A Microstrip Printed Band-Notched UWB Antenna Using Modified CSRR Structure

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Abstract **—** A compact triple band-notch ultra-wideband (UWB) antenna with microstrip-feed is presented. The desired band-notch antenna is achieved by etching a narrowband triple complementary split-ring resonator into the radiating element of an existing UWB antenna. By attenuation of the measured return, the new antenna reduces interference from UWB in the C-band (3.7 GHz - 4.2 GHz) satellite communication systems and wireless local area network (5.15 GHz - 5.35 GHz, 5.725 GHz - 5.825 GHz bands). The built prototypes have a compact size of 25 × 27.9 mm^2 including the ground plane. This miniature size also delivers advantageous radiation patterns with good mono-polar characteristics across the UWB band with the gain attenuated within the desired notch bands. The antenna demonstrates omnidirectional and stable radiation patterns across all the relevant bands. Moreover, a prototype of the proposed antenna is fabricated, and the measured results are shown to be in good agreement with the simulated results.

Index Terms **—** Multiband, notch bands, printed slot antenna, and ultra-wideband (UWB).

I. INTRODUCTION

As the need for high-data-rate wireless communication becomes more urgent, various solutions have been suggested. Ultra-wide band (UWB) radio is a good candidate technology that has the advantages of higher data rates; good immunity to multi-path cancellation; a possible increase in communication operational security and low interference into legacy systems [1]. As they are required to be small and operate relative bandwidths, antennas are a particularly challenging aspect of UWB technology. The Federal communications commission (FCC) version of UWB radio has within its spectrum (3.1 GHz – 10.6 GHz), C-band (3.7 GHz – 4.2 GHz) satellite communication systems and the IEEE802.11a frequency band (5.15 GHz – 5.825 GHz), which are also a low-power technology. Therefore FCC UWB may be seen as an interferer for both the IEEE802.11a and C-band satellite communication systems. To address this problem, various UWB antennas with multi-notch band-stop characteristics have been proposed [2-5].

In this paper, a new band-notched printed monopole antenna with good gain characterization over a wide bandwidth is presented. By using a co-directional hexagon complementary split-ring resonators strip and by inserting a wave strip in the ground plane, the gain of the square antenna is enhanced, and also much wider impedance bandwidth can be produced, especially at the higher band. Different from the conventional structure, the notched band, covering the 3.68 GHz - 4.25 GHz, 5.05 GHz - 5.38 GHz, 5.7 GHz - 6.12 GHz band, is provided by electromagnetically adjusting coupling between a pair of co-directional hexagon complementary split-ring resonators strips protruded inside the swallow radiation pattern in our model. Experimental and simulated results of the constructed prototype are presented. The size of the designed antenna is smaller than the UWB antennas with band-notched function reported recently [6-9].

II. ANTENNA DESIGN

Microstrip antennas are key components in 1 GHz - 50 GHz frequency range. Compared with normal microwave antennas, the microstrip

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antennas have several advantages, including low loss, high integration, low profile, and compact size. To fabricate swallow-shaped microstrip triple band-notched antenna mentioned in this paper, a half ellipse is cut from a rectangle shape radiating patch firstly and then moved into the bottom side of the radiating patch. This new shape with a gradient structure has the same area as the rectangle shape. In addition, the ground of the antenna has wave-like shape so that this ground also has a gradient structure. Since both the swallow-shaped radiating patch and the wave-like shape ground have a gradient structure, the antenna can ensure a smooth transition from one mode to another. In this case, the antenna will have a good impedance matching within a broad bandwidth.

The quarter wavelength corresponding to the lowest cutoff frequency can be derived using equation (1)

$$\frac{\lambda}{4}=\frac{c}{4f}\ , \tag{1}$$

where λ represents the wavelength in free space, f is the frequency, and c is the speed of light. In this case, the radiating patch is similar to a disk. The lowest cutoff frequency of the corresponding quarter wavelength is equal to twice the radius of this disk,

$$2R=\frac{\lambda_p}{4}\ . \tag{2}$$

Therefore, the width of the antenna W < 2R.

According to earlier research, the band-notched can be introduced by the complementary split ring resonator (CSRR) structures in the radiating patch. If the length of the CSRR is roughly the same as the half wavelength of the corresponding central band-notched frequency, the currency is restricted around the CSRR, resulting in a no radiating antenna, which is due to band-notched [10-12]. In order to achieve three bands, three co-directional hexagon complementary split-ring resonators, are embedded into the radiating patch in the antenna. This can be expressed by,

$$L\ =\ \frac{c}{2\ f_{notch}\sqrt{\varepsilon_r}} \tag{3}$$

where c represents the speed of light, f is the central frequency of the notched band, and ε_r is the effectively dielectric constant.

In order to reduce the interference from the UWB in the C-band (3.7 GHz – 4.2 GHz) satellite communication systems and wireless local area network (5.15 GHz – 5.35 GHz, 5.725 GHz – 5.825 GHz). Parameters like the radius of the complementary split ring resonator (CSRR), position of the CSRR, and the width of the CSRR have been optimized. These optimization works were managed by using commercial 3-D electromagnetic software HFSS [13-15].

The geometry of the proposed antenna is shown in Fig. 1. The overall antenna size is 25× 27.9 mm^2. As can be seen, it consists of the following major parts: main radiation patch with a microstrip feed and a wave shape conductor ground plane in the back. The radius of the swallow radiating patch is fixed at 12.5 mm. The width of the feeding microstrip line is 1.55 mm, and its characteristic impedance is 50 Ω. Meanwhile, the conducting ground plane has size of 25 × 10.78 mm^2. The modified wave shape ground plane is applied to achieve broadband characteristics over the entire UWB band because the truncation creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly pure resistive input impedance. An SMA is connected to the port of the feeding microstrip line [16]. The specified characteristics of this substrate are 0.508 mm in thickness and 2.2 in relative permittivity (ε_r). Good performance of multiple band-notched characteristic is simply accomplished by embedding a common direction hexagon CSRR to the swallow patch.

Figure 2 shows the current distributions at three center notched bands. The dimensions of the three co-directional hexagon CSRR are corresponding to three notched bands. When the antenna is working at the center of the lower notched band near 3.9 GHz, the outer complementary SRR behaves as a separator in Fig. 2 (a), which almost has no relation to the other band-notches [17]. Similarly, the middle complementary SRR operates as a second separator for the center of the middle notched band near 5.2 GHz in Fig. 2 (b). From Fig. 2 (c), the upper notched band near 5.9 GHz is ensured by the inner complementary SRR [18]. Additionally, as a certain current crowded on the ground plane near the microstrip feed line would affect the antenna performance, we take simulation and find that the dimension of the ground plane, especially, has a significant effect on the triple band-notches performance, as well as the impedance bandwidth.

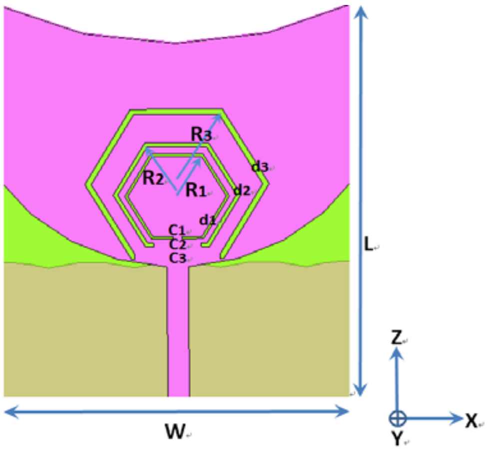
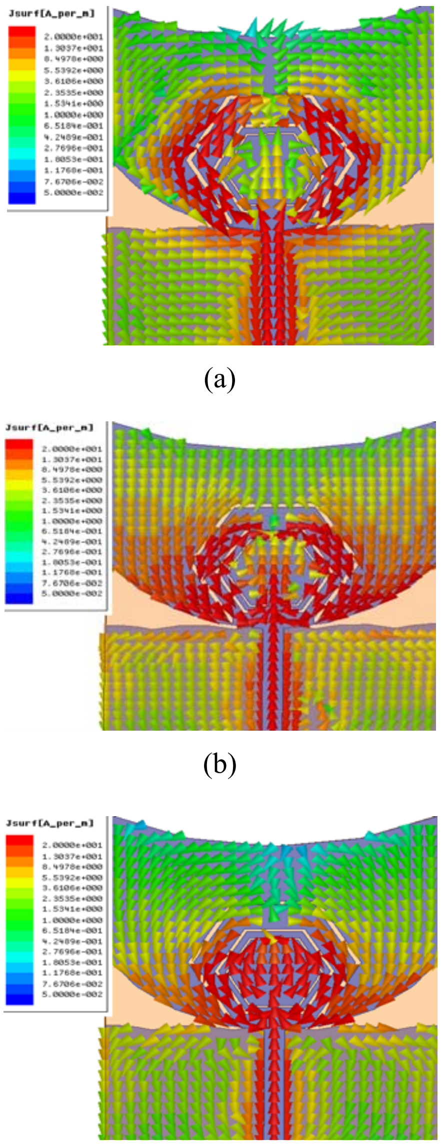


Fig. 1. Geometry of the antenna, having $R_1 = 4.01$ mm, $R_2 = 4.83$ mm, $R_3 = 6.98$ mm, $C_1 = 0.6$ mm, $C_2 = 3.35$ mm, $C_3 = 6$ mm, $d_1 = 0.2$ mm, $d_2 = 0.32$ mm, $d_3 = 0.45$ mm, W = 25 mm, and L = 27.9 mm.

III. RESULTS AND DISCUSSION

With the optimal parameters demonstrated in Fig. 1, an example monopole antenna was fabricated, which is shown in Fig. 3. As illustrated in Fig. 4, the proposed antenna has an impedance bandwidth (VSWR < 2) from 2.4 GHz to 11.8 GHz, which covers the entire UWB frequency band. Basically, this broad bandwidth is mainly determined by a conventional UWB antenna. By attaching co-directional hexagon complementary split-ring resonators, it is clearly observed from the measured results that the designed antenna exhibits triple stop bands of 3.68 GHz – 4.25 GHz, 5.05 GHz – 5.38 GHz, 5.7 GHz – 6.12 GHz. The center frequencies of the notched bands are 3.9 GHz, 5.2 GHz, and 5.9 GHz, respectively [19]. There is good agreement between simulated and measured results; the little difference between them may be caused by the soldering effects of an SMA connector, which have been neglected in our simulations [20].

The far-field radiation characteristics at 3.5 GHz, 5.5 GHz, and 7.5 GHz are given in Fig. 5, respectively. Nearly, omnidirectional radiation patterns in the xy-plane and dipole-like radiation patterns in the yz-plane are obtained at these frequencies [21]. Due to the limitations of laboratory instruments, the radiation patterns above 12 GHz were not measured. All the obtained radiation patterns accord with those of the conventional printed UWB monopole antennas. The proposed antenna has proved to be capable of providing favorable spatial-independent band-notched characteristics [22].



(a)

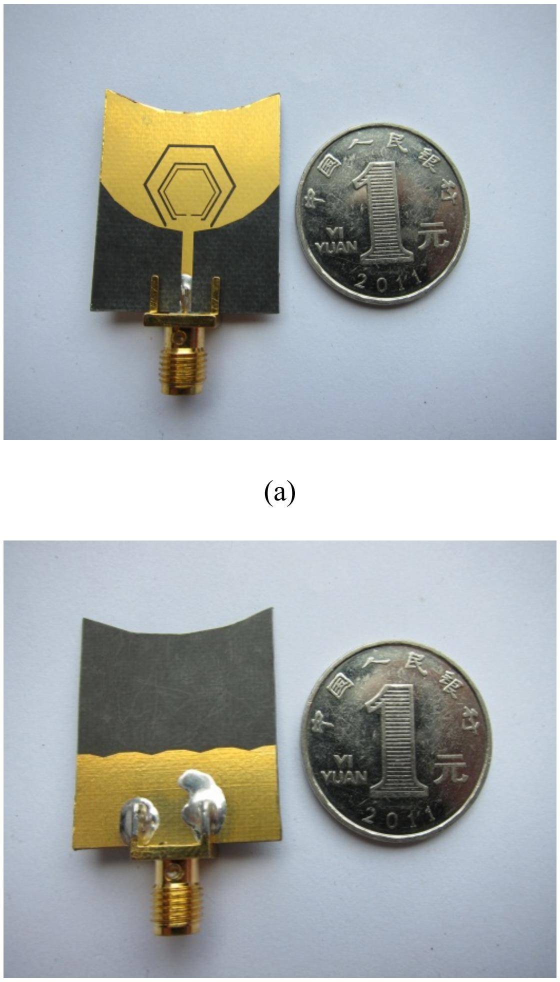
(b)

(c)

Fig. 2. The current distribution of the proposed antenna at (a) 3.9 GHz, (b) 5.2 GHz, and (c) 5.9 GHz.

Figure 6 shows the measured radiation efficiency of the antenna. The proposed antenna features an efficiency between 50 % and 70 % over the whole UWB frequency and lower than 5 % in the notch band. The features of about 60 %

average radiation efficiency is good enough to satisfy an acceptable variation for practical power transmission [23]. The measured gain of the proposed antenna is illustrated in Fig. 7. It can be seen that stable antenna gain with a variation of less than 3 dBi is achieved except for smaller values in the notched band, within which the smallest one is as low as -12 dBi. This confirms that the proposed antenna provides a high level of rejection to signal frequencies within the notched band [24-25].



(a)

(b)

Fig. 3. Photograph of the proposed antenna; (a) front view and (b) bottom view.

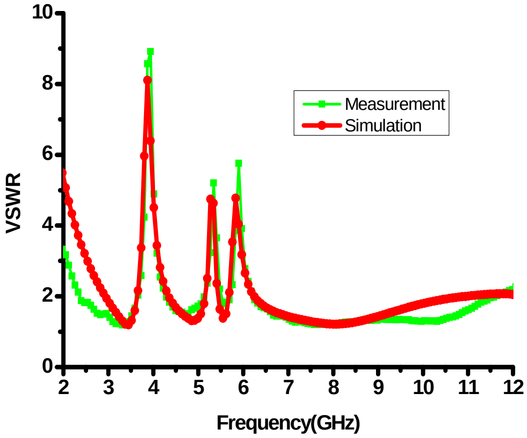
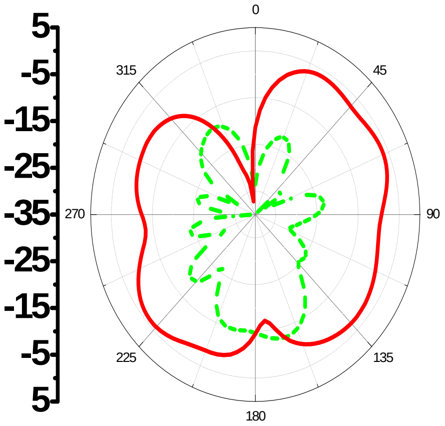
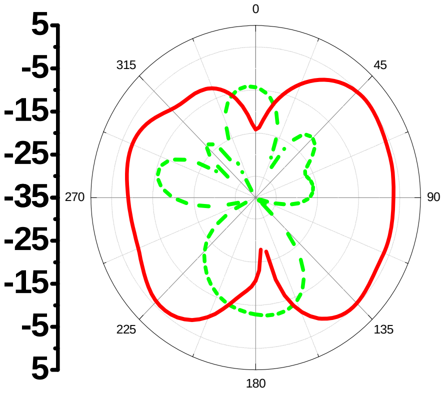


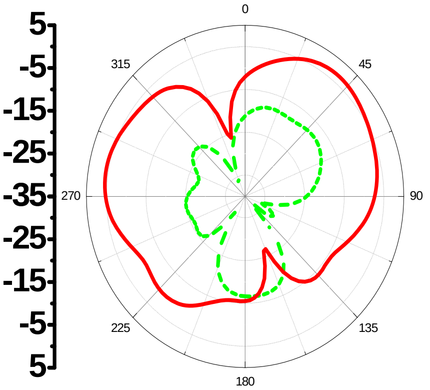
Fig. 4. Comparison of simulated and measured VSWR of the proposed antenna.



F=3.5GHz

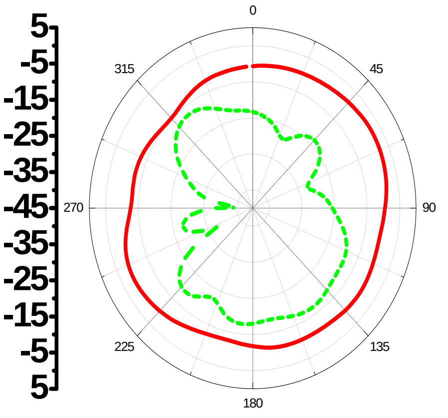


F=5.5GHz

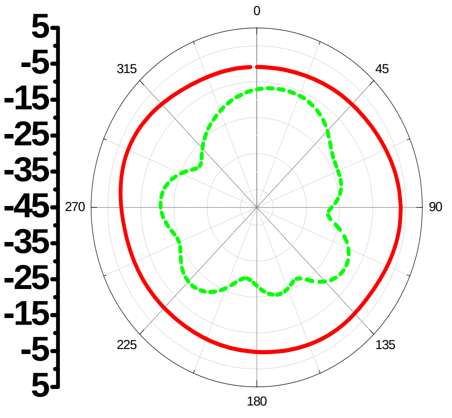


F=7.5GHz

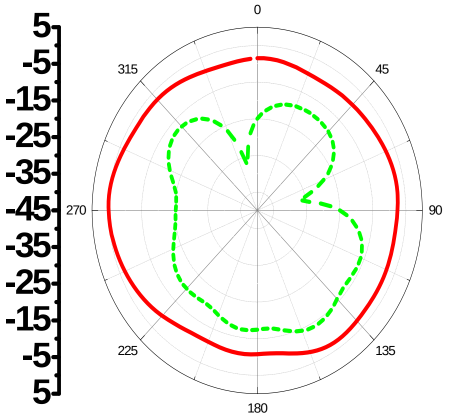
(a)



F=3.5GHz



F=5.5GHz



F=7.5GHz

(b)

Co-polar: ▬ Cross-polar: ▬ ▬ ▬

Fig. 5. Measured radiation patterns at (a) yz -plane and (b) xy-plane.

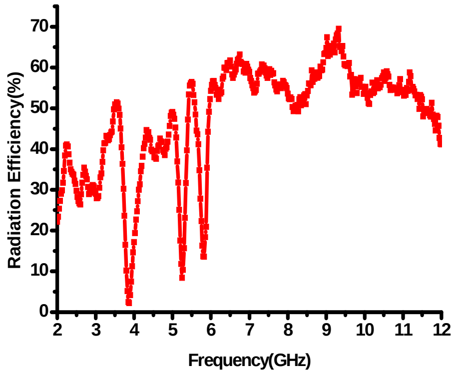


Fig. 6. Measured radiation efficiency of the proposed antenna.

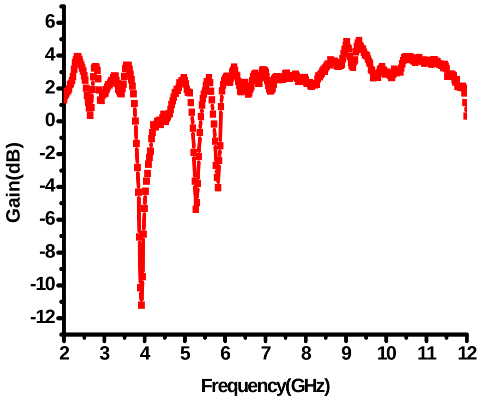


Fig. 7. Measured gain of the proposed antenna.

IV. CONCLUSIONS

A novel compact printed microstrip-fed monopole antenna with band-notched characteristics has been proposed for UWB applications. We showed that by embedding co-directional hexagon complementary split-ring resonators slots with proper dimensions and position in the radiation pattern, triple more resonances are excited, and as a result, wide impedance bandwidth from 2.4 GHz to 11.8 GHz is achieved, and also a rejection band around 3.68 GHz – 4.25 GHz, 5.05 GHz – 5.38 GHz, 5.7 GHz – 6.12 GHz can be achieved with the wave shape structures on the backside of the substrate. The designed antenna has a simple configuration and easy fabrication process. The experimental results show that the realized antenna with a very compact size, simple structure, and wide bandwidth can be a good candidate for UWB application. Therefore, the results of the work are useful for short-range wireless communication systems.

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REFERENCES

[1] Federal Communications Commission, Washington, DC, "Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems, First note and order," ET-Docket 98-153, 2002.

[2] N. Farrokh-Heshmat, J. Nourinia, and C. Ghobadi, "Band-notched ultra-wideband printed open-slot antenna using variable on-ground slits," *Electron. Lett.*, vol. 45, no. 21, pp. 1060-1061, Oct. 2009.

[3] G. Zhang, J. S. Hong, B. Z. Wang, and G. Song, "Switched band-notched UWB/ WLAN monopole antenna," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 3, pp. 256-260, March 2012.

[4] C. Yu, W. Hong, L. Chiu, G. Zhai, C. Yu, W. Qin, and Z. Kuai, "Ultra-wideband printed log-periodic dipole antenna with multiple notched bands," *IEEE Trans. Antennas Propag.*, vol. 59, no. 3, pp. 725-732, March 2011.

[5] M. T. Partovi, N. Ojaroudi, and M. Ojaroudi, "Small slot antenna with enhanced bandwidth and band-notched performance for UWB applications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 9, pp. 772-778, Sep. 2012.

[6] F. Wei, L. Xu, X.-W. Shi, and B. Liu, "Compact UWB bandpass filter with two notch bands based on folded SIR," *Electron. Lett.*, vol. 46, no. 25, pp. 1679-1680, Dec. 2010.

[7] A. M. Montaser, K. R. Mahmoud, and H. A. Elmikati, "Integration of an optimized E-shaped patch antenna into laptop structure for bluetooth and notched-UWB standards using optimization techniques," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 10, pp. 786-794, Oct. 2012.

[8] A. A. Eldek, "Numerical analysis of a small ultra wideband microstrip fed tap monopole antenna," *Prog. Electromagn. Res.*, vol. 65, pp. 59-69, 2006.

[9] B. H. Siahkal-Mahalle, M. Ojaroudi, and N. Ojaroudi, "Enhanced bandwidth small square monopole antenna with band-notched functions for UWB wireless communications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 9, pp. 759-765, Sep. 2012.

[10] Y. D. Dong, W. Hong, Z. Q. Kuai, C. Yu, Y. Zhang, J. Y. Zhou, and J. Chen, "Development of ultra wideband antenna with multiple band-notched characteristics using half mode substrate integrated waveguide cavity technology," *IEEE Trans. Antennas Propag.*, vol. 57, no. 12, pp. 2894-2902, Dec. 2009.

[11] M. Ojaroudi, N. Ojaroudi, and Y. Ebazadeh, "Dual band-notch small square monopole antenna with enhanced bandwidth characteristics for UWB applications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 5, pp. 420-426, May 2012.

[12] A. Valizade, Ch. Ghobadi, J. Nourinia, N. Ojaroudi, and M. Ojaroudi, "Band-notch slot antenna with enhanced bandwidth by using Ω-shaped strips protruded inside rectangular slots for UWB applications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 10, pp. 816-822, Oct. 2012.

[13] D. Jiang, Y. Xu, R. Xu, and W. Lin, "Compact dual-band-notched UWB planar monopole antenna with modified CSRR," *Electro. Lett.*, vol. 48, no. 20, pp. 1250-1252, Sep. 2012.

[14] 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 Propag.*, vol. 57, no. 12, pp. 3942-3950, Dec. 2009.

[15] X. N. Low, Z. N. Chen, and T. S. P. See, "A UWB dipole antenna with enhanced impedance and gain performance," *IEEE Trans. Antennas*

Propag., vol. 54, no. 10, pp. 2959-2966, Oct. 2009.

[16] X. L. Ma, W. Shao, and G. Q. He, "A novel dual narrow band-notched CPW-fed UWB slot antenna with parasitic strips," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 7, pp. 581-586, July 2012.

[17] A. Nouri and G. R. Dadashzadeh, "A compact UWB band-notched printed monopole antenna with defected ground structure," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1178-1181, 2011.

[18] C.-M. Wu, Y.-L. Chen, and W.-C. Liu, "A compact ultra wideband slotted patch antenna for wireless USB dongle application," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 596-599, 2012.

[19] Z. L. Zhou, L. Li, and J. S. Hong, "A novel compact monopole antenna with triple high quality rejected bands for UWB applications," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 8, pp. 654-659, August 2012.

[20] M. Mighani, M. Akbari, and N. Felegari, "A CPW dual band notched UWB antenna," *Appl. Comp. Electro. Society (ACES) Journal*, vol. 27, no. 4, pp. 352-359, April 2012.

[21] W. Jiang and W. Che, "A novel UWB antenna with dual notched bands for WiMAX and WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 293-5296, 2012.

[22] C.-T. Chuang, T.-J. Lin, and S.-J. Chung, "A band-notched UWB monopole antenna with high notch-band-edge selectivity," *IEEE Trans. on Antennas and Propagation*, vol. 60, no. 10, pp. 4492-4499, Oct. 2012.

[23] S. W. Wong, T. G. Huang, C. X. Mao, Z. N. Chen, and Q. X. Chu, "Planar filtering ultra-wideband (UWB) antenna with shorting pins," *IEEE Trans. on Antennas and Propagation*, vol. 61, no. 2, pp. 948-953, Feb. 2013.

[24] Y. Sung, "Triple band-notched UWB planar monopole antenna using a modified H-shaped resonator," *IEEE Trans. on Antennas and Propagation*, vol. 61, no. 2, pp. 953-957, Feb. 2013.

[25] F. Wei, Z. D. Wang, F. Yang, and X. W. Shi, "Compact UWB BPF with triple-notched bands based on stub loaded resonator," *Electro. Lett.*, vol. 49, no. 2, Jan. 2013.

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