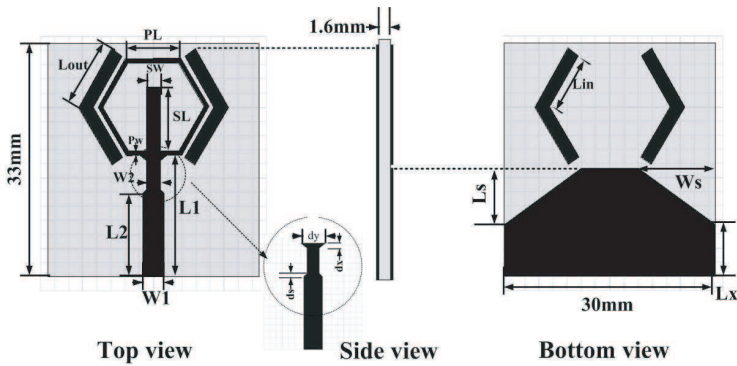


Figure 1. Dimensions of the proposed antenna.

the software named TXLINE is 3.06 mm. The final width is optimized to match 50Ω and attain a wider impedance matching range based on the numerical results. The detailed parameters of the proposed antenna are summarized in Table 1.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype of the proposed hexagonal ring antenna with dual band notches is measured by application of a WILTRON37269A Vector Network Analyzer in an anechoic chamber. The photograph of the manufactured antenna is presented in Fig. 2.

In order to reject the band extending from 5 GHz to 6 GHz, two pairs of parasitic elements are introduced, seen in Fig. 2. While the outer and inner lengths L_{out} and L_{in} of the parasitic elements are

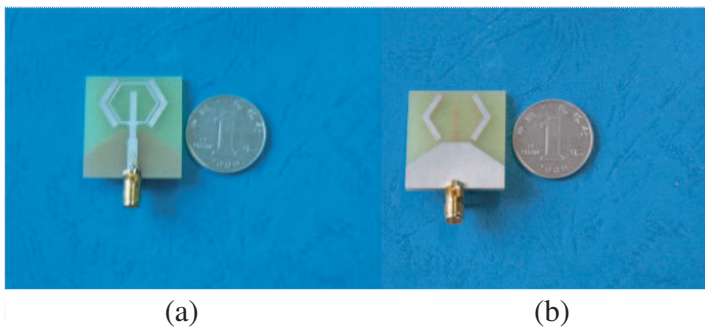


Figure 2. Configuration of the proposed antenna. (a) Upper view of the fabricated antenna. (b) Bottom view of the fabricated antenna.

selected according to the following expressions [11]:

$$L_{out} = \frac{c}{4f_L \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (2)$$

$$L_{in} = \frac{c}{4f_u \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (3)$$

where f_L represents the lower edge of the 5–6 GHz notch band, f_u is the upper edge, c is the velocity of light in the free space, and ε_r is the relative permittivity of the substrate. It can be easily found that the entire outer and inner length ($2 * L_{out}$, $2 * L_{in}$) of the parasitic elements are about half an effective wavelength of the notch band. The resonant stub is chosen to generate a band notch for 3.4–3.69 GHz and it is one quarter effective wavelength at the desired notch band [8]. Variations of L_{out} , L_{in} , and SL lead to tunable rejection bands.

It can be seen in Fig. 4 that the simulated VSWR (voltage standing wave ratio) of the proposed antenna agrees well with the measured one. The frequency departure of the WLAN band is due mainly to the fabrication error and impact of the measurement environment. Fig. 5 shows that the center of the 3.2–3.8 GHz notch band varies from 3.2 GHz to 3.7 GHz by changing SL from 9.2 mm to 11.2 mm, with an acceptable deterioration effect on the 5.5 GHz notch band. As seen in Fig. 6, changes of L_{out} impact almost only on the lower edge of the WLAN notch band. The figure also presents the dependence on L_{in} of the center of 5.15–6 GHz rejecting band. Obviously, the smaller L_{in} is, the higher the center is. Hence, it is of ease to determine and tune the two band notches.

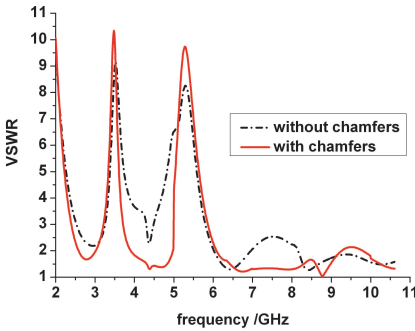


Figure 3. Impact of ground chamfers on VSWR.

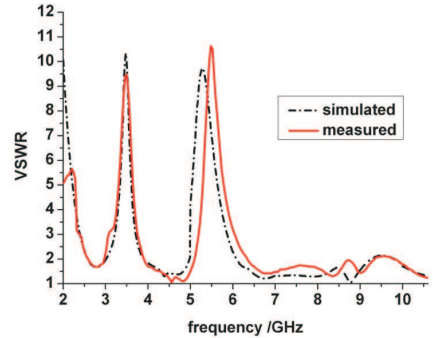


Figure 4. Simulated and measured VSWR.

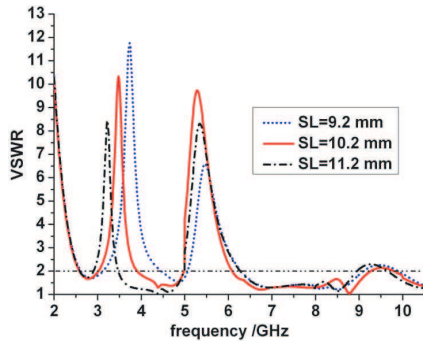


Figure 5. Variation of center of 3–4 GHz notch band with length of stub (SL).

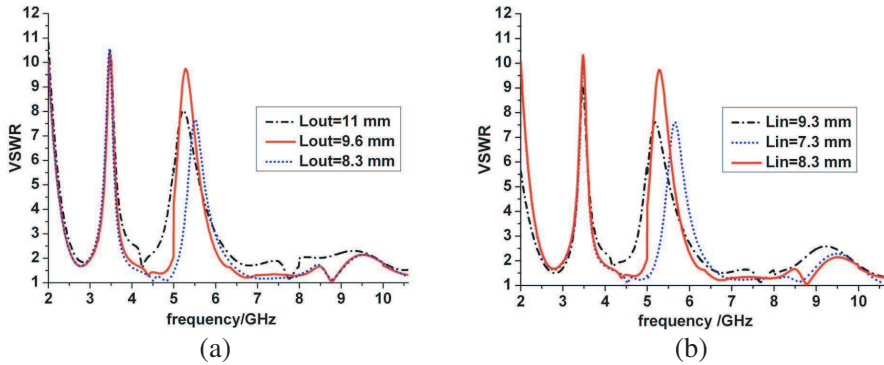


Figure 6. Dependence of the 5–6 GHz notched band on L_{out} and L_{in} . (a) Variation of notched band with L_{out} . (b) Variation of notched band with L_{in} .

Additionally, the distance s between the ground plane and the bottom edge of the hexagonal ring as well as w_2 (width of the narrower section of the feed network) has a significant impact on higher frequencies (around the vicinity of 9.5 GHz), shown in Fig. 7. Therefore, it is desirable to select a proper sizes ($s = 1.9$ mm, $w_2 = 2$ mm) to achieve a wider frequency band. The radiation patterns at 2.8, 4.5, and 8 GHz are shown in Fig. 8. From the data we can see that the antenna gives an approximate Omni-directional radiation in the H -plane (y - z plane, $\Phi = 0^\circ$). The peak realized-gain of the antenna in the entire operating band is also presented in Fig. 9. As seen in the figure, sharp decreases in the vicinity of 3.5 and 5.5 GHz are obtained because of the band notches.

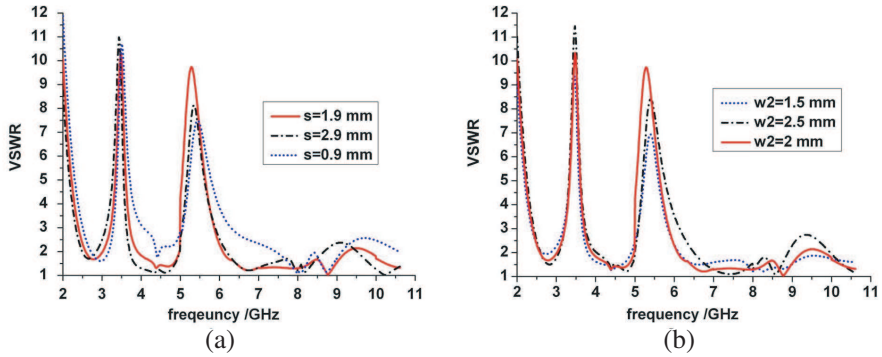


Figure 7. Impact of s and w_2 on VSWR. (a) Impact of s . (b) Impact of w_2 .

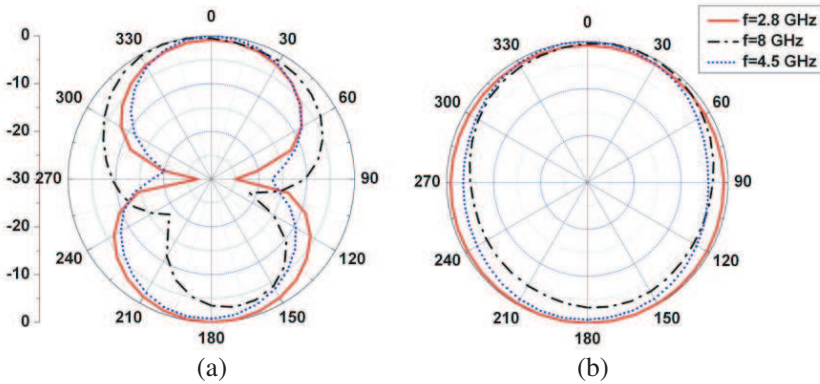


Figure 8. Radiation patterns. (a) E -plane ($\Phi = 0^\circ$). (b) H -plane ($\Phi = 90^\circ$).

Table 1. Dimensions of the proposed antenna (unit: mm).

L_1	17.3	L_s	8	W_s	11	P_w	0.62
L_2	11.8	L_x	7.3	SL	10.2	dx	1
L_{out}	9.6	W_1	3	SW	2	dy	4
L_{in}	8.3	W_2	2	PL	8	ds	0.5

In the end, the transfer function and group delay of the proposed antenna were measured from 2–11 GHz using a WILTRON37269A Vector Network Analyzer. A pair of identical antennas served as the transmitting and receiving antennas in the measurement system. The two antennas were connected to the double ports of the analyzer and

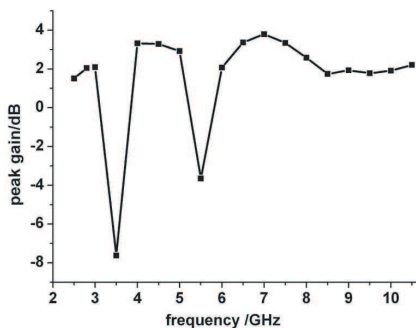


Figure 9. Realized gain of the proposed antenna.

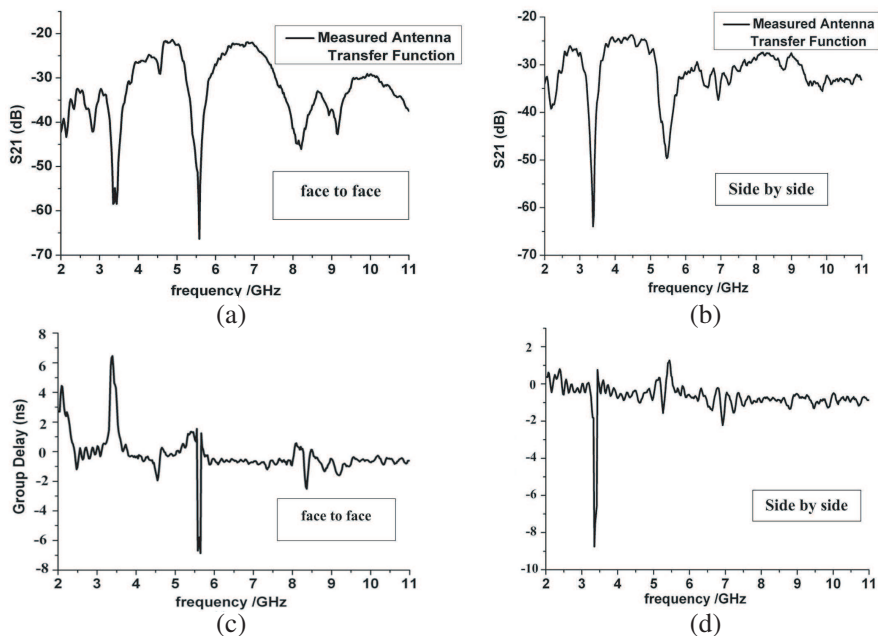


Figure 10. Transfer functions and group delays of the proposed antenna. (a) Transfer function for face to face antenna pair, (b) transfer function for side by side antenna pair, (c) group delay for the face to face antenna pair, (d) group delay for the side by side antenna pair.

aligned face to face and side by side at a distance of 30 cm. Fig. 10 presents the transmission response of the antenna pair, where (a) and (c) are transfer function and group delay for the face to face antenna

pair, while (b) and (d) are for the side by side pair. From the data we can see that the group delays in both face to face and side by side directions of the proposed antenna are almost in ± 1 ns throughout the operating band, except for the dual notched bands. It is much better than that in [14]. With measurement limitations, we cannot supply a time domain performance of the proposed antenna.

4. CONCLUSION

A printed UWB hexagonal ring antenna with dual tunable notch characteristics has been designed, manufactured, and measured. By utilization of a resonant stub and two pairs of parasitic elements, dual band notches are generated for WiMAX and WLAN, respectively. Due to the independence of the radiating element, the notch-generating structures can be easily tuned to determine the desired notches. The measured results of the proposed antenna indicate that the impedance bandwidth covers from 3.1 to 10.6 GHz with dual tunable band notches at 3.5 GHz and 5.5 GHz, which minimize the potential interferences over the released UWB frequency band range. And the measured transfer functions along with group delays show ability of the investigated antenna to operate normally. Moreover, the proposed antenna has good pattern characteristics as well as a stable gain throughout the UWB band.

REFERENCES

1. Dong, L., S. Quan, and Z. Wang, "A printed ultra-wideband hexagon monopole antenna with WLAN band-notched design for wireless communication," *Microw. Opt. Technol. Lett.*, Vol. 51, No. 4, 1049–1052, April 2009.
2. Chu, Q.-X. and Y.-Y. Yang, "3.5/5.5 GHz dual band-notch ultra-wideband antenna," *Electro. Lett.*, Vol. 44, No. 3, January 2008.
3. Dong, Y. D., W. Hong, Z. Q. Kuai, and J. Y. Zhou, "Band-notched ultra-wideband antenna designed and optimized by current distribution analysis," *International Conference on Microwave and Millimeter Wave Technology*, Vol. 3, 1062–1065, April 2008.
4. Yin, K. and J. Xu, "Compact ultra-wideband monopole antenna with band-stop characteristic," *International Conference on Microwave and Millimeter Wave Technology*, Vol. 3, 1174–1176, April 2008.
5. Wong, K.-L., Y.-W. Chi, C.-M. Su, and F.-S. Chang, "Band-notched ultra-wideband circular-disk monopole antenna with an

- Arc-shaped slot,” *Microw. Opt. Technol. Lett.*, Vol. 45, No. 3, 188–191, May 2005.
6. Kim, Y. and D.-H. Kwon, “CPW-fed planar ultra wideband antenna having a frequency band notch function,” *Electro. Lett.*, Vol. 40, No. 7, April 2004.
 7. Ding, Y., G.-M. Wang, and J.-G. Liang, “Compact band-notched ultra-wideband printed antenna,” *Microw. Opt. Technol. Lett.*, Vol. 49, No. 11, 2686–2689, November 2007.
 8. Zhang, L.-N., S.-S. Zhong, X.-L. Liang, and C.-Z. Du, “Compact omni-directional band-notch ultra-wideband antenna,” *Electro. Lett.*, Vol. 45, No. 13, June 2009.
 9. Dong, Y. D., W. Hong, Z. Q. Kuai, et al., “Development of ultra-wideband antenna with multiple band-notched characteristics using half mode substrate integrated waveguide cavity technology,” *IEEE Trans. Antennas Propag.*, Vol. 56, No. 9, 2894–2902, September 2008.
 10. Gao, Y., B.-L. Ooi, and A. P. Popov, “Band-notched ultra-wideband ring-monopole antenna,” *Microw. Opt. Technol. Lett.*, Vol. 48, No. 1, 125–126, January 2006.
 11. Abbosh, A. M. and M. E. Bialkowski, “Design of UWB planar band-notched antenna using parasitic elements,” *IEEE Trans. Antennas Propag.*, Vol. 57, No. 3, March 2009.
 12. Bialkowski, M. E. and A. M. Abbosh, “Design of UWB planar antenna with improved cut-off at the out-of-band frequencies,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 408–410, 2008.
 13. Liang, C.-H., Y.-J. Xie, and B.-R. Guan, *Microwave Theory*, 172, Higher Education Publishing Press, Beijing, China, 2006.
 14. Dong, Y. D., W. Hong, Z. Q. Kuai, and J. X. Chen, “Analysis of planar ultra-wideband antennas with on-ground slot band-notched structures,” *IEEE Trans. Antennas Propag.*, Vol. 57, No. 7, 1886–1893, July 2009.