Design of Planar Differential-Fed Antenna with Dual Band-Notched Characteristics for UWB Applications

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Abstract **─** A planar differential-fed antenna with dual band-notched characteristics is presented for ultra-wideband (UWB) applications. The proposed antenna mainly consists of two V-shaped radiating patches placed face to face and an octagonal slot ground plane. To avoid the potential electromagnetic interference from narrowband services, V-shaped slots embedded in the radiating patches are adopted to reject 5.5 GHz WLAN band, while T-shaped stubs connected with the radiating patches are introduced to filter 8 GHz ITU band. A prototype of the proposed antenna is fabricated and tested. Measured results demonstrate that the obtained impedance bandwidth is from 2.82 to more than 11 GHz, along with two notched bands of 4.83-6.12 GHz and 7.86-8.57 GHz. In addition, the proposed antenna exhibits good radiation patterns and stable gain.

Index Terms **─** Differential-fed, notched band, T-shaped stub, UWB antenna, V-shaped slot.

I. TRODUCTION

With the allocation of 3.1-10.6 GHz band for ultra-wideband (UWB) applications by the Federal Communications Commission (FCC), ultra-wideband wireless communication technology has attracted increasing attention due to the inherent features such as high data rate, wide bandwidth, low power consumption and low cost. As an important component of the UWB wireless communication systems, various UWB antennas with good performances have been developed [1-9]. In practical applications, existing narrowband services like 5.15-5.825 GHz WLAN and 8.025-8.4 GHz ITU may cause electromagnetic interference with the UWB band. To reduce interference, bandstop filters are often utilized to realize the desired notched band. However, it is inevitable to increase the complexity and the size of communication systems. Therefore, UWB antennas with band-notched characteristics are desirable [10-18]. In the design of UWB antenna [19], by applying an electromagnetic band-gap (EBG) structure, a notched band around 5.5 GHz is obtained to filter the 5.5 GHz WLAN band. In [20], a Koch fractal slot is used to yield a notched band covering from 4.65 to 6.40 GHz to reject the 5.5 GHz WLAN.

Recently, with the widespread application of differential signal operation in the radio frequency systems, the conventional single-ended antenna is not suitable for the differential circuits because it cannot be integrated with the differential circuit. Generally, baluns are needed to transform differential signals into single-ended signals between the differential circuits and the conventional antennas, which would cause additional losses and decrease the impedance matching bandwidth. Hence, differential-fed antennas excited by two signals with out of phase but equal amplitude are particularly significant, due to the fact that they can be directly integrated with differential circuits and no baluns are needed. In the design of [21], a differential-fed microstrip antenna is presented for UWB applications. Nevertheless, the proposed antenna does not have band-notched characteristics. In [22], a differential-fed magneto-electric dipole antenna is reported, but the antenna is not a planar structure. A differential UWB patch antenna with band-notched characteristics is developed in [23]. However, the rejected band only covers 5.2-6.0 GHz, and it cannot cover the 8 GHz ITU band.

In this paper, a planar differential-fed antenna with dual band-notched characteristics is proposed for UWB applications. This antenna, with a simple structure, is composed of two V-shaped radiating patches placed face to face and an octagonal slot ground plane. To diminish potential electromagnetic interference, V-shaped slots and T-shaped stubs are employed to achieve dual notched bands to filter 5.5 GHz WLAN and 8 GHz ITU, respectively. Details of the antenna design and the measured results are presented and discussed.

Submitted On: July 17, 2016
Accepted On: January 28, 2017

II. ANTENNA DESIGN

As is generally known, standard two-port s-parameter matrix is shown in (1):

$$S^{std}=\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}. \tag{1}$$

For the convenience in analyzing differential signals, a form of mixed-mode s-parameter matrix S^{mm} is developed in [24], which apply to describe the transmission characteristic of four-port differential microwave circuits.

Usually, a differential-fed antenna can be regarded as a differential two-port network. And the mixed-mode s-parameter matrix can be simplified as (2):

$$S^{mm}=\begin{bmatrix} S_{dd} & S_{dc} \\ S_{cd} & S_{cc} \end{bmatrix}. \tag{2}$$

Each of the mixed-mode s-parameter terms is as follows:

$$S_{dd}=\frac{1}{2}\left(S_{11}-S_{12}-S_{21}+S_{22}\right), \tag{3}$$

$$S_{dc}=\frac{1}{2}\left(S_{11}+S_{12}-S_{21}-S_{22}\right), \tag{4}$$

$$S_{cd}=\frac{1}{2}\left(S_{11}-S_{12}+S_{21}-S_{22}\right), \tag{5}$$

$$S_{cc}=\frac{1}{2}\left(S_{11}+S_{12}+S_{21}+S_{22}\right), \tag{6}$$

S_{dd}: Differential-mode s-parameters;
S_{dc}: Common-mode to differential-mode;
S_{cd}: Differential-mode to common-mode;
S_{cc}: Common-mode s-parameters.

Thus, the differential reflection coefficient of the proposed antenna can be calculated as below:

$$\Gamma_{odd}=S_{dd}=\frac{\left(S_{11}-S_{12}-S_{21}+S_{22}\right)}{2}. \tag{7}$$

Figure 1 shows various planar antenna structures involved in the design evolution process, and the corresponding simulated reflection coefficients for each antenna are depicted in Fig. 2. Note that, antennas involved in Fig. 1 are all designed on 1 mm-thick FR-4 epoxy substrates with a relative permittivity of 4.4 and loss tangent of 0.02. Each antenna is a double-layer metallic structure. The V-shaped radiating patches are printed on the top layer of the substrate, compared with the ground plane with an octagonal slot etched on the bottom layer. In the beginning, the antenna (Ant. 1) is two UWB V-shaped monopoles placed face to face. This simple design can obtain a wide frequency band ranging from 2.97 to more than 11 GHz. The feeding lines are tapered from 1.9 to 0.7 mm to reach good impedance matching. For the purpose of minimizing the electromagnetic interference from narrowband communication systems of WLAN (5.15-5.825 GHz) and ITU (8.025-8.4 GHz), two different approaches are applied to realize filtering behavior. In Ant. 2, V-shaped slot structures are etched on the radiating patches of Ant. 1 to achieve a notched band for rejecting 5.5 GHz WLAN. And the corresponding reflection coefficient of Ant. 2 is plotted in Fig. 2. This notched band can be controlled by adjusting the dimension of the V-shaped slots because the length of each slot is approximately equal to half of one guided wavelength λ_g at 5.6 GHz. The guided wavelength λ_g is defined as:

$$\lambda_g=\frac{c}{f\sqrt{\varepsilon_{eff}}}, \tag{8}$$

where c is the free-space speed of light, f is the center frequency of notched band, and ε_{eff} is the effective relative permittivity of the substrate. Based on the Ant. 2, two T-shaped stubs are introduced to obtain the other notched band around 8.25 GHz to filter 8 GHz ITU. Notably, the length of the T-shaped stub determines the center frequency of the notched band. The final antenna (Ant. 3) proposed in this design is obtained as shown in Fig. 1.

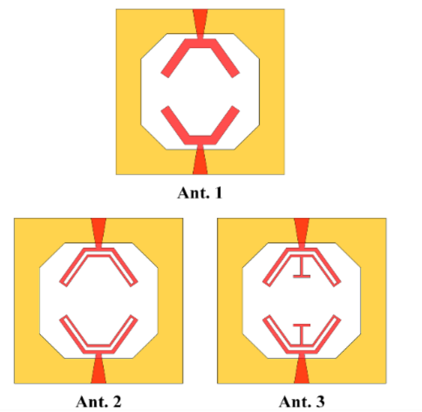


Fig. 1. Geometry of various antennas involved in the design evolution process.

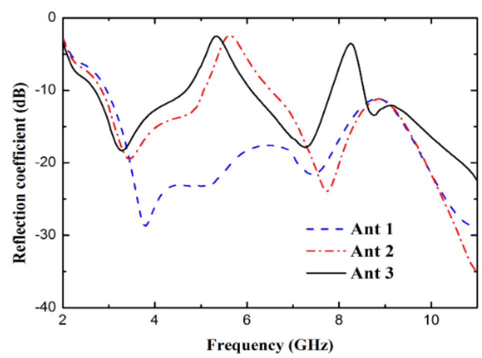


Fig. 2. Simulated reflection coefficients of various antennas involved.

To further investigate the dual band-notched working mechanism of the proposed antenna, the surface current distributions of the whole antenna at frequencies of 5.6 and 8.25 GHz are presented in Fig. 3. It is clear that the surface current distributions mainly concentrate along the edges of the V-shaped slots at 5.6 GHz in Fig. 3 (a), whereas a large surface current density is observed along the T-shaped stubs at 8.25 GHz in Fig. 3 (b). The results from figures indicate that the V-shaped slots and T-shaped stubs work as resonators at rejected frequencies. This leads to serious impedance mismatching of the proposed antenna at 5.6 and 8.25 GHz. Thereby, the antenna cannot radiate electromagnetic energy outside in the notched bands.

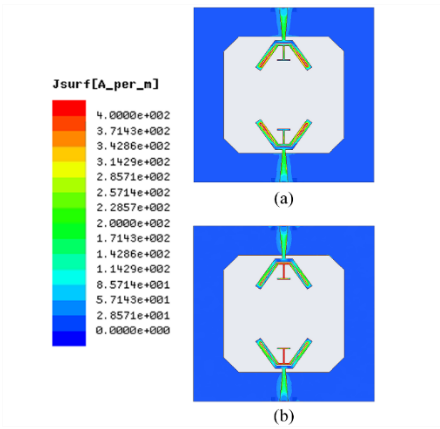


Fig. 3. Surface current distributions of proposed antenna at (a) 5.6 GHz and (b) 8.25 GHz.

The geometry of the proposed antenna (Ant. 3) with the detailed design parameters is illustrated in Fig. 4. The antenna consists of two parts: two V-shaped monopoles placed face to face and a square ground plane with an octagonal slot. A V-shaped slot and a T-shaped stub are embedded in each monopole. The simulation and analysis for the proposed antenna are performed using the electromagnetic simulator ANSYS HFSS. The optimized dimensions of the antenna are listed in Table 1.

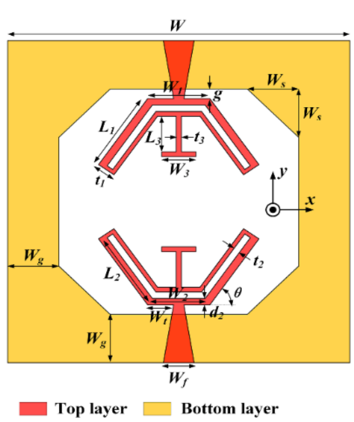


Fig. 4. Geometry of the proposed antenna with the detailed design parameters.

Table 1: Optimized parameters of the proposed antenna

Parameters	W	W_g	W_s
Values (mm)	42.0	7.0	3.5
Parameters	W_f	W_t	g
Values (mm)	1.9	1.4	0.8
Parameters	W_1	L_1	t_1
Values (mm)	4.0	8.0	1.4
Parameters	W_2	L_2	t_2
Values (mm)	3.5	6.7	0.2
Parameters	d_2	W_3	L_3
Values (mm)	0.8	3.0	3.3
Parameters	t_3	θ	
Values (mm)	0.3	55 *deg*	

III. RESULTS AND DISCUSION

Based on the optimized dimensions indicated in Table 1, a prototype of the proposed antenna is fabricated and tested to verify the operation performance. The photograph of the fabricated antenna is given in Fig. 5. The impedance bandwidth is measured by using a WILTRON 37269A vector network analyzer. Figure 6 shows the simulated and measured reflection coefficients of the proposed antenna. It is found that the antenna has a wide bandwidth from 2.82 to more than 11 GHz, along with two notched bands of 4.83-6.12 GHz and 7.86-8.57 GHz. There is a good agreement between the simulated and measured results. The discrepancy at high frequencies may be attributed to the fabrication errors.

Figure 7 exhibits the measured and simulated far-field normalized radiation patterns for frequencies at 4, 7 and 9 GHz, respectively. From the figure, we can conclude that the proposed antenna features good quasi-omnidirectional radiation patterns in the H-plane and dipole-like radiation patterns in the E-plane. Meanwhile, the proposed antenna also achieves relatively low cross polarization. The simulated and measured gains of the antenna are shown in Fig. 8. It can be seen that the measured gain is flat in all operating bands, and it declines rapidly in the notched bands.

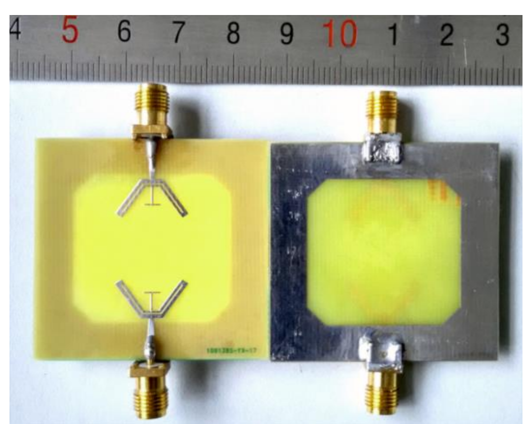


Fig. 5. Photograph of the fabricated antenna.

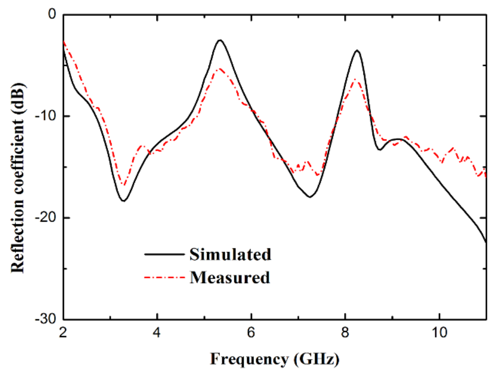
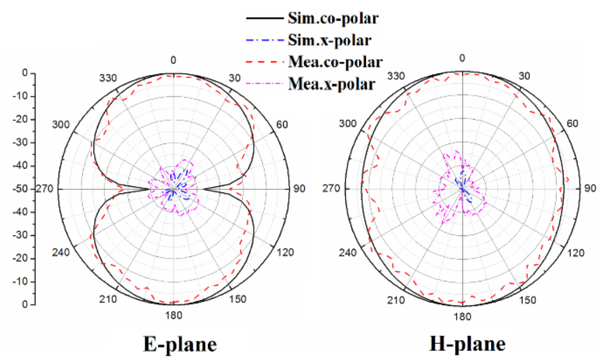
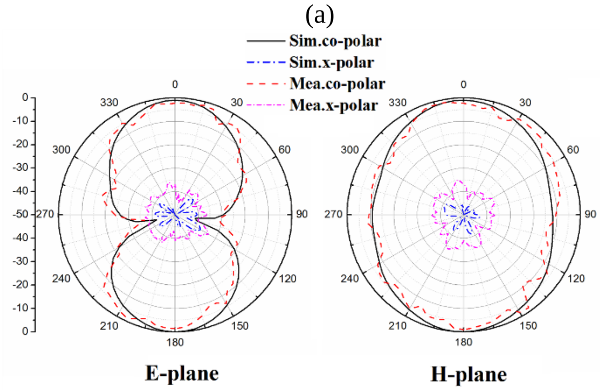


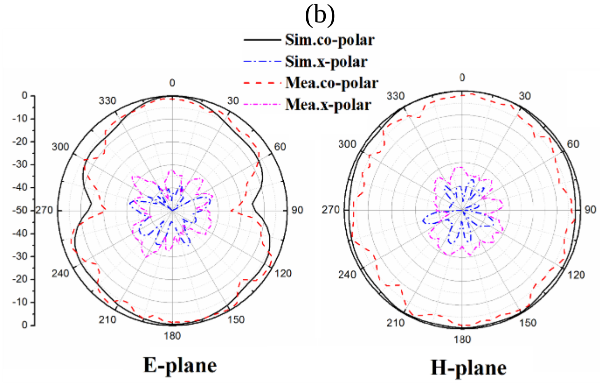
Fig. 6. Simulated and measured reflection coefficients of the proposed antenna.



(a)



(b)



(c)

Fig. 7. Simulated and measured radiation patterns of the proposed antenna at (a) 4 GHz, (b) 7 GHz, and (c) 9 GHz.

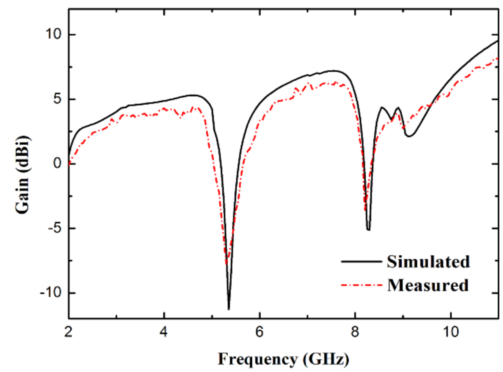


Fig. 8. Simulated and measured gains of the proposed antenna.

IV. CONCLUSION

A planar differential-fed ultra-wideband antenna with dual band-notched characteristics is proposed in this paper. To generate filtering behavior, the V-shaped slots and the T-shaped stubs are introduced in the antenna design. The obtained two notched bands of 4.83-6.12 GHz and 7.86-8.57 GHz can cover the 5.5 GHz WLAN and 8 GHz ITU bands. The antenna prototype has been designed, fabricated and tested. Measured results show reasonable agreement with simulated results, validating our design concept. Moreover, the proposed antenna features good radiation patterns, relatively low cross polarization and stable gain, which indicates it can be a good candidate for the UWB communication systems.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 61501340).

REFERENCES

[1] J. J. Liu, S. S. Zhong, and K. P. Esselle, “A printed elliptical monopole antenna with modified feeding structure for bandwidth enhancement,” *IEEE Trans. Antennas Propagat.*, vol. 59, no. 2, pp. 667-670, Feb. 2011.

[2] A. K. Gautam, S. Yadav, and B. K. Kanaujia, “A CPW-fed compact UWB microstrip antenna,” *IEEE Antennas Wireless Propagat. Lett.*, vol. 12, pp. 151-154, 2013.

[3] K. Song, Y. Z. Yin, B. Chen, and S. T. Fan, “Bandwidth enhancement design of compact UWB step-slot antenna with rotated patch,” *Progress In Electromagnetics Research Letters*, vol. 22, pp. 39-45, 2011.

[4] M. N. Shakib, M. Moghavvem, and W. N. L. Mahadi, “Design of a compact planar antenna for ultra-wideband operation,” *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 30, no. 2, pp. 222-229, Feb. 2015.

[5] L. Wang, W. Wu, X. W. Shi, F. Wei, and Q. L.

Huang, "Design of a novel monopole UWB antenna with a notched ground," *Progress In Electromagnetics Research C*, vol. 5, pp. 13-20, 2008.

[6] G. P. Gao, B. Hu, and J. S. Zhang, "Design of a miniaturization printed circular-slot UWB antenna by the half-cutting method," *IEEE Antennas Wireless Propagat. Lett.*, vol. 12, pp. 567-570, 2013.

[7] Q. Wu, R. H. Jin, J. P. Geng, and M. Ding, "Printed omni-directional UWB monopole antenna with very compact size," *IEEE Trans. Antennas Propagat.*, vol. 56, no. 3, pp. 896-899, Mar. 2008.

[8] B. S. Yildirim, B. A. Cetiner, G. Roqueta, and L. Jofre, "Integrated bluetooth and UWB antenna," *IEEE Antennas Wireless Propagat. Lett.*, vol. 8, pp. 149-152, 2009.

[9] A. Foudazi, H. R. Hassani, and S. M. A. Nezhad, "Small UWB planar monopole antenna with added GPS/GSM/WLAN bands," *IEEE Trans. Antennas Propagat.*, vol. 60, no. 6, pp. 2987-2992, June 2012.

[10] M. Moosazadeh and Z. Esmati, "Simple and compact dual-notched monopole antenna using U-shaped forms on the conductor-backed plane for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 28, no. 11, pp. 1074-1079, Nov. 2013.

[11] N. Ojaroudi, M. Ojaroudi, and N. Ghadimi, "Square monopole antenna with band-notched characteristic for UWB communications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 28, no. 8, pp. 712-718, Aug. 2013.

[12] K. S. Ryu and A. A. Kishk, "UWB antenna with single or dual band-notches for lower WLAN band and upper WLAN band," *IEEE Trans. Antennas Propagat.*, vol. 57, no. 12, pp. 3942-3950, Dec. 2009.

[13] J. W. Jang and H. Y. Hwang, "An improved band-rejection UWB antenna with resonant patches and a slot," *IEEE Antennas Wireless Propagat. Lett.*, vol. 8, pp. 299-302, 2009.

[14] M. Shokri, Z. Amiri, S. Asiaban, and B. Virdee, "Diamond shaped ring antenna for UWB applications with inherent band-notched functionality," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 11, pp. 911-915, Nov. 2014.

[15] Y. Ojaroudi, N. Ojaroudi, N. Ghadimi, and S. Ojaroudi, "Design of UWB CPW-fed slot antenna with a band-stop notch using a parasitic strip on the substrate backside," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 8, pp. 618-624, Aug. 2014.

[16] J. R. Kelly, P. S. Hall, and P. Gardner, "Band-notched UWB antenna incorporating a microstrip open-loop resonator," *IEEE Trans. Antennas Propagat.*, vol. 59, no. 8, pp. 3045-3048, Aug. 2011.

[17] A. Chen, C. Yang, Z. Chen, K. An, J. Fang, and W. Jiang, "A CPW-fed band-notched UWB antenna with T-shape construct and matching branches," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 2, pp. 134-139, Feb. 2014.

[18] Y. Ojaroudi, S. Ojaroudi, and N. Ojaroudi, "An UWB microstrip-fed slot antenna with enhanced bandwidth and WLAN band-notched characteristics," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 29, no. 9, pp. 685-691, Sep. 2014.

[19] M. Yazdi and N. Komjani, "Design of a band-notched UWB monopole antenna by means of an EBG structure," *IEEE Antennas Wireless Propagat. Lett.*, vol. 11, pp. 170-173, 2011.

[20] W. J. Lui, C. H. Cheng, and H. B. Zhu, "Compact frequency notched ultra-wideband fractal printed slot antenna," *IEEE Microw. Wireless Compon. Lett.*, vol. 26, no. 7, pp. 481-483, July 2016.

[21] J. H. Wang and Y. Z. Yin, "Ultra-wideband (UWB) differential-fed antenna with improved radiation patterns," *Progress In Electromagnetics Research C*, vol. 53, pp. 1-10, 2014.

[22] M. J. Li and K. M. Luk, "A differential-fed magneto-electric dipole antenna for UWB applications," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 1, pp. 92-99, Jan. 2013.

[23] Z. H. Tu, W. A. Li, and Q. X. Chu, "Single-layer differential CPW-fed notch-band tapered-slot UWB antenna," *IEEE Antennas Wireless Propagat. Lett.*, vol. 13, pp. 1296-1299, 2014.

[24] W. R. Eisenstadt and B. M. Thompson, *Microwave Differential Circuit Design Using Mixed-Mode S-Parameters*. Artech House, 2006.

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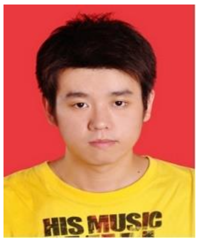

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