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Design and Analysis of a Compact Ultra Wideband Antenna with Frequency Notch in WiMAX Band

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Abstract

A compact co-planar waveguide (CPW) fed planar monopole antenna that is constructed by integrating multiple conventional circular shaped radiators is proposed in this paper. The antenna has dimension of (0.4×0.3×0.008) λ_L where λ_L is the lower band wavelength. WiMAX band (3.3-3.8 GHz) notch feature with high Q-factor is ensured by embedding a rectangular shaped split ring resonator slot on lower end of patch. The antenna provides pass band coverage of 3-6.6GHz and notch band coverage of 3.28-3.82GHz. Stable gain, high radiation efficiency and omnidirectional radiation patterns are realized in the pass band of antenna. Flat group delay and linear antenna transfer function response are obtained at antenna pass band that ensures its low dispersive nature. The antenna is useful for various short range ultra-wideband (UWB) communication applications without interfering to the popular WiMAX technologies.

Keywords— Ultra wideband antenna, frequency notch, Slotted antenna, WiMAX

1. Introduction

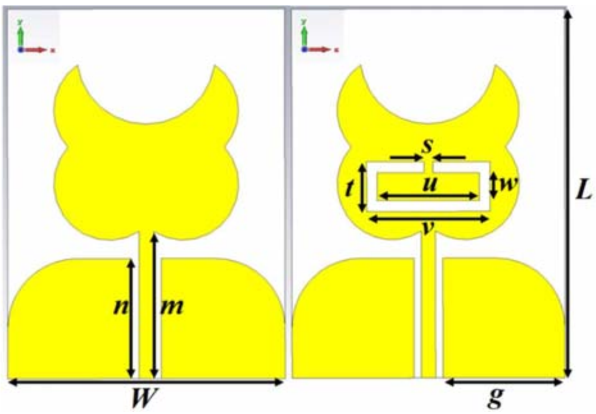
Ultra-wideband (UWB) antennas have garnered significant attention in recent years due to their broad frequency spectrum, which allows for high data rate communication, low power consumption, and reduced interference with other communication systems. One of the critical challenges in UWB antenna design is mitigating interference from existing narrowband systems, which can be effectively addressed using notch bands. Sharma et al. presented a compact UWB antenna with dual notch characteristics for WiMAX and WLAN bands. It utilized a modified ground plane and slots on the radiating patch to achieve the desired notching performance [1]. Kumar et al. presented a UWB antenna with a single notched band achieved through open-loop resonators. The design demonstrated significant attenuation in the notched band while maintaining UWB performance [2]. Gupta et al. introduced a UWB antenna with a single notched band created by a parasitic strip. The antenna shows excellent impedance bandwidth and effective notch performance for the targeted frequency band [3]. Zhang et al. proposed a UWB antenna with a tuneable notched band, utilizing a defected ground structure (DGS). The antenna's notched frequency can be adjusted, offering flexibility for various applications [4]. Wang et al. focused on a UWB antenna designed specifically to notch the WLAN band. The notched band is achieved using an inverted T-shaped slot, providing a sharp rejection at the desired frequency [5]. Singh et al. presented a printed monopole UWB antenna with band-notched characteristics for the IEEE 802.11a band. The design incorporates a U-shaped slot to create the notch [6]. Khan et al. introduced a reconfigurable UWB antenna with a single notch controlled by PIN diodes. The antenna can switch the notched band on and off, providing versatile performance for dynamic environments [7]. Patel et al. described a UWB antenna with a single notched band implemented via split ring resonators (SRRs). The SRRs effectively suppress unwanted signals in the specified band [8]. Li et al. discussed a flexible UWB antenna designed for wearable applications, incorporating a single notch band to avoid interference with the WLAN band. The antenna was fabricated on a flexible substrate [9]. Chen et al. presented a miniaturized UWB antenna with a single notched band achieved through slot loading techniques. The antenna maintained compact dimensions while providing effective notch characteristics [10]. Das et al. explored a high gain UWB antenna with a single notched band using metamaterial structures. The metamaterials enhanced gain and create a sharp notched band, improving overall performance [11]. Rao et al. introduced a broadband UWB antenna with a single notched band using Electromagnetic Band Gap (EBG) structures. The EBG structures created a precise notch, effectively filtering out unwanted signals [12]. The reviewed papers highlight various techniques for implementing single notched bands in UWB antennas such as, Slot Techniques: Commonly used to create notched bands, such as U-shaped, T-shaped, and inverted slots. Resonators: Including open-loop resonators and split ring resonators, provide effective notch characteristics. Parasitic Elements: Used to achieve specific notched bands without significantly altering the antenna design. Defected Ground Structures (DGS): Enable tunable and flexible notched bands. Reconfigurability: Implemented using PIN diodes to dynamically control the notched band. Metamaterial and EBG Structures: Enhance gain and create precise notched bands, improving the antenna's overall performance. However, one limitation of such notched antenna works is that it also eliminates some parts of the desired frequency band along with the notch band due to poor Q-response. In this paper, the author has presented a compact planar UWB antenna with single notch frequency which is realized to eliminate the WiMAX (3.3-3.8 GHz) band successfully with very high Q factor. The notch band is realized using rectangular shaped split ring resonator slot embedded on patch.

2. Antenna Design

The circular disk monopole antenna is a conformist radiator for wide spectrum coverage. Integration of multiple circles of different radii is considered to obtain the desired radiator shape. The integrated shape looks alike the body of a Teddy-bear. The antenna ground lanes are symmetrically placed at both sides of coplanar feed (CPW) to build design symmetry. The upper peripherals at the outermost corners of ground plane is bended to create a flare angle between the patch and ground which helps to resonate the higher spectrums. Notch band is employed by popular slot etching method. A rectangular fashioned split ring slot is fused at the end of patch, close to feed. The antenna design schematic is displayed in Fig. 1 with design parameters. The antenna model is designed and optimized by parametric analysis in CST Microwave Studio suite simulator [13]. The notch structure (slot) design parameters are calculated from equation-1 [14] where notch center frequency (f_n) is considered to be 3.55 GHz.

$$f_n = \frac{1.414 \times c}{4(u+v-w-s-\frac{3t}{2})\sqrt{\varepsilon_r+1}} \quad (1)$$

The optimized design parameters are L=40; W=30; g=13.4; m=15.92; n=13; s=1; t=5.4; u=11.2; v=13.6; w=3 (all dimensions are in mm). The antenna is finally fabricated on cheap and easily available FR-4 (permittivity (ε_r) 4.4 and loss tangent 0.018) substrate. The fabricated antenna prototypes are shown in Fig. 2.



(a) (b)

Figure 1. Schematic of antenna design with design parameters: (a) antenna without notch structure (slot) and (b) antenna with notch structure (slot).

Figure 2. Fabricated prototype of notched antenna.

3. Results and Discussion

The antenna characteristic is evaluated by obtaining antenna's reflection coefficient (S_{11}), gain, radiation efficiency, surface current, radiation patterns, group delay and transfer function (S_{21}) results. The S_{11} profile over frequency is obtained by both EM simulator and experimental analysis. As depicted in Fig. 3, the notched antenna exhibits -10 dB impedance bandwidth from 3 to 6.6GHz with prominent notch band realization at 3.28-3.82 GHz to eliminate the WiMAX (3.3-3.8 GHz) band interference. Good pact between EM simulator result and measured result is detected. The almost exact notch band realization similar to the WiMAX spectrum results high Q-factor of notch characteristic which is very desired to properly utilize the precious spectrums.

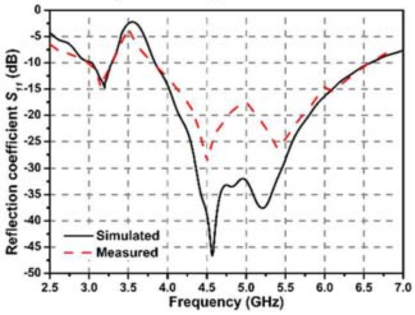


Figure 3. Reflection coefficient (S_{11}) plot of the antenna.

The simulated surface current of the antenna at notch centre frequency is plotted in Fig. 4. As depicted, strong surface current is observed on patch which are oppositely oriented inside and outside the slot. Also the surface current is opposite directional inside and outside the feed. This anti directional surface currents cancelled each other and results almost zero radiation to justify the notch creation at that frequency.

The E and H-plane antenna radiation patterns are plotted at 3.2, 4.5, 5.3 and 6.5 GHz, covering the whole impedance bandwidth. The plots are exhibited in Fig. 5. As shown, the antenna presents omnidirectional H-plane and bidirectional (figure of eight) E-plane patterns in all the frequencies similar to conventional wideband monopole antennas.

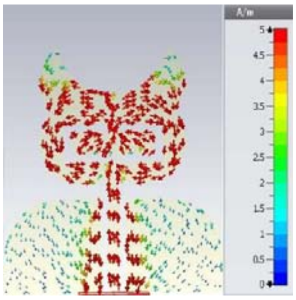
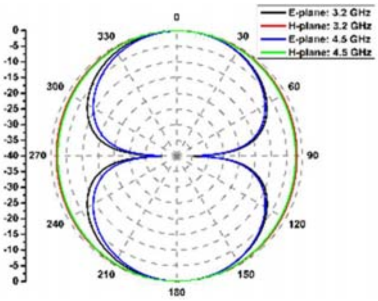
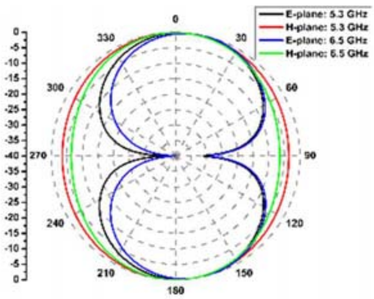


Figure 4. Simulated surface current of notched antenna at 3.55GHz.



(a) at 3.2 & 4.5 GHz



(b) at 5.3 & 6.5 GHz

Figure 5. E and H-plane antenna radiation patterns.

The antenna gain is plotted in Fig. 6 for both antenna without slot and antenna with slot. Clearly, the antenna gain varies between 2-4.5 dBi for both slotted antenna and antenna without slot except the notch band. The antenna gain reduces significantly at the notch band which justify the notch creation. Non-varying gain profile also ensures antenna's steady response over wideband spectrum.

The radiation efficiency for antenna and notched antenna are also plotted in Fig. 7. Clearly, the antenna exhibits very high radiation efficiency that is around 95% except notch band. At notch frequency band, the antenna efficiency degrades prominently due to the notch creation.

The antenna group delay and magnitude response of transfer function (S_{21}) are crucial parameters to examine the dispersive nature of the antenna. To measure the group delay and $|S_{21}|$, two similar antenna prototypes are placed at face-to-face and side-by-side orientations at a distance less than its far field zone. As plotted in Fig 8, the antenna exhibits almost flat (variation $\leq$ 1ns) group delay response over frequency band except notch band. At notch spectrum, the group delay variation is significantly high. Similarly from the plot of magnitude response of transfer function (Fig. 9), it is shown that the antenna has linear (variation less than 15dB) transfer function response over the pass band for both notched antenna and antenna without notch. However, the antenna $|S_{21}|$ varies non linearly at notch frequency band. These results depict that the antenna exhibits non-dispersive nature in its pass band, however the antenna is highly dispersive at the notch frequency band.

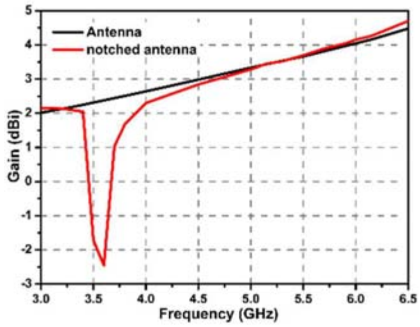


Figure 6. Gain plots of antenna without notch and antenna with notch.

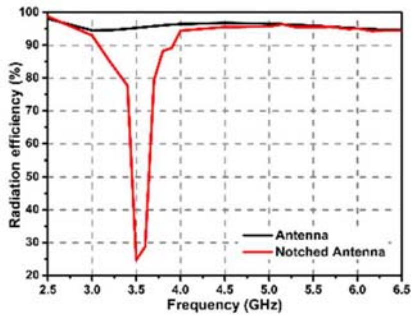


Figure 7. Radiation efficiency plots of antenna without notch and antenna with notch.

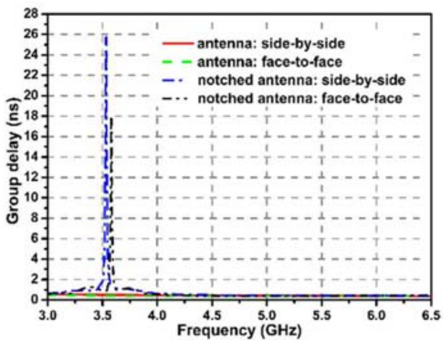


Figure 8. Group delay plots of antenna without notch and antenna with notch.

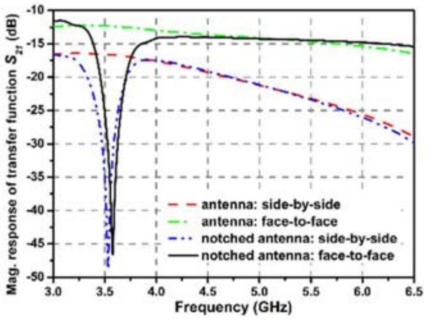


Figure 9. $|S_{21}|$ plots of antenna without notch and antenna with notch.

4. Conclusion

A very compact planar UWB monopole antenna is presented. The antenna is providing prominent WiMAX band notch characteristic. The antenna offers flat gain variation from 2 to 4.5 dB, high radiation efficiency of around 95% and omnidirectional radiation patterns except at notch band. The antenna is also featured with linear magnitude response of transfer function and non-varying group delay in both face-to-face and side-by-side orientations except notch band. Clearly, the antenna has dispersive characteristic with poor gain and unacceptable radiation efficiency at notch band which signifies proper WiMAX notch creation. The main attention of the work is the creation of notch band that is very similar to the WiMAX spectrum as it ensures no loss of valuable spectrums due to notch creation. This notched antenna is applicable for short range UWB technologies without any WiMAX interferences.

6. Acknowledgements

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7. References

1. S. K. Sharma, V. K. Singh, and M. K. Meshram, "Design of a Compact UWB Antenna with Dual Notch Bands," *Proc. IEEE Int. Symp. Antennas Propag.*, 2017, pp. 456-459.

2. P. Kumar, S. S. K. Chaitanya, and K. P. Ray, "Compact UWB Antenna with Single Band Notched Characteristics Using Open-Loop Resonators," *Proc. IEEE Int. Conf. Microw. Optoelectron. Antennas Commun.*, 2018, pp. 123-126.

3. R. Gupta, S. Sinha, and A. K. Singh, "A Novel Single Notched Band UWB Antenna Using Parasitic Strip," *Proc. IEEE Int. Symp. Antennas Propag.*, 2019, pp. 789-792.

4. H. Zhang, Y. Wang, and J. Zhang, "UWB Antenna with Tunable Notched Band Using Defected Ground Structure," *Proc. IEEE Int. Conf. Commun. Technol.*, 2019, pp. 210-213.

5. L. Wang, H. X. Zhao, and J. Y. Liu, "Single Notched UWB Antenna for WLAN Applications," *Proc. IEEE Int. Symp. Antennas Propag.*, 2020, pp. 345-348.

6. A. Singh, P. Bhardwaj, and R. P. Yadav, "Compact Printed Monopole UWB Antenna with Band-Notched Characteristics," *Proc. IEEE Int. Conf. Recent Adv. Innov. Eng.*, 2020, pp. 567-570.

7. M. Khan, I. Siddique, and H. A. Khan, "Reconfigurable UWB Antenna with a Single Notch Using PIN Diodes," *Proc. IEEE Int. Conf. Adv. Commun. Technol.*, 2021, pp. 112-115.

8. N. Patel, R. Mishra, and S. K. Verma, "A Novel Single Notched Ultra-Wideband Antenna Using Split Ring Resonators," *Proc. IEEE Int. Symp. Antennas Propag.*, 2021, pp. 789-792.

9. Y. Li, J. Zhao, and T. Huang, "Flexible UWB Antenna with Single Notch for Wearable Applications," *Proc. IEEE Int. Symp. Antennas Propag.*, 2022, pp. 123-126.

10. J. Chen, X. Liu, and W. Zhang, "Miniaturized UWB Antenna with Single Notched Band Using Slot Loading," *Proc. IEEE Int. Conf. Ubiquitous Wireless Broadband.*, 2022, pp. 210-213.

11. S. Das, P. Kumar, and R. Singh, "High Gain UWB Antenna with Single Notch Using Metamaterial Structures," *Proc. IEEE Int. Conf. Recent Trends Electr. Electron.*, 2023, pp. 456-459.

12. K. Rao, S. B. Desai, and A. R. Patel, "Broadband UWB Antenna with Single Band Notched Using EBG Structures," *Proc. IEEE Int. Symp. Antennas Propag.*, 2023, pp. 789-792.

13. https://www.3ds.com/products/simulia/cst-studio-suite

14. S. Kundu, "Gain augmentation of a triple notched ultra-wideband antenna using compact uniplanar frequency selective surface for ground penetrating radar," *IETE Journal of Research*, vol. 69, No. 2, 2023, pp.813-824.