UWB Monopole Antenna with Band Notched Characteristics Mitigating Interference with WiMAX

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Abstract. *Compact asymmetric coplanar strip (ACS)-fed monopole antenna is presented in this paper for operation in ultra wide-band (UWB) applications. The antenna is composed of a semi-elliptical monopole and lateral coplanar ground plane to operate in the UWB range. It occupies a very small size of 28 × 11.5 mm*^{2} *and is mounted on low cost FR4 substrate of 1.6 mm thickness and dielectric constant of 4.4. Band notched structure is applied to the proposed antenna to assure the rejection of WiMAX frequency band centered at 3.5 GHz to minimize the interference of the communication system with this service. The radiation characteristic of the proposed ACS-fed monopole antenna is nearly omnidirectional with moderate gain over the entire UWB frequency range. The measurements of the fabricated model confirm the designed behavior. The compactness in size, cheap cost and simple feeding technique make it as a good candidate to be integrated within the portable devices for wireless communication.*

Keywords

UWB monopole antenna, band notched characteristics, WiMAX

1. Introduction

After the allocation of the unlicensed frequency band (3.1–10.6 GHz) for ultra wide-band (UWB) communications by the Federal Communications Commission (FCC) in 2002 [1], many researchers focus their interests to design antennas working in this band with attractive specifications. Compact size, low cost, light weight and easy fabrication process are the main promising requirements of the antenna to be integrated in portable devices that can operate with different wireless communication applications in the UWB frequency range [2–5]. One of the serious problems facing any UWB antenna is the electromagnetic interference (EMI) problem since there are other wireless communication systems operating in the same frequency band of UWB communications such as Worldwide Interoperability for Microwave Access (WiMAX) working at 3.3–3.6 GHz [6]. To overcome the presented problem, a band notched structure is urgently needed. Various methods have been reported to achieve a band rejection behavior, such as by etching slots in the radiating patch [7], [8], or in the ground plane [9] or in the microstrip line [10]. Parasitic resonators beside the partial ground plane are loaded as in [11]. Also, resonators beside the feeding line are added in [12]. However, all the aforementioned UWB antennas do not have their structure compact enough in order to be easily integrated in systems without deteriorating the overall performance. Also, some of these antennas do not have uniplanar structure, and require double sided etching and alignment. This increases the fabrication complexity and decreases the accuracy of the fabricated designs.

In order to reduce the complexity of the fabricated antennas, a coplanar waveguide (CPW) structure is used which facilitates the fabrication process and is preferable for the microwave integrated circuit applications [13]. Furthermore, in order to minimize the overall size of an antenna, asymmetric coplanar strip (ACS) structure is introduced. The overall size of this antenna can be reduced to about one half of the common coplanar waveguide CPW-fed monopole antennas as reported in [13–19].

In this paper, a semi-elliptical monopole antenna with ACS structure is proposed for UWB applications. Covering the frequency band of UWB communications (3.1 to 10.6 GHz) is the main goal of the designed antenna. An inherent band rejection structure is utilized to achieve a notch at 3.5 GHz to mitigate the interference with WiMAX applications allocated in 3.3–3.6 GHz frequency band. The proposed antennas were fabricated and then scattering parameters and radiation characteristics were measured to verify the simulations done by the commercial software (CST). Good agreement between simulated and measured results confirms the ability of the proposed band notched ACS-fed antenna for operation in the UWB communication systems without interfering the allocated WiMAX frequency band at 3.5 GHz.

2. Configuration of ACS-Fed Antenna without and with Stub Responsible for Band Notched Characteristic

The geometry of the proposed UWB monopole antenna with the optimized dimensions is shown in Fig. 1(a). First of all, an elliptic CPW feed antenna is designed. Asymmetric coplanar strip feed with half ground plane is used to reduce the antenna size. Also, instead of using complete elliptic radiator, half of the elliptic radiator is used as shown in Fig. 1(a). The impedance matched from 3.1 GHz to more than 10.6 GHz as shown in Fig. 2 has been achieved by properly changing the width of the gap between the microstrip line and ground strip, and by making the ground metallization round. The antenna is mounted on low cost FR4 substrate with h = 1.6 mm, ε_r = 4.4, and tanδ = 0.02. The antenna consists of semi-elliptical radiator with ACS feeding line. The ACS feeding line has a signal strip 3 mm in width, and distance between the signal strip and the coplanar ground plane equal to 0.3 mm to match the 50 Ω SMA connector. The lateral ground plane is presented with bended edge to efficiently enhance the impedance characteristics of the proposed UWB antenna. The overall dimensions of the antenna are $28 \times 11.5 \times 1.6$ mm^3. The antenna was successfully designed and optimized by using the CST Microwave Studio software. To mitigate the interference with WiMAX systems, the band rejection function is desirable in UWB communication systems. The geometry of the proposed band notched UWB monopole antenna with the optimized dimensions is shown in Fig. 1(b). A nearly U-shaped stub is utilized to achieve the band rejection at 3.5 GHz for the proposed structure. The central frequency f_{notch} of the band notched response is controlled by the overall length of the resonator using the following equation:

$$L_{\text{total}} \approx \frac{\lambda_g}{2} = \frac{c}{2 f_{\text{notch}} \sqrt{\varepsilon_{\text{eff}}}} \tag{1}$$

where the rough estimate of the effective permittivity is

$$\varepsilon_{\text{eff}} \approx \frac{\varepsilon_r + 1}{2}\,. \tag{2}$$

c is speed of light, ε_r is substrate permittivity. The notch bandwidth is controlled namely by the stub strip width that determines its wave impedance.

3. Results and Discussion

The surface current distribution of the proposed ACS-fed UWB antenna without and with the stub creating the band notched characteristic was simulated by the CST software. Figure 3 shows the current distribution on the surface of UWB antenna at 3.5 GHz and it can be noticed that the current flows uniformly on the antenna surface. This is the standard current distribution of any radiating antenna. This current distribution can be significantly distorted by connecting a stub to the layout edge.

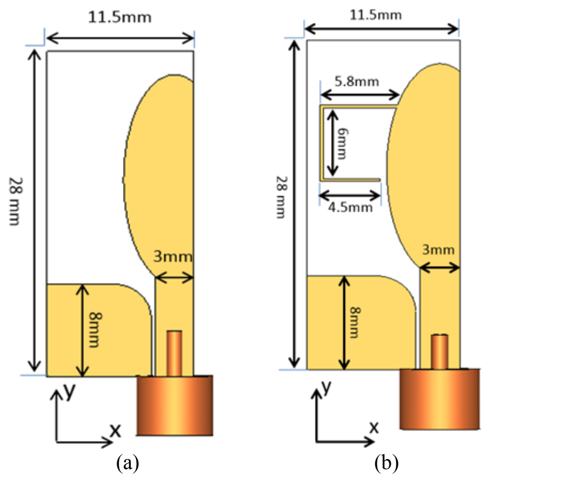


Fig. 1. Geometry of the proposed ACS-fed UWB monopole antenna.

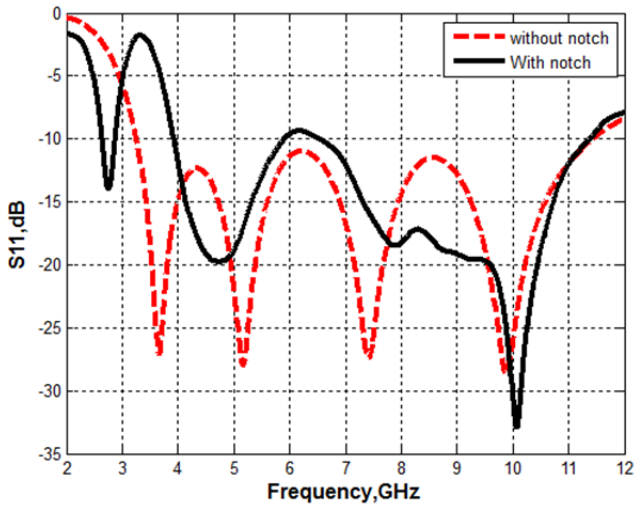


Fig. 2. The simulated reflection coefficient of the proposed structures.

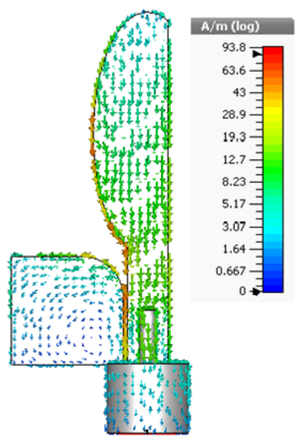
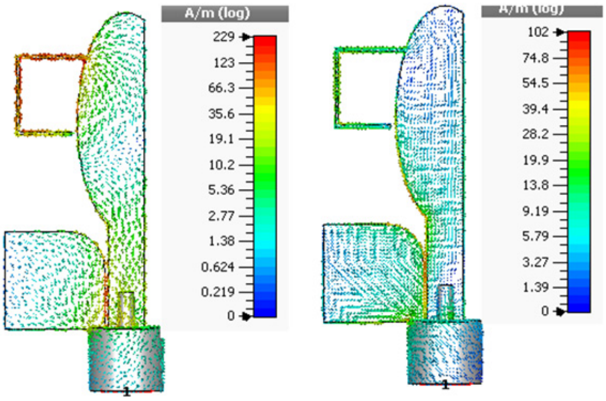


Fig. 3. Simulated surface current distributions of UWB antenna at 3.5 GHz.

For better demonstration of the band notched characteristics, the magnitude of the current distribution is investigated at two different frequencies, one in the coverage-band and the other in the rejection-band as shown in Fig. 4. It can be observed that at the notched frequency band at

3.5 GHz, the surface current is highly concentrated over the resonating stub as shown in Fig. 4(a), which means that the energy is stored in the resonator rather than radiated in the air. In Fig. 4(b), the current is uniformly distributed over the antenna surface at 7 GHz, which confirms that the antenna radiates.



(a) (b)

Fig. 4. Simulated surface current distributions of UWB antenna with band notched filter (a) at 3.5 GHz, (b) at 7 GHz.

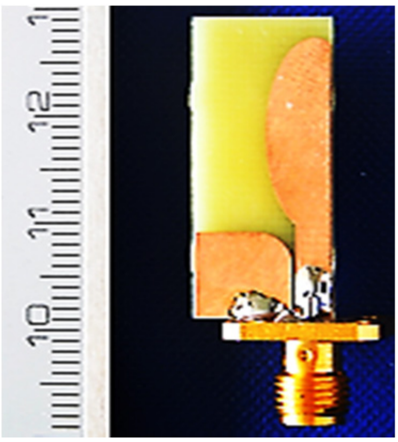


Fig. 5. Photograph of fabricated UWB monopole antenna.

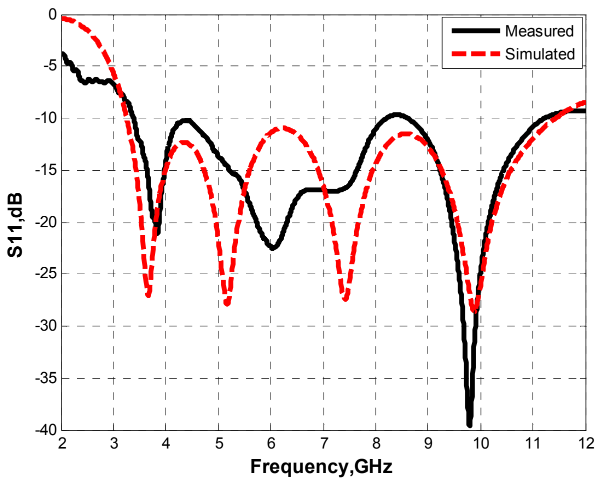


Fig. 6. The simulated and measured reflection coefficient of the UWB monopole antenna.

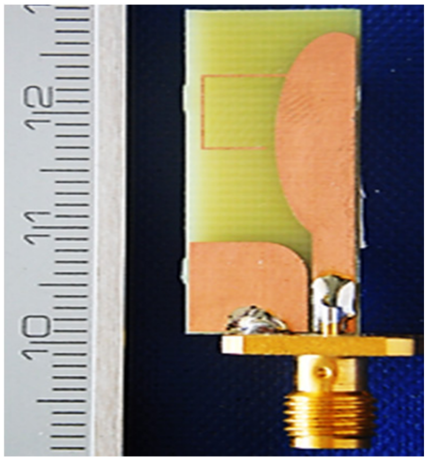


Fig. 7. Photograph of fabricated band notched UWB antenna.

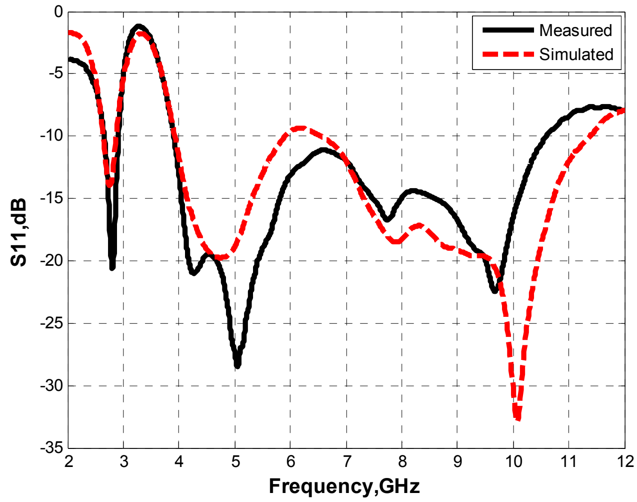


Fig. 8. The simulated and measured reflection coefficient of the band notched UWB antenna.

The semi-elliptical radiator connected with 50 Ω ACS line and the lateral partial ground plane are printed on the top layer of low cost FR4 epoxy substrate defined above as shown in Fig. 5. Figure 6 shows simulated and measured reflection coefficient. They are in a good consistency. The antenna is working in the UWB range from 3.2 GHz till 11.4 GHz with a reflection coefficient lower than –10 dB over the achieved frequency band. Figure 7 shows the fabricated prototype of the band notched UWB antenna with compact size of 28 × 11.5 mm^2. This antenna uses the resonant stub in order to achieve a notch in the operating band of WiMAX. As can be seen from Fig. 8, the measured S_{11} tracks the simulated S_{11} well. Both results cover the operating band of UWB application from 2.7 GHz to 10.7 GHz except rejected band from 2.9 GHz to 3.9 GHz with reflection coefficient greater than –10 dB as illustrated in Fig. 8 confirming that the proposed antenna is capable of mitigating the interference with WiMAX service. The reflection coefficient characteristics were measured using R&S vector network analyzer ZVA40, the radiation patterns were measured in an anechoic chamber using the NSI 800F-30 system.

A comparison between simulated realized gains of the two proposed UWB antennas without and with band notch is demonstrated in Fig. 9. The simulated realized gain of both antennas is almost constant over the achieved frequency band except the case of band notched antenna, which has notched gain between 3 GHz to 3.9 GHz with a minimum value of –5.5 dB at 3.4 GHz. The average measured gain is 3.5 dBi. For the case of UWB antenna without notch, the simulated efficiency has a maximum value of 98 % and a minimum value of 83 % within the frequency range from 3–11 GHz as depicted in Fig. 10. Furthermore, the simulated efficiency for the case of band notched UWB antenna has a maximum value of 93 % and minimum value of 14 % at 3.4 GHz.

The radiation patterns of the proposed antenna with band notched characteristic in the *x-z* plane ($\varphi = 0°$), *y-z* plane ($\varphi = 90°$) and *x-y* plane ($\theta = 90°$) were measured inside an anechoic chamber. The normalized simulated and measured radiation patterns are measured at 3.5 GHz, 6 GHz and 10 GHz in the three aforementioned planes of the proposed antenna as shown in Fig. 12, Fig. 13 and Fig. 14, respectively. It is clearly deduced that the UWB monopole antenna has nearly omni-directional patterns in the three planes at the three different frequencies except the occurrence of bi-directional pattern in *y-z* plane at 3.5 GHz. From comparison of radiation patterns of the proposed notched antenna with those of the original antenna (not presented here), one can conclude that the resonant stub does not affect the shape of radiation patterns. Of course, the radiating field intensities at 3.5 GHz of the notched antenna are much lower, relative to gain behavior shown in Fig. 9.

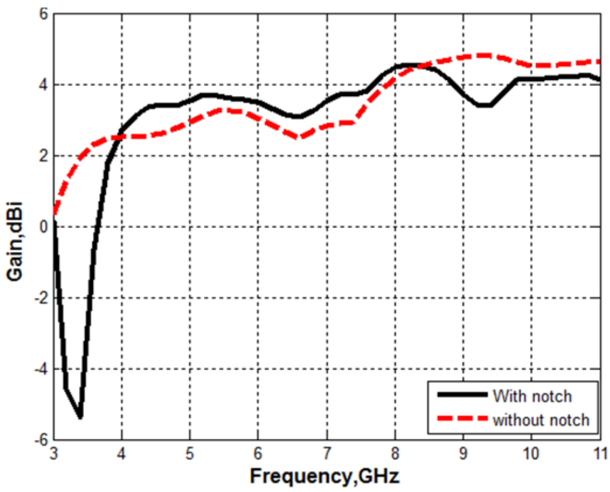


Fig. 9. The simulated realized gain of the fabricated antennas.

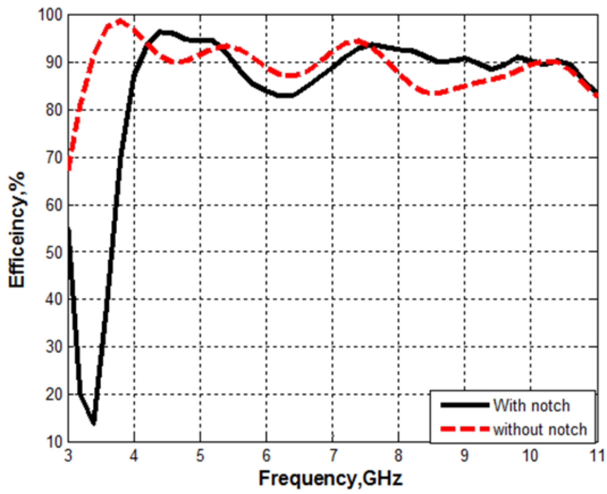


Fig. 10. The simulated efficiency of the fabricated antennas.

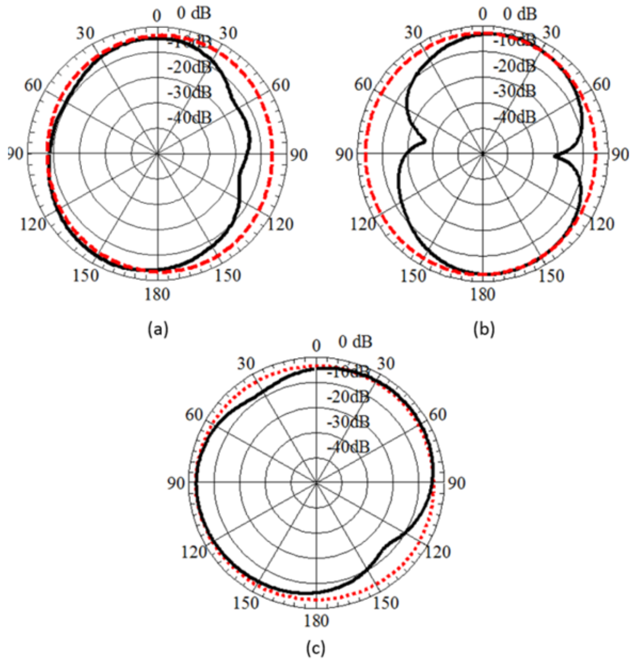


Fig. 12. The simulated red (dashed) and measured black (solid) normalized radiation patterns at f = 3.5 GHz: (a) *x-z* plane, (b) *y-z* plane, (c) *x-y* plane.

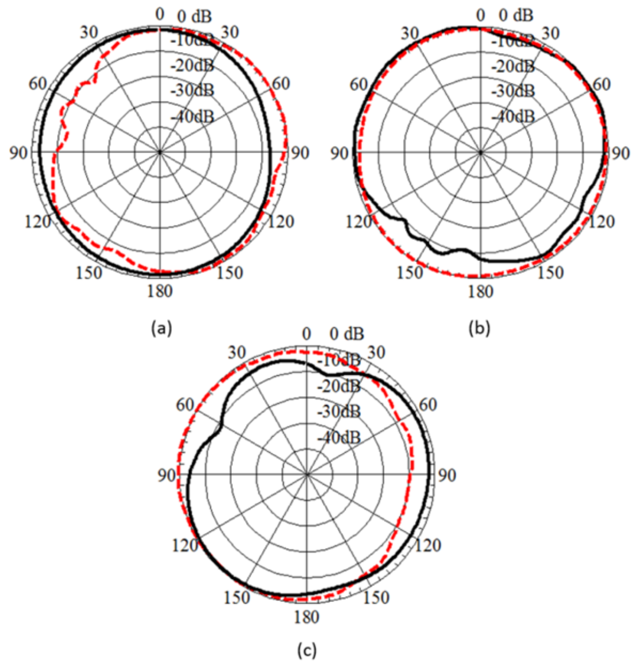


Fig. 13. The simulated red (dashed) and measured black (solid) normalized radiation patterns at f = 6 GHz: (a) *x-z* plane, (b) *y-z* plane, (c) *x-y* plane.

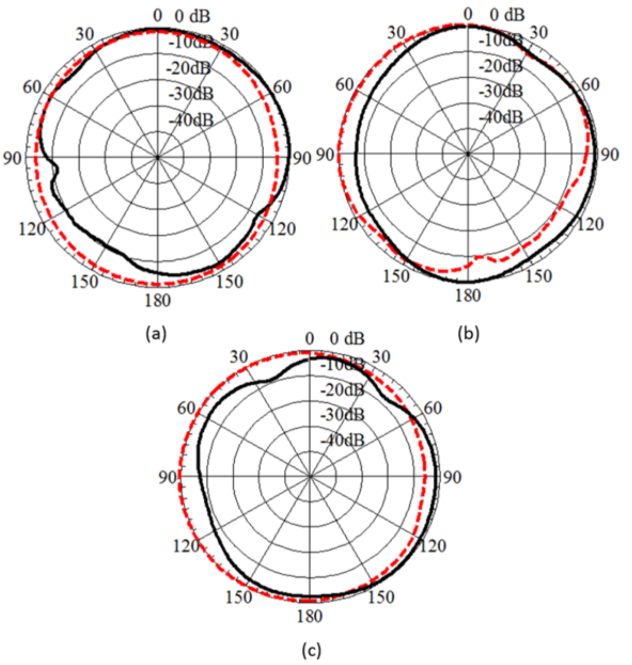


Fig. 14. The simulated red (dashed) and measured black (solid) normalized radiation patterns at $f = 10$ GHz: (a) x-z plane, (b) y-z plane, (c) x-y plane.

Ref.	Size [mm^2]	Frequency range [GHz]	Notch frequencies [GHz]	Realized gain at notch [dBi]
[20]	25 × 32	3-11	5.5	–5.2
			8.7	–3.6
[21]	58 × 65.5	3.1-11	-	-
[22]	24 × 32	2.9-12.5	5.5	–4.9
			7	–3.9
[23]	45 × 55	2-10.5	2.4	-
			3.5	-
			5.2	-
[16]	12.3 × 28	3-12.8	3.5	–3.3
			8.2	–2.5
[24]	30 × 32	3.1-14	5.5	–2
			6.8	–0.9
			11.5	–0.7
[25]	24 × 32	2.7-12	3.5	–4.3
			8	–2.1
This work	11.5 × 28	2.7-11.4	3.4	–5.5

Tab. 1. Comparison of the proposed antenna and other published works.

A comparison between the proposed antenna and other published work is demonstrated in Tab. 1. The presented antenna occupies the smallest area 11.5 × 28 mm^2 and shows the lowest gain at the notch frequency –5.5 dBi.

4. Conclusion

Compact size UWB monopole antennas without/with band notched characteristics have been designed, fabricated and tested. A semi-elliptical radiator connected with 50 Ω ACS line is printed on low cost FR4 substrate together with an asymmetric coplanar ground. An excellent impedance bandwidth has been experimentally achieved from 2.7 GHz to 11.4 GHz with notched band 2.9–3.9 GHz for interference mitigation purpose. The rejected band coincides with the band allocated for WiMAX applications (3.3–3.6 GHz). Furthermore, good omnidirectional radiation patterns with almost constant gain and efficiency over the UWB range have been achieved. The very small size due to ACS-feeding, makes the proposed UWB band notched antenna suitable for size-restricted systems.

Acknowledgments

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References

[1] FEDERAL COMMUNICATIONS COMMISSION. *First Report and order, Revision of part 15 of the commission's Rule Regarding Ultra-Wideband Transmission System FCC 02-48*. 2002.

[2] REDDY, G. S., KAMMA, A., MISHRA, S. K., MUKHERJEE, J. Compact bluetooth/UWB dual-band planar antenna with quadruple band-notch characteristics. *IEEE Antennas and Wireless Propagation Letters*, 2014, vol. 13, p. 872–875. DOI: 10.1109/LAWP.2014.2320892

[3] BOUTEJDAR, A., ABD ELLATIF, W. A novel compact UWB monopole antenna with enhanced bandwidth using triangular defected microstrip structure and stepped cut technique. *Microwave and Optical Technology Letters*, 2016, vol. 58, no. 6, p. 1514–1519. DOI: 10.1002/mop.29820

[4] ALI, W. A., ZAKI, A. I., ABDOU, M. H. Design and fabrication of rectangular ring monopole array with parasitic elements for UWB applications. *Microwave and Optical Technology Letters*, 2016, vol. 58, p. 2268–2273. DOI: 10.1002/mop.30021

[5] ABDALLA, M. A., IBRAHIM, A. A., BOUTEJDAR, A. Resonator switching for UWB antenna in wireless applications. *IET Microwaves, Antennas and Propagation*, 2015, vol. 9, no. 13, p. 1468–1477. DOI: 10.1049/iet-map.2014.0838

[6] LI, T., HUO, F. F., ZHAI, H. Q., LIANG, C. H. Compact ultra-wideband antenna with sharp band-notched characteristics for WiMax and WLAN. *Electronics Letters*, 2012, vol. 48, no. 22, p. 1380–1382. DOI: 10.1049/el.2012.2924

[7] XU, J. SHEN, D., ZHANG, X., WU, K. A compact disc ultrawide band (UWB) antenna with quintuple band rejections. *IEEE Antennas and Wireless Propagation Letters*, 2012, vol. 11, p. 1517-1520. DOI: 10.1109/LAWP.2012.2234075

[8] DAS, S., MITRA, D., CHAUDHURI, S. R. B. Design of UWB planar monopole antennas with etched spiral slot on the patch for multiple band-notched characteristics. *International Journal of Microwave Science and Technology*, 2015, Article ID 303215, 9 p. DOI: 10.1155/2015/303215

[9] OJAROUDI, N., GHADIMI, N., OJAROUDI, Y. Compact multi-resonance monopole antenna with dual band-stop property for UWB wireless communications. *Wireless Personal Communications,* 2015, vol. 81, no. 2, p. 563–579. DOI: 10.1007/s11277-014-2145-9

[10] CAI, Y. Z., YANG, H. C., CAI, L. Y. Wideband monopole antenna with three band-notched characteristics. *IEEE Antennas and Wireless Propagation Letters*, 2014, vol. 13, p. 607–610. DOI: 10.1109/LAWP.2014.2313178

[11] LI, L., ZHOU, Z. L., HONG, J. S. Compact UWB antenna with four band-notches for UWB applications. *Electronics Letters,* 2011, vol. 47, no. 22, p. 1211–1212. DOI: 10.1049/el.2011.2334

[12] SARKAR, D., SRIVASTAVA, K. V., K. SAURAV, K. A compact microstrip-fed triple band-notched UWB monopole antenna. *IEEE Antennas and Wireless Propagation Letters*, 2014, vol. 13, p. 396–399. DOI: 10.1109/LAWP.2014.2306812

[13] FEI, P., JIAO, Y.-C., ZHU, Y., ZHANG, F.-S. Compact CPW-fed monopole antenna and miniaturized ACS-fed half monopole antenna for UWB applications. *Microwave and Optical Technology Letters*, 2012, vol. 54, p. 1605–1609. DOI: 10.1002/mop.26909

[14] LIU, Y.-F., WANG, P., QIN, H. A compact triband ACS-fed monopole antenna employing inverted-L branches for WLAN/WiMAX applications. *Progress In Electromagnetics Research C*, 2014, vol. 47, p. 131–138. DOI: 10.2528/PIERC14012002

[15] LI, X., SHI, X. W., HU, W., FEI, P., YU, J. F. Compact triband ACS-fed monopole antenna employing open-ended slots for wireless communication. *IEEE Antennas and Wireless Propagation Letters*, 2013, vol. 12, p. 104–107. DOI: 10.1109/LAWP.2013.2252414

[16] LI, Y., LI, W., YE, Q. Miniaturization of asymmetric coplanar strip-fed staircase UWB antenna with reconfigurable notch band. *Microwave and Optical Technology Letters*, 2012, vol. 55, no. 7, p. 1467–1470. DOI: 10.1002/mop.27634

[17] DEEPU, V., RAJ, R. K., JOSEPH, M., SUMA, M. N., MOHANAN, P. Compact asymmetric coplanar strip fed monopole antenna for multiband applications. IEEE Transactions on Antennas and Propagation, 2007, vol. 55, no. 8, p. 2351–2357. DOI: 10.1109/TAP.2007.901847

[18] ASHKARALI, P., SREENATH, S., SUJITH, R., et al. A compact asymmetric coplanar strip fed dual-band antenna for DCS/WLAN applications. *Microwave and Optical Technology Letters*, 2012, vol. 54, p. 1087–1089. DOI: 10.1002/mop.26731

[19] SOLTANI, S., AZARMANESH, M. N., LOTFI, P. Design of small ACS fed band-notch UWB monopole antenna using particle swarm optimization, *Microwave and Optical Technology Letters,* 2010, vol. 52, p. 1510–1513. DOI: 10.1002/mop.25269

[20] LI, Y., LI, W., YU, W. A switchable UWB slot antenna using SIS-HSIR and SIS-SIR for multi-mode wireless communications applications. *Applied Computational Electromagnetics Society Journal*, 2012, vol. 27, no. 4, p. 340–351.

[21] TAWK Y., CHRISTODOULOU, C. G. A new reconfigurable antenna design for cognitive radio. *IEEE Antennas and Wireless Propagation Letters*, 2009, vol. 8, p. 1378–1381. DOI: 10.1109/LAWP.2009.2039461

[22] LI, Y., LI, W., YE, Q. A reconfigurable wide slot antenna integrated with sirs for UWB/multiband communication applications. *Microwave and Optical Technology Letters*, 2012, vol. 55, p. 52–55. DOI: 10.1002/mop.27253

[23] *Al-Husseini, M., Ramadan, A., El-Hajj, A.,* et al. Design based on complementary split-ring resonators of an antenna with controllable band notches for UWB cognitive radio applications," In *Proceedings of the IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (APSURSI '11).* Spokane (WA, USA), 2011, p. 1120 to 1122. DOI: 10.1109/APS.2011.5996479

[24] LI, Y., LI, W., YE, Q. A reconfigurable triple-notch-band antenna integrated with defected microstrip structure band-stop filter for ultra-wideband cognitive radio applications. *International Journal of Antennas and Propagation*, 2013, Article ID 472645, 13 p. DOI: 10.1155/2013/472645

[25] LI, Y., LI, W., MITTRA, R. A compact CPW-fed circular slot antenna with reconfigurable dual band-notch characteristics for UWB communication applications. *Microwave and Optical Technology Letters*, 2014, vol. 56, no. 2, p. 465–468. DOI: 10.1002/mop.28087

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