A Novel UWB Monopole Antenna with Controllable Band-Notch Characteristics

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Abstract **─** A novel microstrip monopole antenna for Ultra Wide Band applications with switchable band-notch function is presented. For this purpose, elliptical radiator and a half circular shape ground plane are modified. Using these modifications, including a rectangular and an arc-shaped slots on ground plane and a complex form of slot, etched on the patch, new resonances are excited and hence bandwidth is enhanced. In addition, by adding one rectangular step to patch, wide fractional bandwidth of more than 124% (2.7-11.61 GHz), defined by 10 dB return loss is achieved, in following part effects of the rectangular step is investigated. The rejection of 3.01-3.9 GHz, WiMAX and 5.07-6 GHz, WLAN bands is achieved using small connections as switches across the circular slot and rectangular arm on the radiation patch in specific positions. The total size of antenna is only 21×26 mm^2. Parametric simulation of the proposed modifications and measurement results of the manufactured antenna are presented and discussed.

Index Terms **─** Frequency band-notched, microstrip-fed monopole antenna, switches, Ultra Wide Band (UWB).

I. INTRODUCTION

Due to rapid growth of Ultra Wide Band communication systems and their inherent properties such as low-spectral-density radiated power and positional for accommodating higher data rate [1], there is essential call for efficient communication devices to work in such environments. Special frequency band, 3.1 to 10.6 GHz, has allocated by FCC for unlicensed use of ultra-wide band devices [2]. Printed monopole antennas are potential candidates in emerging UWB applications because of their low cost and compact size and stable radiation properties. To avoid the electromagnetic interference between UWB systems and narrowband communication systems, such as Worldwide Interoperability for Microwave Access (WiMAX) operating at 3.4-3.69 GHz and the wireless local area network (WLAN) operating at 5.15-5.825 GHz, band-notched characteristic should be considered in UWB antenna design. For this purpose, recently, modified UWB monopole antennas with frequency band-notched function have been attempted. To get Reconfigurable capability, various electronic switches such as p-i-n diodes [3], radio frequency micro-electromechanical systems (RFMEMS) [4], and varactor [5] can be used. Extensive discussions of reconfigurable antenna, switches and their advantages were investigated in [6]. Also different shapes of the slots are used to obtain desired rejected bands [7-9]. In [10], using SRRs elements leads to triple band-notched characteristics. Parasitic strips with dual band notches in [11], band stop filter in [12], fractal structure [13] and DGS structure [14] are other methods used for band-notch characteristics.

In this letter, a new microstrip-fed monopole antenna with modified radiation patch and ground plane is suggested to provide UWB characteristics and band-notch function. Etching a rectangular and an arc shaped slot on the ground plane, leads to improvement of bandwidth. Additionally, a circular slot with three arms is employed on radiating patch to get much wider impedance bandwidth. Small connections as switches across the circular slot and one of arms on the patch, lead to desired reconfigurable frequency band-notches covering 3.01-3.9 GHz WiMAX and 5.07-6 GHz WLAN. Dimensions of designed antennas are small, also its structure has less complexity and better functionality. Additionally novelty in comparison to previously presented antennas is another specification of this design.

II. ANTENNA CONFIGURATION AND DESIGN

The configuration of proposed monopole antenna is illustrated in Fig. 1, which is fabricated on a FR4 substrate with the size of 21 (x-axis) × 26 (y-axis) × 1 mm^3, relative dielectric constant of 4.4, and loss tangent of 0.018. The basic antenna structure is made up of a half circular shape ground plane, feed line and elliptical radiating patch. On the front surface of substrate, the radiuses of elliptical patch are 10 mm and 8 mm

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respectively. On the other side of the substrate, ground plane has radius of R. The width of the microstrip feed line is fixed at $W_f = 2$ mm to obtain 50 Ω characteristic impedance. The ground plane with a rectangular and an arc-shaped slot has substantial efficacy on controlling frequency response. In this case, the main parameter of these slots is H_g which will be investigated in the following part. A circular slot with three arms is employed on the elliptical radiation patch to enhance the impedance bandwidth and provide notch function. One of these arms is placed on the feed line and by optimizing its length (Y_f), surface currents are dispersed in new paths, so notch function focuses on desired frequency bands. Furthermore, the rectangular step is added on the patch to achieve smooth transition between frequency bands and avoid unwanted notched bands as considered by parametric study in Fig. 2. The location of rectangular step, K_n, is critical parameter to control UWB bandwidth. Also α connects feed line to radiation patch with angle of 45 degrees. Optimal dimensions of desired antenna are as shown in Table 1.

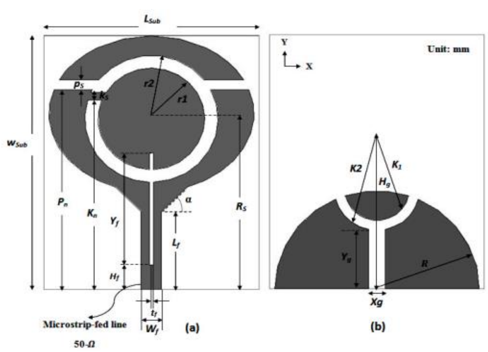


Fig. 1. Geometry of the proposed microstrip monopole antenna: (a) front view (including a microstrip-fed slotted patch) and (b) bottom view (including ground plane with slots).

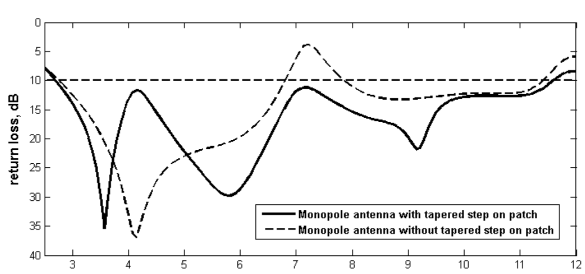


Fig. 2. Simulated return loss characteristics of the proposed monopole antenna with and without rectangular step.

Table 1: Parameters of antenna (Unit: mm)

$L_{Sub} = 21$		$W_{Sub} = 26$
Patch		Ground Plane
$r_1 = 5.2$	$R_S = 17.5$	$Y_g = 6.08$
$r_2 = 6.5$	$Y_f = 11.5$	$X_g = 1.6$
$P_n = 20.5$	$L_f = 8$	$H_g = 10.2$
$P_s = 1$	$H_f = 2.5$	$R = 10$
$K_s = 0.8$	$t_f = 0.4$	$K_2 = 4.2$
$K_n = 19.4$		$K_1 = 3.2$

III. RESULTS AND DISCUSSION

A. Full band UWB monopole antenna

Ansoft simulation software high frequency structure simulator (HFSS) [15] is used for design and parametric analysis of antenna.

The optimized parameters are defined by changing selected parameter while fixing others. Figure 3 illustrates the structure of the various antennas used for simulation studies. Return loss characteristics for ordinary modified monopole antenna [Fig. 3 (a)], defected ground plane [Fig. 3 (b)], and the proposed antenna with slotted elliptical patch [Fig. 3 (c)], respectively are compared in Fig. 4. As shown in Fig. 4, slotted ground plane has an important effect on exciting new resonances and achieving different frequency responses. In this case, the new coupling paths between the modified patch and slotted ground plane can be obtained. Therefore the number of resonances, matching and bandwidth of antenna can be controlled. In this case, the covered bandwidth is from 2 to 8.35 GHz. To work in UWB frequency band, the simple elliptical patch is changed to slotted patch and in following, a tapered step is added to the patch. By this modification, it is found that good impedance bandwidth and matching is achieved at upper frequencies. Essential parameters for ultra wide band characteristics of proposed antenna are H_g, R, r_1, r_2, K_n and α. By carefully adjusting these parameters, ultra wide band operation is achieved. K_n is a key parameter in controlling the resonances of antenna. As shown in Fig. 5 (a), while K_n swaps form 16.4 mm to 19.4 mm, additional resonance will be added at 9.5 GHz but first and second resonances have almost fixed position. By selecting $K_n = 19.4$ mm, good matching in all frequency bands is realized. The other main parameter is H_g. Its effect on antenna performance is indicated in Fig. 5 (b).

By increasing Hg, the matching of high frequencies is considerably improved. In optimal value of Hg, frequency bands from 2.7 to 11.61 GHz are covered.

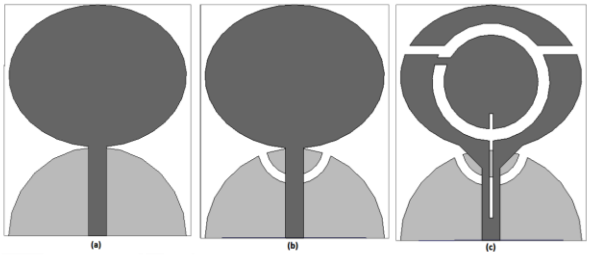


Fig. 3. (a) The ordinary elliptical patch and half circular shape ground plane. (b) The antenna with slotted ground plane. (c) Proposed antenna with defected ground plane and slotted patch.

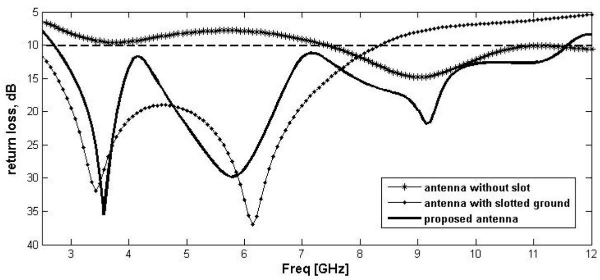


Fig. 4. Simulated return loss characteristics for antennas shown in Fig. 3.

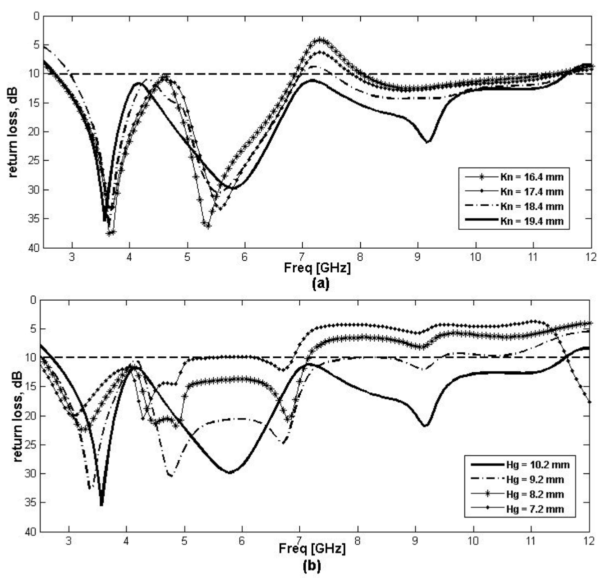


Fig. 5. Simulated return loss characteristics of the proposed antenna with different values of: (a) K_n (H_g is fixed at 10.2 mm), and (b) H_g (K_n is fixed at 19.4 mm).

B. UWB monopole antenna with switchable frequency band-notch characteristics

UWB monopole antenna with two band-notch modes is introduced here by using proposed structure depicted in Fig. 1 and adding two slots across the circular slot and rectangular arm on radiation patch with connections used as switches. Positions of connections, *D1* and *D2*, are adjusted appropriately to create desirable frequency notched bands. For the proposed structure, two operating states are investigated. At first, *D1* is connected as a switch. By selecting *D1*= 8.3 mm, first rejected band of 3.01-3.9 GHz, WiMAX is obtained. In second configuration, when other connection as a switch at *D2* =2 mm is attached, band-notch of 5.07-6 GHz WLAN is clearly seen. In this case, as shown in Fig. 6 (a) and Fig. 6 (b) simulated return loss curves with various values of *D1* and *D2* are optimized to reach desired notched bands. The phenomenon of switching between UWB and band-notch performances is clarified here by simulated current distributions on the radiation patch of proposed antenna according to the switching conditions. As shown in Fig. 7 (a), at 4.5 GHz, main part of surface current flows on the transmission line and dispersed by the means of rectangular slit, while around the circular slot current is small. The simulated current distributions at frequencies 3.5 and 5.5 GHz are illustrated in Figs. 7 (b) and (c). It can be observed that the current distributions mainly concentrate around the specific parts of circular slot. Impedance nearby feed-point changed markedly making considerable reflection at the desired rejected frequencies in three optimal designs. UWB antenna and two single band-notch antennas were built and tested. The photographs of fabricated prototypes are presented in Fig. 8. Simulated and measured reflection coefficients of selected designs are considered in Fig. 9. From this figure, it is clear that in all of designs, the simulated and measured results are in acceptable agreement. In first design, as indicated in Fig. 9 (a), fabricated antenna shows UWB performance from 2.8 to 12 GHz. In Fig. 9 (b), the results of second proposed antenna design with a connection on rectangular arm is shown. It reveals that measured rejected band from 3 to 4.1 GHz is obtained. Finally, Fig. 9 (c) illustrates the third design with a connection across circular slot. In this case, the antenna has measured notched frequency band from 5 to 6.2 GHz. The discrepancy between the measured and simulated values may be due to the errors of the manufactured antenna and the effects of the SMA port which is not considered in simulated results. Figure 10 indicates that gain of dual and single band-notched antenna is between 0 dB to 5dB and has comprehensive level during frequency bands except for two notched bands. Figure 11 shows the measured and simulated patterns including the co and cross polarization in the H-plane (x-z plane) and E-plane (y-z plane). It is clear that radiation patterns in H-plane are nearly omni-directional in the four frequencies and by such results antenna behavior is alike to the usual printed monopole antennas.

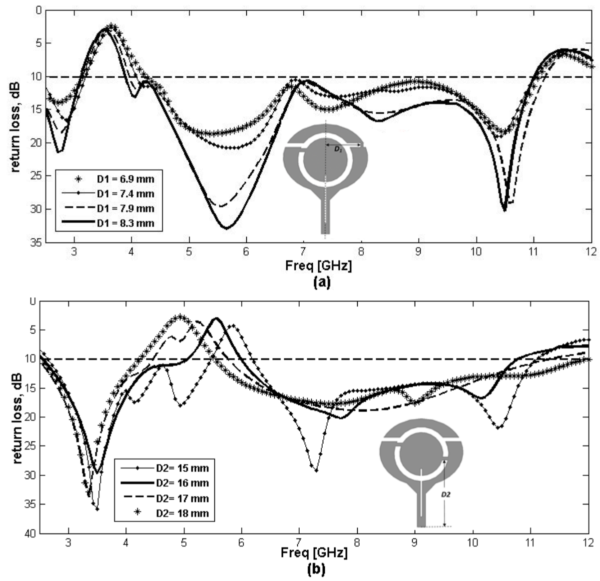


Fig. 6. Simulated return loss characteristics of the proposed antenna with different values of: (a) D1 and (b) D2.

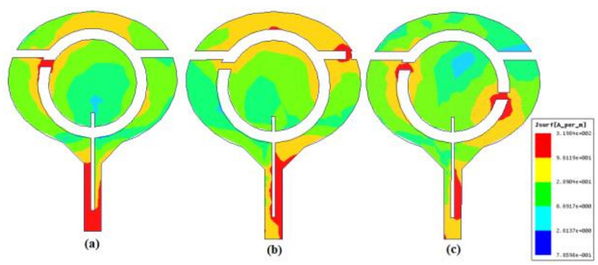


Fig. 7. Simulated surface current distributions on radiation patch: (a) UWB monopole antenna at 4.5 GHz, (b) single band-notch antenna with connected D1 at 3.5 GHz, and (c) single band-notch antenna with connected D2 at 5.5 GHz.

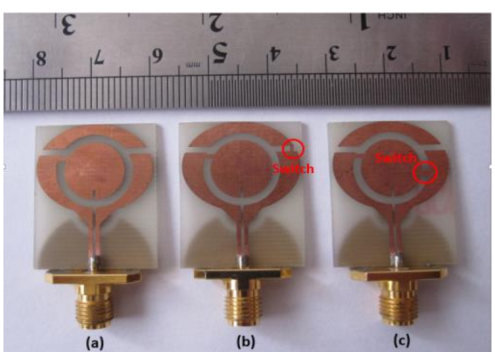


Fig. 8. Prototype antennas: (a) UWB monopole antenna, (b) single band-notch monopole antenna (WiMAX), and (c) single band-notch monopole antenna (WLAN).

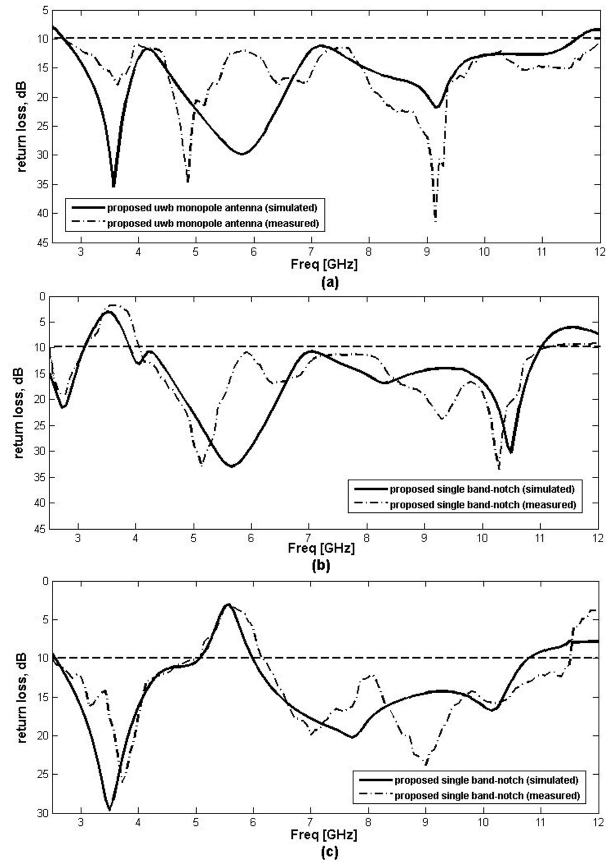


Fig. 9. Measured and simulated return loss results of: (a) UWB monopole antenna, (b) single band-notch (WiMAX), and (c) single band-notch (WLAN).

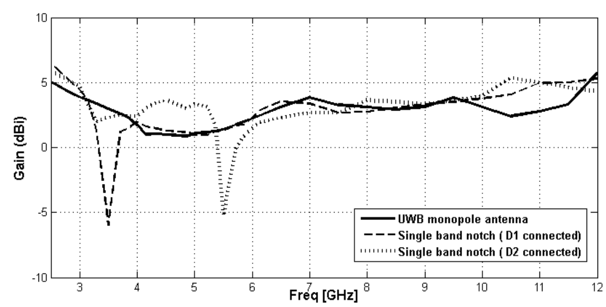
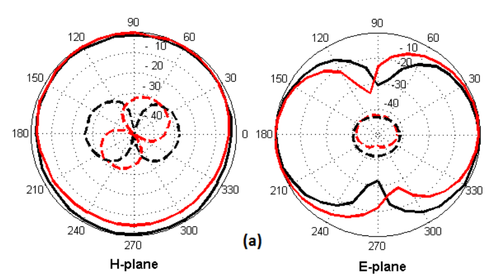


Fig. 10. Measured antenna gain of the proposed antennas.



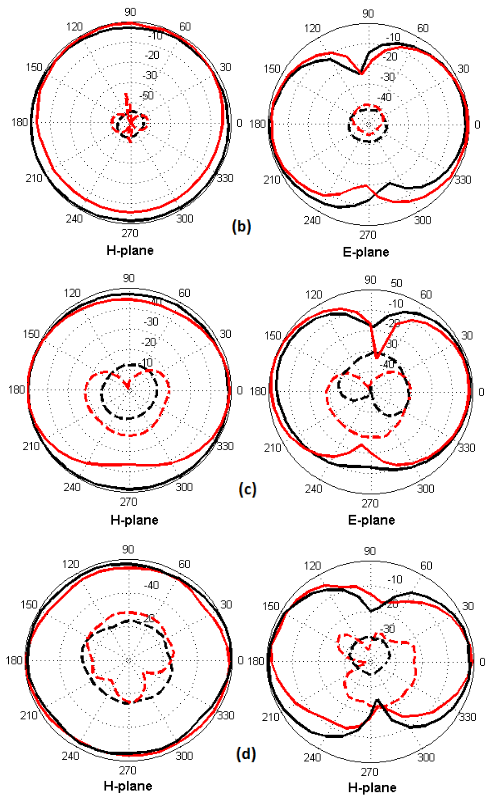


Fig. 11. Simulated and measured H- and E-planes radiation patterns of proposed antenna: (a) 3 GHz, (b) 4 GHz, (c) 5 GHz, and (d) 10 GHz.

IV. CONCLUSION

This letter has presented a novel printed UWB monopole antenna with switchable band-notch characteristics supporting various wireless applications. It has been shown that using circular slots with three arms etched on patch can enhance bandwidth from 2.7 to 11.61 GHz. In addition, using defected ground plane by inserting two rectangular and arc-shaped slots can also improve input reflection coefficient. By embedding a pair of connections as switches in proper situations, across the slotted patch, two single stop-bands will be created, which exempt from interfaces with existing WiMAX and WLAN bands.

REFERENCES

[1] G. P. Gao, M. Li, S. F. Niu, X. J. Li, B. N. Li, and J. S. Zhang, "Study of a novel wideband circular slot antenna having frequency band-notched function," *Progress In Electromagnetic Research, PIER*, vol. 96, pp. 141-154, 2009.

[2] G. R. Aiello and G. D. Roberson, "Ultra-wideband wireless systems," *IEEE Microwave*, pp. 36-38, June 2003.

[3] N. Tasouji, J. Nourinia, Ch. Ghobadi, and F. Tofigh, "A novel printed UWB slot antenna with reconfigurable band-notch characteristics," *922-5-1536-1225 © 2013 IEEE*, 2013.

[4] S. Nikolaou, N. D. Kingsley, G. E. Ponchak, J. Papapolymerou, and M. M. Tentzeris, "UWB elliptical monopoles with a reconfigurable band notch using MEMS switches actuated without bias lines," *IEEE Trans. Antennas Propag*., vol. 57, no. 8, pp. 2242-2251, Aug. 2009.

[5] B. Trad, J. M. Floch, H. Rmili, M. Drissiand, and H. Zangar, "Design of a planar reconfigurable band-rejected UWB antenna," *2012 Loughborough Antennas & Propagation Conference 978-1-4673-2220-1/12/$31.00 © 2012 IEEE*, 2012.

[6] S. Yang, Ch. Zhang, H. K. Pan, A. E. Fathy, and V. K. Nair, "Frequency-reconfigurable antennas for multiradio wireless platforms," *IEEE Microwave Magazine*, pp. 66-83, Feb. 2009.

[7] M. Ojaroudi, N. Ojaroudi, and Y. Ebazadeh, "Dual band-notch small square monopole antenna with enhanced bandwidth characteristics for UWB applications," *420-6-1054-4887 © 2012 ACES*, 2012.

[8] G. Zhang, J.-S. Hong, B.-Z. Wang, and G. Song, "Switched band-notched UWB/WLAN monopole antenna," *256-260-1054-4887 © 2012 ACES*, 2012.

[9] D. Jiang, Y. Xu, R. Xu, and W. Lin, "A compact ultra-wideband antenna with improved triple band-notched characteristics," *130-6-1054-4887 © 2013 ACES*, 2013.

[10] J. Zhang, H. Yang, and H. Liang, "Band-notched split-ring resonators loaded monopole antenna for ultrawideband applications," *137-142-1054-4887 © 2013 ACES*, 2013.

[11] X.-L. Ma, W. Shao, and G.-Q. He, "A novel dual narrow band-notched CPW-fed UWB slot antenna with parasitic strips," *581-6-1054-4887 © 2012 ACES*, 2012.

[12] J. Zhang, X. L. Sun, S. W. Cheung, and T. I. Yuk, "Simple dual-band notched design for CPW-coupled-fed elliptical UWB monopole antenna," *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE*, 2012.

[13] W. J. Lui, C. H. Cheng, Y. Cheng, and H. Zhu, "Frequency notched ultra-wideband microstrip slot antenna with fractal tuning stub," *Electronic Lett*., vol. 41, no. 6, pp. 294-296, Mar. 2005.

[14] X. Wang, G. Fu, J. Zhao, and J. Dong, "A novel UWB patch antenna with dual notched band by etching DGS on the ground plane," *Microwave and Millimeter Wave Technology (ICMMT), 2012 International Conference*, 2012.

[15] Ansoft High Frequency Structure Simulation (HFSS), ver. 10, Ansoft Corporation, 2005.

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