Progress In Electromagnetics Research C, Vol. 35, 161–175, 2013

AN OPTIMAL DESIGN OF CPW-FED UWB APERTURE ANTENNAS WITH WIMAX/WLAN NOTCHED BAND CHARACTERISTICS

Tapan Mandal[1, *] and Santanu Das[2]

[1]Department of Information Technology, Government College of Engineering and Textile Technology, Serampore, Hooghly 712201, India

[2]Department of Electronics & Tele-Comm. Engineering, Bengal Engineering and Science University, Shibpur, Howrah PIN-711103, India

Abstract—In this paper, a printed slot antenna fed by a co-planar waveguide for ultra wide bandwidth (UWB) with dual notch bands has been presented and discussed. The band notches are realized by etching one C-slot resonator inside a plaque shape exciting stub as well as symmetrically adding a pair of open-circuit stubs at the edge of the slot resulting in dual stop band filtering properties for WiMAX, WLAN application. Surface current distributions are used to analyze the effects of the slot and open circuit stub. The proposed antenna is fabricated and experimental results show that it has an impedance bandwidth of 2.6–14.34 GHz for VSWR ≤ 2, except dual frequency stop-bands of 3.3–3.7, 5.04–6.0 GHz. From the simulation results, it is observed that the radiation patterns are omnidirectional in the H-plane and dipole like nature in the E-plane. The gain varies from 3.7 dB to 5.7 dB over the whole UWB region excluding at notch bands.

1. INTRODUCTION

Ultra wideband (UWB) communication is a promising wireless communication technology since the allocation of 3.1–10.6 GHz bandwidth (BW) by the US-Federal Communication Commission in 2002 (FCC) [1]. This type of UWB antenna has been realized by using either microstrip line or coplanar waveguide (CPW) feeding structure. The advantages of printed UWB antennas are low profile,

Received 6 November 2012, Accepted 14 December 2012, Scheduled 24 December 2012
* Corresponding author: Tapan Manda (tapanmandal20@rediffmail.com).

light weight, wide BW, low cost and good omnidirectional radiation pattern [2, 3]. In particular, CPW fed antennas have many salient features like less radiation loss, less dispersion, easy integration with monolithic microwave integrated circuits (MMIC). Therefore, CPW fed slot antennas are currently under consideration for use of UWB systems for the numerous applications such as remote sensing, radar, imaging, localization and medical applications.

In these systems, printed slot (aperture) antennas with different structures and performances have been developed [3–6]. From the literature survey, it has been observed that the slot antenna [7–12] is one of the promising candidates for UWB applications. CPW fed square slot antennas have been presented for wide band characteristics [13, 14]. In general, the wideband CPW-fed slot antenna can be developed by tuning their impedance. One of the impedance tuning techniques is to vary the slot dimensions. This tuning technique has been carried out with various slot geometries like bowtie [15], wide rectangular [16, 17], circular [5, 7] and hexagonal slots [18]. The CPW feed line with various possible patch shapes, such as T, cross, fork like, volcano and square is used to obtain wider bandwidth [19–25]. In addition to this, a notched ground plane can be used to act as an impedance matching network to control the impedance bandwidth of the proposed antenna. The notch creates a capacitive load that neutralizes the inductive nature of the stub antenna to produce nearly-pure resistive input impedance.

On the other hand, the frequency range for UWB systems will cause electromagnetic interference with existing narrowband wireless communication systems, for instance, the wireless local area network (WLAN: IEEE 802.11a) and wireless microwave access (WiMAX: IEEE 802.16) operating at 5.15–5.825 GHz and 3.3–3.7 GHz respectively. Two band stop filters connected to a UWB antenna can be used to reject these bands. However, this increases the sizes and complexity of the system. Thus to avoid the potential interference UWB antennas with band-notched characteristics are desirable. Generally, the band-notched characteristics are realized by introduction of an additional resonant structure to the antenna body. The introduced resonant structure degrades the impedance matching of the antenna and thus less energy can be transmitted to/received from free space. Furthermore, the presence of the resonant structure changes the current distributions on the antenna and may cause cancellation of the radiation in far-field zone. The normally used techniques to realize a band-notched performance include etching slots or slits on the radiator [4], placing parasitic strips in close proximity to the antenna [3, 26]. To design slot antennas with band-notched function, one simple and effective way is to incorporate slots (known as half-wave resonant structures) in the antenna's tuning stub, such as a U-shaped [27], V-shaped [3], C-shaped slots [27, 28], etc. In this paper a dual notch band UWB antenna has been proposed by using the above technique.

2. ANTENNA GEOMETRY AND DESIGN THEORY

2.1. Prototype Antenna Geometry

Figure 1 shows configuration of a prototype antenna which has been printed on a substrate with dielectric constant (ε_r) = 4.4, height (h) = 1.59 mm and loss tangent ($\tan\delta$) = 0.002. It consists of a rectangular aperture, ground plane, CPW feed and exciting plaque stub. The antenna and feeding structure are implemented on the same plane. Therefore only one layer of substrate with single-sided metallization is used. A 50 Ω CPW transmission line is designed with a strip width of 3.8 mm.

The design of the rectangular aperture is determined by minimizing the aperture area while satisfying the input impedance matched for the entire UWB especially for the lower frequencies. In this paper, aperture area of 23 mm × 14 mm is achieved, that is, the dimension is less than a half wavelength for the lowest frequency (3.1 GHz). The dimensions of the prototype antenna are LL-39, WW-35, Ls-23, Ws-15, L-12, W-6, T-3.5. (All dimensions are in mm.)

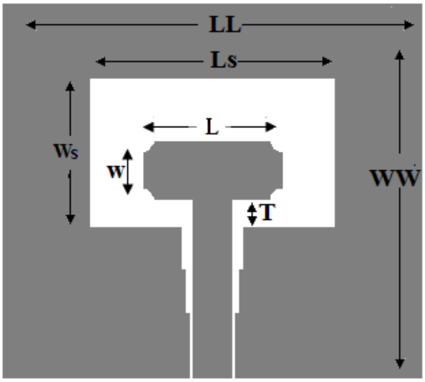


Figure 1. Geometry of the prototype antenna.

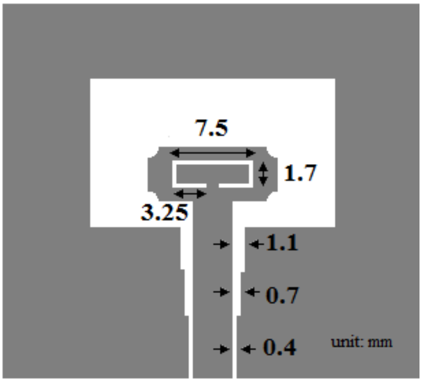


Figure 2. Geometry of prototype antenna with C-slot.

2.2. Band-notched Antenna Design

In order to obtain a notch band in the frequency range of 3.15–5.88 GHz a thin C-slot is etched out from the plaque shape stub. Usually, the length of the slot is made approximately equal to half the guided wavelength at the notch frequency of the band. This is given by

$$L_{total\_WLAN} = \frac{\lambda_g}{2} = \frac{c}{2f_{notch\_WLAN}\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

where L_{total_WLAN} is the length of the slot. For the notch frequency $f_{notch\_WLAN} = 5.47\,\text{GHz}$ the length of the slot is calculated as 17.4 mm. The optimum slot width is found to be 0.3 mm by way of simulation. The antenna layout is shown in Fig. 2 with dimensions.

In addition to this WiMAX stop band is realized by positioning symmetrically a pair of narrow open circuited L-shape stub on both sides of the aperture area (Fig. 3). Each stub has length of quarter a wavelength at desired notch frequency. The center-rejected frequencies for the stop bands may be empirically approximated by

$$L_{total\_WiMAX} = \frac{\lambda_g}{2} = \frac{c}{4f_{notch\_WiMAX}\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{2}$$

where L_{total_WiMAX} is the length of the stub. For center notch $f_{notch\_WiMAX} = 3.5\,\text{GHz}$, the length of the stub can be determined as 13.06 mm. The optimum strip width is found to be 1 mm. From Equations (1) and (2) the total length of the C-shape slot and L-shape stubs may be obtained at the beginning of the design. Finally the lengths are adjusted by using simulator for obtaining the desired results.

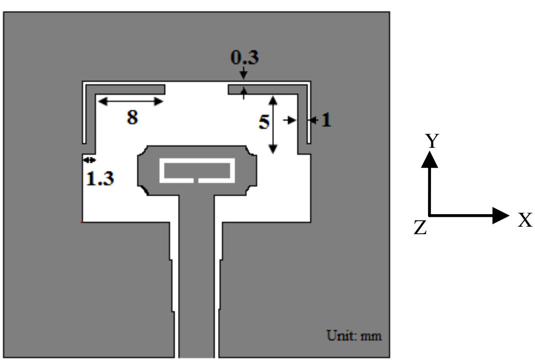


Figure 3. Geometry of proposed antenna with C-slot and L-shape stubs.

3. PARAMETRIC STUDY AND DISCUSSION

The method of moment (MoM) based simulation software IE3D$^{\mathrm{TM}}$ is employed in this paper for design and optimization process. The exciting stub is the key factor in the optimization process. Its three parameters L, W, and T are selected to perform the parametric study. Fig. 4 shows that the stub length L may affect the impedance in both low and middle bands. Fig. 5 indicates that the stub width W mainly influences the impedance at lower frequencies (3–4 GHz). Compared to the stub width W and length L, the extrusion depth T is relatively sensitive to the input impedance over the entire frequency span of UWB as given in Fig. 6. The notched ground is used for the impedance matching resulting in wider BW (Fig. 7). The optimum values of $L = 12\,\mathrm{mm}$, $W = 5\,\mathrm{mm}$, and $T = 3.5\,\mathrm{mm}$.

The C-slot configuration on plaque shape stub has been used independently to obtain WLAN stop band as shown in Fig. 2. The

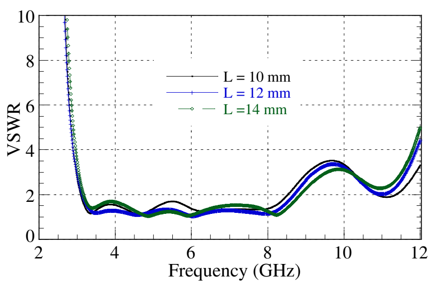


Figure 4. Effects of the stub length L on the VSWR.

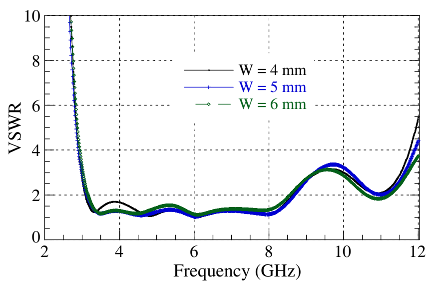


Figure 5. Effects of the stub width W on the VSWR.

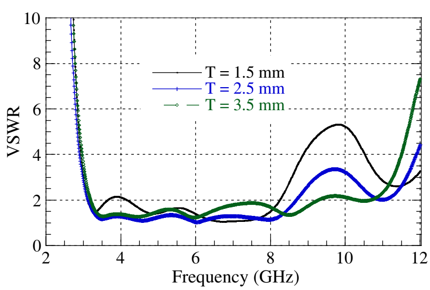


Figure 6. Effects of the extrusion depth T on the VSWR.

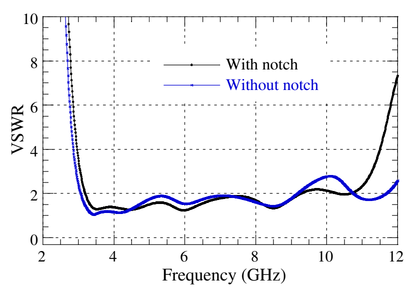


Figure 7. Simulated VSWR with and without notch in ground plane.

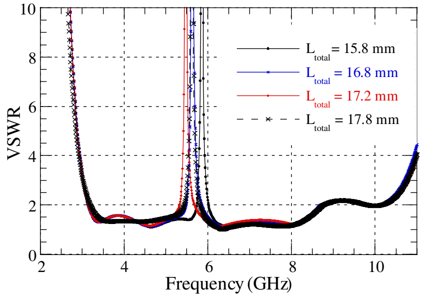


Figure 8. VSWR for various lengths of L_{total} of C-slot.

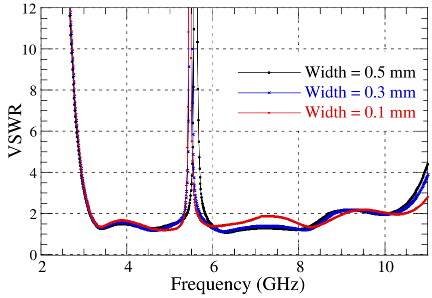


Figure 9. VSWR for various width of C-slot.

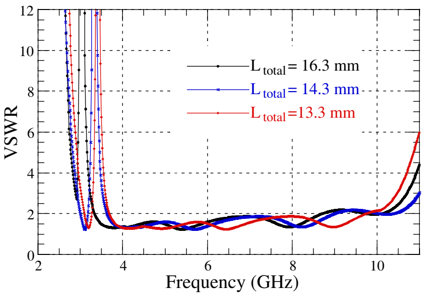


Figure 10. VSWR for various lengths of L_{total} of L-strip.

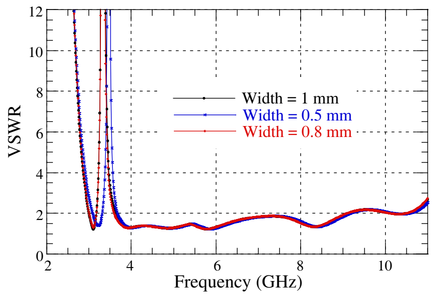


Figure 11. VSWR for various width of L-strip.

simulated VSWR characteristics for these configurations of slot with varying length and width are shown in Figs. 8 and 9 respectively. The lengths are important factors to design the band stop structure. As the total slot length increases, the stop band region moves toward the lower frequency with higher VSWR peak. Slot width has less impact over the length of the slot. Due to the slot inside the patch, maximum current flows back to the feeding part and degenerates radiation around 5.13 GHz to 6.04 GHz. All the optimized parameters of the slot configuration are provided in Fig. 2.

To realize the WiMAX stop band in UWB region a pair of L-shape strip have been used in the aperture area. The VSWR versus frequency plots for various length and width are illustrated in Figs. 10 and 11 respectively. From the simulation result it has been observed that the length has sufficient control for shifting the notch frequency.

The simulated return loss characteristics of all the configurations (Fig. 1, Fig. 2 and Fig. 3) are presented in Fig. 12. Prototype

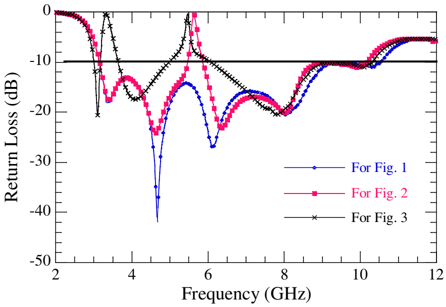


Figure 12. Return loss characteristics.

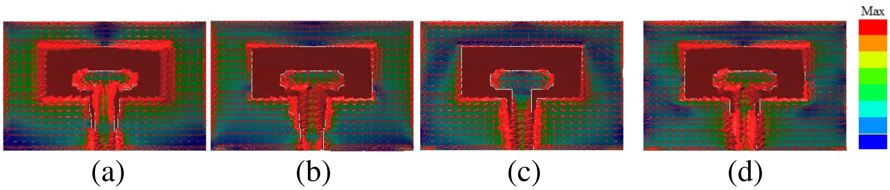
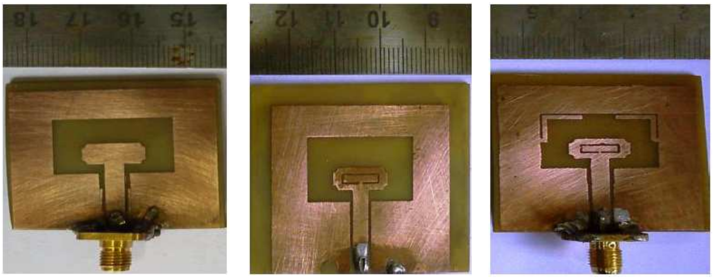


Figure 13. Surface current distribution at (a) 3.59 GHz, (b) 4.59 GHz, (c) 6.2 GHz, (d) 8.1 GHz.

results indicate presence of four resonant frequencies in the desired band. From the surface current distribution (Fig. 13), it has been observed that the rectangular aperture produces lower resonant frequency (3.59 GHz). Plaque shape exciting stub yields second resonant frequency (4.59 GHz) while notches in the ground plane near the feed line are responsible for third (6.2 GHz) and fourth (8.1 GHz) ones.

4. SIMULATION AND MEASURED RESULTS

The prototype antenna is fabricated (Fig. 14(a)) and tested by Agilent make vector network analyzer (N5230A). The simulated and measured VSWR plots are given in Fig. 15. The simulation and tested responses exhibit 7.73 GHz (3.1 $\sim$ 10.80 GHz) and 7.88 GHz (3.14 $\sim$ 10.02 GHz) impedance BW respectively. The simulated result of a prototype antenna without notched characteristics is also shown for comparison. It is clear that the measured result shows a reasonably good agreement with simulated one. Thus it may be considered as a good UWB antenna. The dimensional mismatch between simulated and physical structures and wide flange of the SMA connector used for measurement



(a) (b) (c)

Figure 14. Fabricated antenna structure of (a) prototype, (b) prototype with C-slot, (c) proposed.

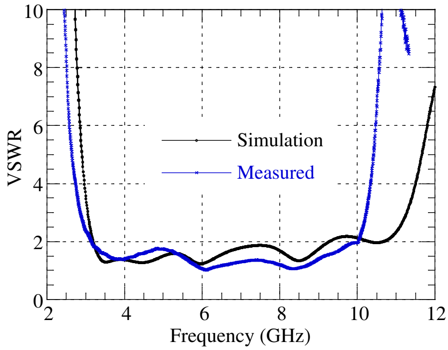


Figure 15. Measured and simulated VSWR of the proposed prototype antenna.

may cause the difference between the simulated and measured results in higher frequency band.

The simulated and measured VSWR performances of Fig. 14(b) are plotted in Fig. 16. These responses yield 0.72 GHz (5.15 $\sim$ 5.87 GHz) and 0.91 GHz (5.13 $\sim$ 6.04 GHz) 2 : 1 VSWR impedance stop band in UWB region, respectively which are very close to each other.

The simulated and measured VSWR responses of Fig. 14(c) are shown in Fig. 17. The simulated VSWR characteristic reveals stop bands of 0.45 GHz (3.18–3.63 GHz), 0.98 GHz (5.00–5.98 GHz) for VSWR $\leq$ 2 within the frequency span from 3 GHz to 14.34 GHz, while the measured characteristic shows 0.4 GHz (3.3–3.70 GHz) and 0.96 GHz (5.04–6.0 GHz) stop band which cover the entire WiMAX and WLAN band. The measured result agrees with simulated result which

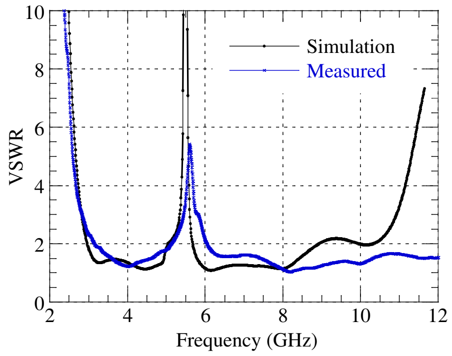


Figure 16. VSWR plot of Fig. 14(b).

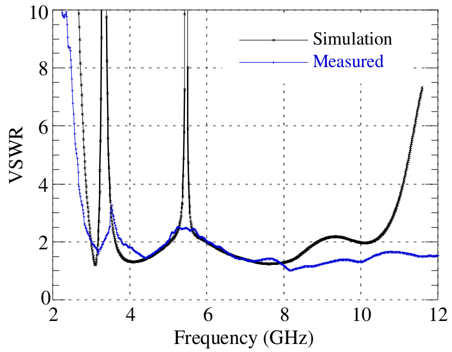


Figure 17. VSWR plot of Fig. 14(c).

has sharp frequency stop band of WiMAX and WLAN band when the C-slot is inserted on the plaque patch and two stubs (L-shape) are placed in the slot area. The discrepancy in VSWR between simulated and measured results should be mostly attributed to the loss tangent ($\tan\delta$) of the FR4 substrate and tolerance in manufacturing.

5. RADIATION PATTERN

The E-plane and H-plane radiation patterns at 3.4, 6, and 8 GHz have been found by simulation as given in Fig. 18. It is found that the antenna exhibits nearly omnidirectional radiation pattern in the H-plane (xz-plane) and a dipole-like radiation pattern in the E-plane (yz-plane). The co-planner ground plane is the main reason for omnidirectional pattern in H-plane. The influences of slot and open stubs on the radiation patterns have also been investigated. It is noticed that by adding a slot in the exciting stub and strips in the aperture area does not significantly alter the radiation pattern of the antenna. The H-plane pattern is nearly omnidirectional at lower frequency, but changes occur at higher frequency. This is due to the tuning stub acting as a radiator itself and its effect becoming more prominent at high frequency. However the E-plane and H-plane patterns are more or less stable in entire UWB region. Thus it may be considered as a good antenna with WiMAX, WLAN notch band characteristics for UWB applications.

6. ANTENNA GAIN AND EFFICIENCY

In the notch band most of the power fed into the antenna is reflected back which leads to a decrease of the antenna efficiency and hence the antenna gain. The simulated gain and radiation efficiency of the proposed (Fig. 3) antenna are shown in Figs. 19 and 20 respectively along with prototype antennas (Fig. 1 and Fig. 2). This is a sharp decrease in gain and efficiency at notch bands. The proposed antenna provides more than 85% efficiency and the gain varies from 3–5.7 dB over the UWB frequency range except in notch bands. These characteristics can make sure the ability of the proposed antenna to reject unwanted bands effectively.

7. FIELD DISTRIBUTION AND ANALYSIS

Simulated surface current distributions of the proposed antenna at different frequencies are shown in Fig. 21.

At a pass band frequency of 4.5 GHz (outside the notch band) the distribution of surface current is uniform as is evident in Fig. 21(a). In Figs. 21(b) and (c) the current distribution is concentrated and oppositely directed on the interior and exterior side of the slot and strips at the notch frequencies. This causes the antenna to operate without significant transmission in the notch band. Therefore slot stops the surface current and as a result notch band is obtained. At the notch frequency the impedance is nearly infinite impedance (open circuit) at the antenna feeding point. This infinite impedance at the feeding point leads to the impedance mismatching near the notch frequency. Therefore slot and strips behaves as open-circuited series stub with infinite input impedance. So minimum amount of currents are coupling between stub and radiating ground plane. Consequently desired notch bands are created.

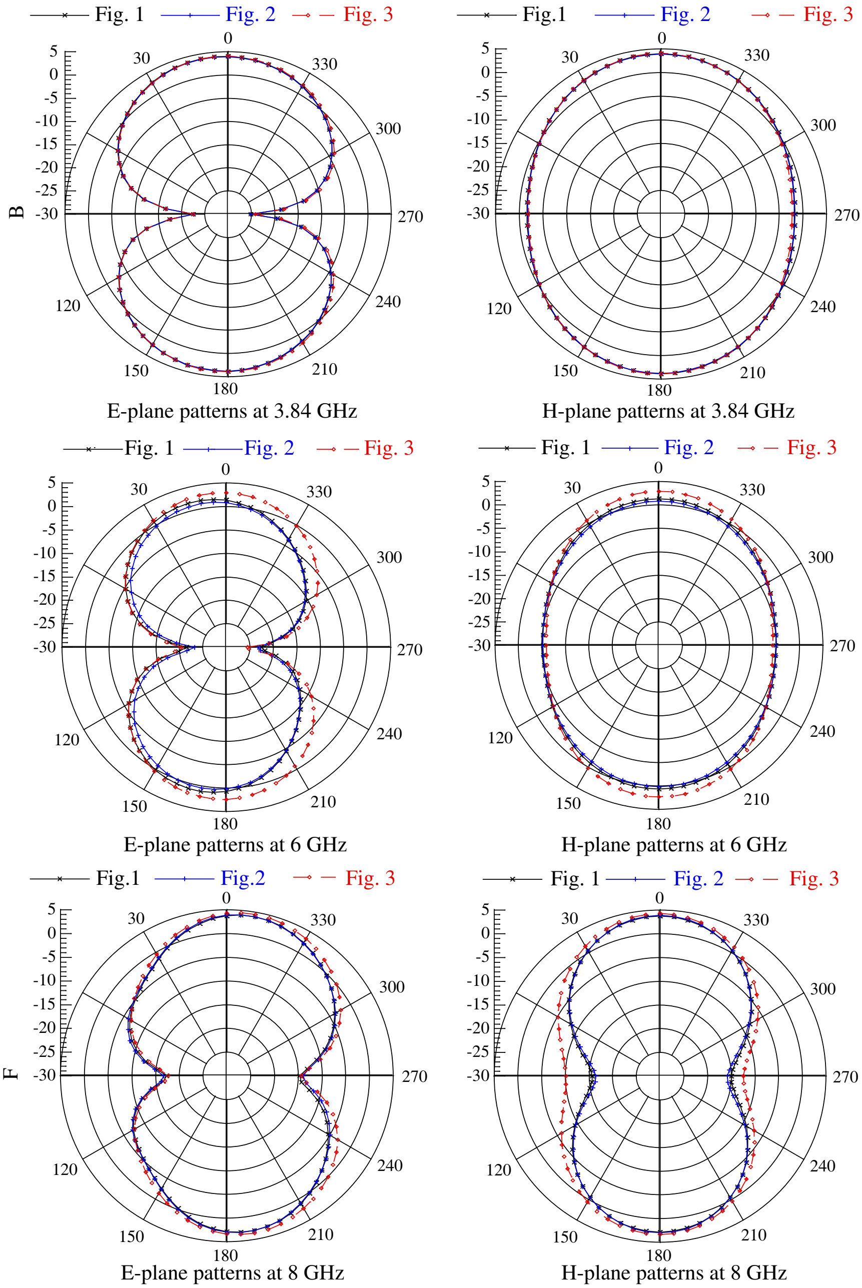


Figure 18. Radiation patterns of Figs. 1, 2 and 3.

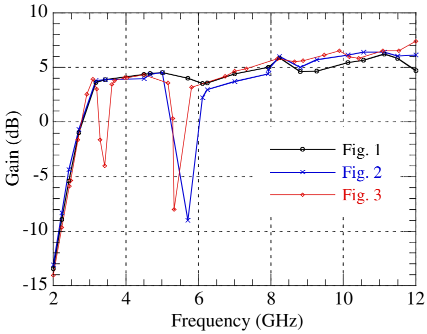


Figure 19. Frequency vs. gain plot.

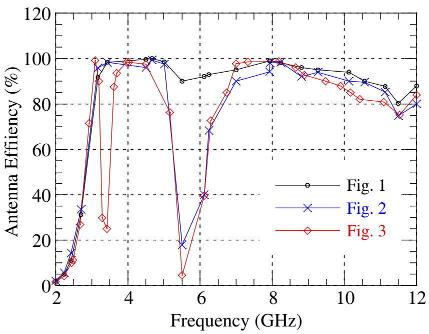


Figure 20. Frequency vs. antenna efficiency plot.

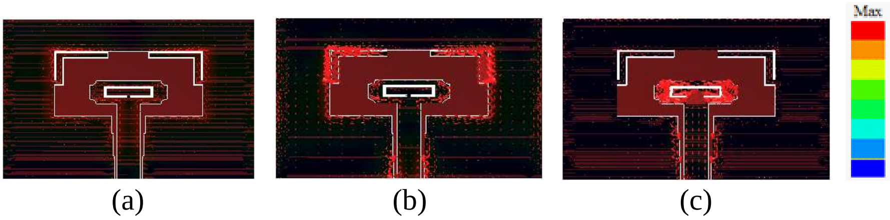


Figure 21. Surface current distributions on the radiating patch at (a) a pass band frequency of 4.5 GHz, (b) WiMAX notched band at 3.5 GHz, (c) WLAN notched band at 5.5 GHz.

8. CONCLUSION

A UWB CPW fed planar aperture antenna with dual notched bands has been proposed and discussed. Parametric studies of the antenna characteristics are presented. Dual stop bands are realised by etching one C-slot inside a plaque exciting stub as well as symmetrically adding a pair of open-circuit stubs at the edge of the slot. Two types of band-notched structures extended from the prototype design are provided and verified. The VSWR performance of this antenna has been studied both by simulation and experiment. E-plane and H-plane patterns are more or less stable over operating band. The dual stop bands of the antenna can significantly suppress potential EM interference in the UWB region. The proposed antenna peak gain varies from 3.7 dB to 5.7 dB over the entire operating band except in notch bands. Therefore the proposed antenna is expected to be a good candidate in various applications.

ACKNOWLEDGMENT

This work was supported by CSIR, New Delhi, India, under Grant Sanctioned No: 22(0512)/EMR-II dt. 31.05. 2010.

REFERENCES

1. "System FCC 02-48," Federal Communications Commission, 2002.
2. Li, X., H.-L. Zheng, T. Quan, and Q. Chen, "A printed discone ultra-wideband antenna with dual-band notched characteristics," *Progress In Electromagnetics Research C*, Vol. 27, 41–53, 2012.
3. Mehdipour, A., A. Parsa, A. R. Sebak, and C. W. Trueman, "Miniaturised coplanar waveguide-fed antenna and band-notched design for ultra-wideband applications," *IET Microwave Antennas Propagation*, Vol. 3, No. 6, 974–986, 2009.
4. Liao, X.-J., H.-C. Yang, N. Han, and Y. Li, "Aperture UWB antenna with triple band-notched characteristics," *Electron Letters*, Vol. 47, No. 2, 2011.
5. Elboushi, A., O. M. H. Ahmed, A. R. Sebak, and T. A. Denidni, "Study of elliptical slot UWB antennas with 5.0–5.6 GHz band-notched capability," *Progress In Electromagnetics Research C*, Vol. 16, 207–222, 2010.
6. Lui, W.-J., C.-H. Cheng, and H.-B. Zhu, "Improved frequency notched ultra-wide band slot antenna using square ring resonator," *IEEE Trans. on Antennas and Propagation*, Vol. 55, No. 9, 2445–2449, 2007.
7. Gao, G.-P., Z.-L. Mei, and B.-N. Li, "Novel circular slot UWB antenna with dual band notched characteristic," *Progress In Electromagnetics Research C*, Vol. 15, 49–63, 2010.
8. Behdad, N. and K. Sarabandi, "A multiresonant single-element wideband slot antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 3, 5–8, Jan. 2004.
9. Sze, J. Y. and K. L. Wong, "Bandwidth enhancement of a microstrip line- fed printed wide-slot antenna," *IEEE Trans. on Antennas and Propagation*, Vol. 49, 1020–1024, Jul. 2001.
10. Chair, R., A. A. Kishk, and K. F. Lee, "Ultra-wideband coplanar waveguide- fed rectangular slot antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 3, No. 1, 227–229, 2004.
11. Sorbello, G., M. Pavone, and L. Russello, "Numerical and experimental study of a rectangular slot antenna for UWB

communications," *Microwave Optical Technol. Lett.*, Vol. 46, No. 4, 315–319, Aug. 2005.

12. Cheng, Y. and K.-J. Hung, "Compact ultra-wide band rectangular aperture antenna and band-notched designs," *IEEE Trans. on Antennas and Propagation*, Vol. 54, No. 11, Nov. 2006.
13. Chiou, J. Y., J. Y. Sze, and K. L. Wong, "A broad-band CPW-fed strip-loaded square slot antenna," *IEEE Trans. on Antennas and Propagation*, Vol. 51, No. 4, 719–721, Apr. 2003.
14. Chen, H. D., "Broadband CPW-fed square slot antenna with a widened tuning stub," *IEEE Trans. on Antennas and Propagation*, Vol. 51, No. 8, 1982–1986, Aug. 2003.
15. Marantis, L. and P. Brennan, "A CPW-fed bow-tie slot antenna with tuning stub," *Proc. 2008 Loughborough Antennas & Propagation Conference*, 389–393, Mar. 2008.
16. Eldek, A., A. Z. Elsherbeni, and C. E. Smith, "Rectangular slot antenna with patch stub for ultra-wide band applications and phased array systems," *Progress In Electromagnetics Research*, Vol. 53, 227–237, 2005.
17. Chen, W. Q., G. F. Ding, et al., "Design and simulation of broad-band unidirectional CPW-fed rectangular slot antennas," *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, 632–635, 2007.
18. Kraisorn, S.-K., V. Vivek, and P. Akkaraekthalin, "A broadband CPW-fed equilateral hexagonal slot antenna," *IEEE ICSIT Proceedings*, 783–786, Sep. 2006.
19. Li, P. C., J. X. Liang, and X. D. Chen, "Study of printed elliptical/circular slot antennas for ultra wide band applications," *IEEE Trans. on Antennas and Propagation*, Vol. 54, No. 6, Jun. 2006.
20. Habib, M. A., A. Bostani, A. Djaiz, M. Nedil, M. C. E. Yagoub, and T. A. Denidni, "Ultra wideband CPW-fed aperture antenna with WLAN band rejection," *Progress In Electromagnetics Research*, Vol. 106, 17–31, 2010.
21. Qu, S. W., C. Ruan, and B. Z. Wang, "Bandwidth enhancement of wide slot antenna fed by CPW and microstrip line," *IEEE Antennas and Wireless Propagation Letters*, Vol. 5, 15–17, 2006.
22. Moeikham, P., C. Mahatthanajatuphat, and P. Akkaraekthalin, "A compact ultra wideband monopole antenna with 5.5 GHz notch band," *Progress In Electromagnetics Research C*, Vol. 26, 13–27, 2012.

23. Zhu, F., S.-C. S. Gao, A. T. S. Ho, C. H. See, R. A. Abd-Alhameed, J. Li, and J.-D. Xu, "Design and analysis of planar ultra-wide band with dual notched function," *Progress In Electromagnetics Research*, Vol. 127, 523–536, 2012.
24. William, J. and R. Nakkeeran, "An optimal design of compact CPW-fed slot antenna for broadband applications," *International Journal of Microwave and Optical Technology* Vol. 4, No. 5, 302–308, 2009.
25. Su, S. W., K. L. Wong, and F. S. Chang, "Compact printed ultra wide band slot antenna with a band notched operation," *Microwave Optical Technol. Lett.*, Vol. 45, No. 2, 128–130, 2005.
26. Islam, M. T., R. Azim, and A. T. Mobashsher, "Triple band-notched planar UWB antenna using parasitic strips," *Progress In Electromagnetics Research*, Vol. 129, 161–179, 2012.
27. Zhou, H.-J., B.-H. Sun, Q.-Z. Liu, and J.-Y. Deng, "Implementation and investigation of U-shaped aperture UWB antenna with dual band notched characteristics," *Electron Letters*, Vol. 44, No. 24, 2008.
28. Yan, Z.-M., Y.-S. Xu, and W. Wang, "Miniaturized ultra-wide band slot antenna with dual notch band notches and eliminating spurious stop band," *Progress In Electromagnetics Research C*, Vol. 30, 119–130, 2012.