Design of a Notch Filter Element to Mitigate WiMAX EMI of an UWB Antenna

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***Abstract*—This paper presents the design and analysis of a notch filter element to mitigate WiMAX electromagnetic interference (EMI) of an ultra-wideband (UWB) antenna. The designed WiMAX band-notched antenna is modeled on an FR-4 substrate (ϵ_r= 4.3, tanδ = 0.02) having a physical dimension of 26×28×0.8 mm^3. A very simple T-shaped slot is incorporated into the patch plane as a notch filter element to mitigate the WiMAX interference in the frequency range of 3.38 GHz to 3.83 GHz effectively. The antenna has a minimum return loss value of -28.03 dB. The maximum gain and directivity values of 3.17 dBi and 3.9 dBi are obtained respectively at 6.05 GHz. It exhibits an average radiation efficiency beyond 80% for the entire operating band (3 GHz to 10.79 GHz) excluding the WiMAX interfering band. The maximum value of the efficiency is 91.76% recorded at 3.1 GHz. The suggested design features a low profile, simple notching technique, and satisfactory performance making it a suitable candidate for future WiMAX EMI free UWB applications.**

***Index Terms*—UWB antenna, WiMAX EMI free, T-shaped filter, Single band-notch, Patch antenna**

I. INTRODUCTION

UWB antennas have become an increasingly appealing and effective option for rapid, short-distance wireless communication systems. In 2002, following the FCC [1] announcement of the unlicensed UWB spectrum (3.1–10.6 GHz), significant efforts were concentrated on the design and development of the UWB antennas. The use of the UWB frequency spectrum is rapidly expanding as wireless technology advances and the volume of wireless communication users grows. This rise in UWB antenna applications is driven by their wider bandwidth, higher data rates, and low power consumption. UWB antennas are now employed in various fields, including biomedical technology, PANs, imaging systems and radar, precision tracking, target recognition automatically, and so on [2]. Designing UWB antennas faces many challenges, such as maintaining in design simplicity and an easy fabrication process, achieving a physically miniature structure, resolving impedance mismatching, ensuring radiation stability, and managing electromagnetic interference (EMI). The EMI is a significant issue for the UWB antennas due to some overlapping services in the narrowband spectrum for instance WiMAX (3.3–3.8 GHz, 5.25–5.85 GHz), WLAN (5.15–5.825 GHz), IEEE INSAT (6.3-7.27 GHz), and X-band (7.9–8.4 GHz) [3]. The band elimination technique is a crucial solution to mitigate the EMI problem. .

In recent years, extensive research works [4], [5], [6], [7], [8] have been conducted to eliminate the interference due to the WiMAX frequency spectrum. In, a semi-circular slot (SCS) is incorporated on the main radiating element to filter out the frequencies from 3.25-3.8 GHz [2]. It exhibits a gain of approximately 5 dBi and a radiation efficiency of 85% over its operating range of 2.7 GHz to 13 GHz. In [4], a UWB antenna having a wideband performance operates from 3.1 to 10.6 GHz. It has a total dimension of 20 × 30 × 1.6 mm^3 which is slightly larger. To block the WiMAX (3.27 to 3.8 GHz) interference effectively, it incorporates a Pi-shaped filter element. Likewise, a rectangular-shaped notch is etched into the ground plane in [5] to exclude the notched band (3.0–4.7 GHz) while ensuring minimal interference and high efficiency. It is modeled on an FR4 substrate and has very large dimensions of $66 \times 66 \times 1.59$ mm^3. It achieves wideband performance from 1.6 GHz to 9.2 GHz but the inclusion of a ground notch adds complexity to the antenna's fabrication process, which might increase production costs and time. Additionally, a split ring resonator (SRR) with a rectangular resonator having an open loop configuration loaded WiMAX band-notched UWB antenna is presented in [6]. It has larger dimensions of 36 × 30 mm^2. However, the integration of both SRR and OLRR for notch characteristics adds complexity to the antenna's design and fabrication. Moreover, two slots (U-shaped and L-shaped) are etched in the ground plane in [7] creating a notched band within the 3.3–3.8 GHz WiMAX frequency range, and exhibits excellent performance with a wider operating range of 2.2 to 10.8 GHz and high isolation of $>$30 dB. In [8], a U-shaped stub is intrinsically embedded into the patch element to stop transmission for the WiMAX band (2.9-3.9 GHz). The band-notched functionalities are obtained by designing either intrinsic or extrinsic filter elements. The intrinsic filter is preferable to the extrinsic filter because it does not need an extra filter element to block the interference. Simply, the intrinsic filter element can be carefully designed through engineered slots. Hence, it can reduce the total size, signal processing, and cost of the whole antenna system.

However, to tackle the EMI challenges, the major contribution of this work is to design an efficient intrinsic filter element that is capable of blocking the EMI caused by the WiMAX interfering band. The overall structure of this paper is arranged as the following sequences: Section II presents the details of the notch filter design procedure, Section III discusses the results, and Section IV provides a brief summary of the work.

II. Notch Filter Design Procedure

The proposed T-shaped notch filter is designed on the UWB antenna as shown in Fig. 1. Therefore, the design methodology can be described in two folds. Initially, a planar patch radiator is implemented on an affordable FR-4 substrate (dielectric constant ϵ_r= 4.3, loss tangent tanδ = 0.02) with a thickness of 0.8 mm, ensuring coverage of the full spectrum used for the UWB applications. A rectangular patch for radiation is printed on the front face of the substrate with four-quarter circular and three rectangular slots. Likewise, at the substrate's rear side, a partial ground plane with two symmetrical rectangular slots is incorporated. The antenna is fed by a 50Ω microstrip transmission line of size 13×2.6 mm^2. Here, different slots are incorporated on the patch, feed line, and ground plane to reduce return loss (S11 < - 10 dB) and to improve impedance matching (VSWR < 2). However, the detailed design procedure and the operating principles of the UWB antenna without a notch filter are explained in the author's other paper [9].

After that, a straightforward T-shaped slot is introduced into the patch radiator, functioning as a built-in filter to suppress electromagnetic interference (EMI) caused by the WiMAX band. The T-shaped filter consists of a horizontal section with dimensions (N_{W1} × N_{L1}) of 0.2 × 7.8 mm^2 and a vertical section with dimensions (N_{W2} × N_{L2}) of 2.6 × 1.2 mm^2. The length of the notched filter is determined based on the center frequency (3.55 GHz) of the desired WiMAX notched band. The following equations (1), (2), and (3) are used to estimate the filter length [3], [10].

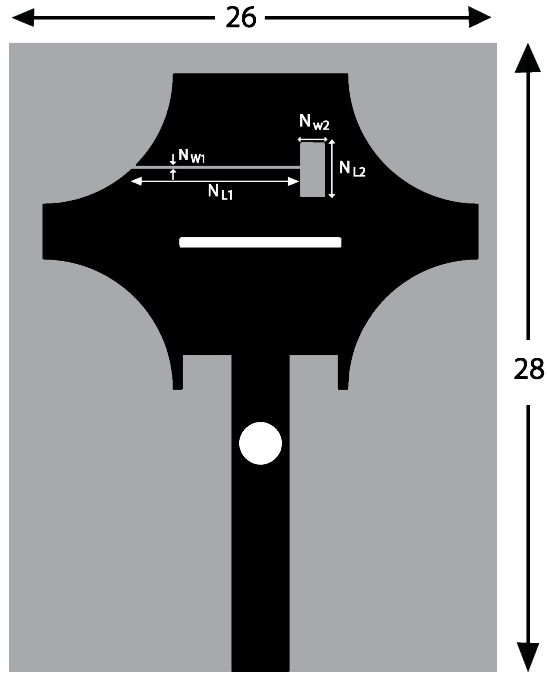
$$f_{center} = \frac{c}{2L_{filter}\sqrt{\epsilon_{eff}}} \tag{1}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}} \tag{2}$$

$$w = \frac{c}{2f_{center}\sqrt{\frac{\epsilon_r+1}{2}}} \tag{3}$$

Where C refers to the speed of light, L_{slot} represents the overall length of the filter element, and ϵ_{eff} is the effective dielectric constant. Initially, the estimated filter length was 20.97 mm. Later, the optimized T-shaped filter of length 10.4 mm was employed to eliminate EMI induced by the WiMAX band.

The surface current distribution and the return loss curve are used to describe the working of the proposed T-shaped notched filter element. The surface current distributions shown in Fig. 2 are analyzed at the lower (3.15 GHz), middle (5 GHz), and higher (9.92 GHz) frequencies of the operating spectrum (3−10.79 GHz) of the antenna as well as at the midpoint frequency (3.55 GHz) of the notched/blocked band. As seen in Fig.2, at the passband frequencies of 3.15 GHz, 5 GHz, and 9.92 GHz, at the main radiating surface, the current distribution is notably strong, while it remains minimal across the T-shaped notched filter element (refer to Fig. 2a, Fig. 2c, and Fig. 2d). On the other hand, at the central frequency of the blocked band, the highest current distribution is observed across the T-shaped notched filter element (Fig. 2 b), and hence it blocks the significant radiation for that band and ensures band elimination characteristics. As a result, the antenna is designed to operate between 3 GHz and 10.79 GHz (with S11 ¡ -10 dB), effectively filtering out the WiMAX band (3.3-3.8 GHz), as shown in Fig. 3.



(a)

(b)

Fig. 1. The final design of the UWB band-notch antenna.

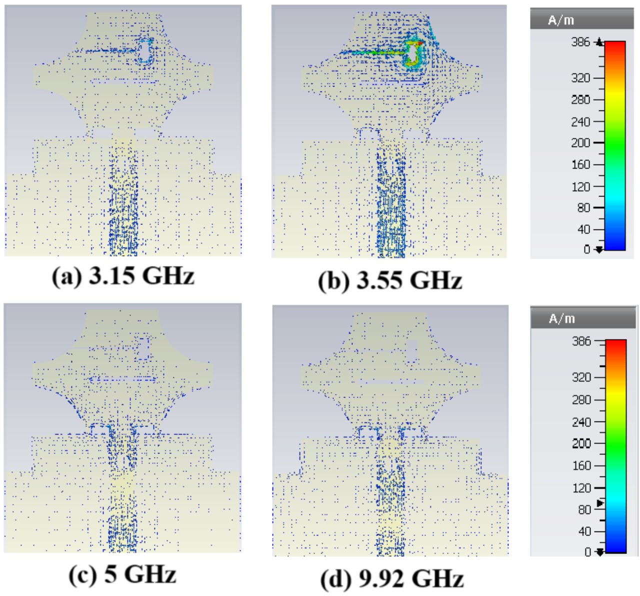


Fig. 2. The distribution of the current in the passband and stopped band.

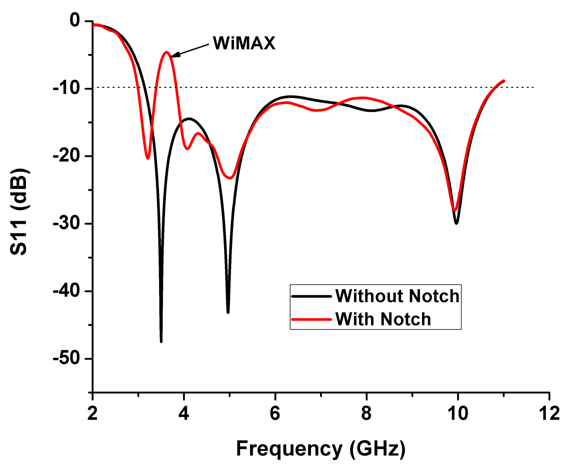


Fig. 3. Return loss curve of the antenna with and without the notch filter element.

III. Result Analysis and Discussion

The primary factors used to assess the antenna's performance are VSWR, gain, efficiency, and radiation characteristics. This section outlines the performance parameters of the suggested band-notched antenna. Fig.4 visualizes the VSWR curve of the antenna. The condition VSWR < 2 signifies how well the designed antenna is impedance matched with the transmission line in the operating band. In the notch frequency region of 3.3 GHz to 3.8 GHz, the VSWR > 2, while it is less than 2 across the whole UWB spectrum of 3 GHz to 10.79 GHz. It indicates the perfect impedance matching within the operating region of the antenna.

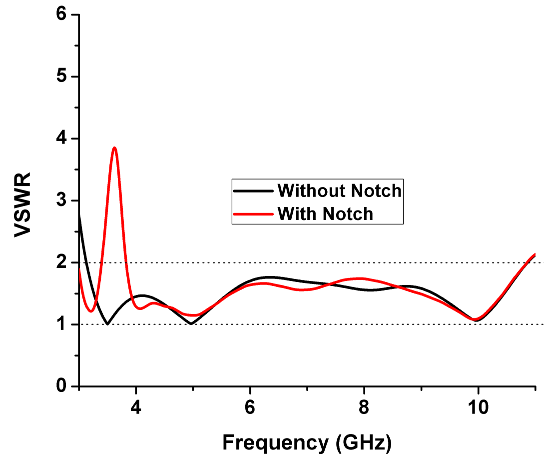


Fig. 4. VSWR of the modeled antenna with and without notch filter element.

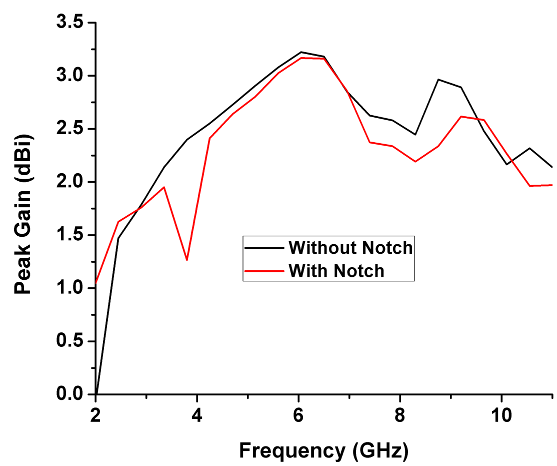


Fig. 5. Gain of the antenna with and without employing the notch filter element.

With and without employing the band eliminating technique, the predicted gain of the designed antenna is illustrated in Fig.5. The antenna gain fluctuates between 1.8 dBi and 3.17 dBi throughout the frequency range of 3 GHz to 10.79 GHz. The highest gain value of 3.17 dBi is recorded at 6.05 GHz. It can be observed that the gain drops significantly within the WiMAX stopped band of 3.3–3.8 GHz (Fig.5), which confirms the band-notched behavior of the proposed antenna. Fig.6 illustrates the radiation efficiency of the proposed UWB antenna featuring a T-shaped notch filter element. The antenna exhibits an average radiation efficiency of more than 80% for almost the covered band of 3 GHz to 10.79 GHz excluding the WiMAX interfering band. The highest radiation efficiency of 91.76% is recorded at 3.1 GHz. The polar plot of the E-field and H-field patterns observed at three different frequencies of

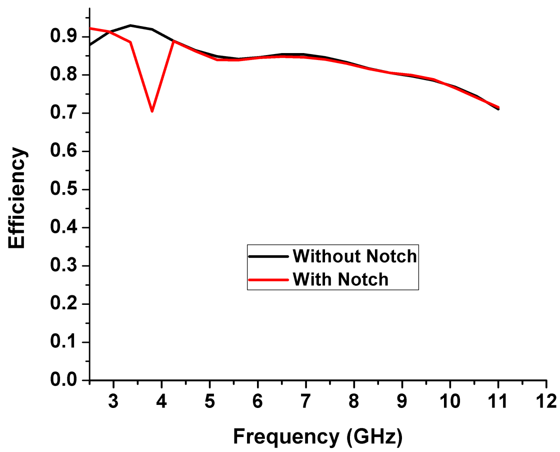


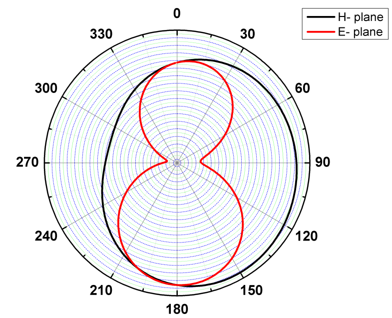
Fig. 6. Radiation efficiency of the antenna with and without using a notch filter element.

3.15 GHz, 5 GHz, and 9.92 GHz is illustrated in Fig.7(a), Fig.7(b), and Fig.7(c) respectively. The proposed antenna displays a nearly omnidirectional radiation pattern throughout the operating band, with only a slightly distorted pattern observed at higher frequencies (Fig.7(c)).

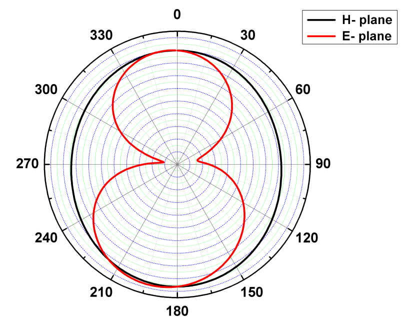
TABLE I. Performance comparison with some recently proposed works

Ref.	Dimensions (mm^3)	Operating Freq. (GHz)	Notched Freq. (GHz)	Technique Used	Eff. (%)
[2]	$26 \times 50 \times 1.6$	2.7-13	3.25-3.8	Semi-circular slot	85
[4]	$20 \times 30 \times 1.6$	3.1-10.6	3.27-3.81	Pi-shaped slot	–
[5]	$66 \times 66 \times 1.59$	1.6-9.2	3-4.7	Rectangular slot	95
[6]	$36 \times 30 \times 1.5$	2.9-12	3.3-3.6	SRR	85
[7]	$25 \times 38 \times 1.6$	2.2-10.8	3.3-3.8	U-shaped & L-shaped slots	80
[8]	$28 \times 11.5 \times 1.6$	2.7-10.7	2.9-3.9	U-shaped stub	93
Ours	$26 \times 28 \times 0.8$	3-10.79	3.38-3.83	T-shaped slot	91.76

A performance comparison between the suggested antenna and a number of newly released WiMAX band-notched UWB antennas is listed in Table I. With the exception of the antenna presented in [8], all the antennas in the comparison table are larger in size than our suggested antenna. The proposed antenna has the lowest profile (thickness) which is highly preferable for PCB technology. It also employs the very simple T-shaped unique notch filter element for eliminating the WiMAX interfering band.



(a)



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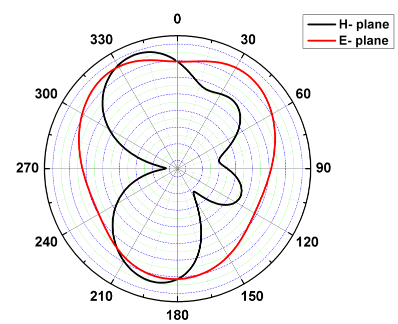

(c)

Fig. 7. 2D power patterns cut in the principle planes (E and H planes) at (a) 3.15 GHz, (b) 5 GHz, and (c) 9.92 GHz.

IV. Conclusion

A single band notched low profile planar patch antenna is presented in this paper for WiMAX EMI-free applications. The patch features a built-in T-shaped slot that serves as a filter element, efficiently suppressing EMI originating from the WiMAX interfering band. The recommended antenna covers a frequency range of 3 GHz to 10.79 GHz, achieving a return loss (S11) less than -10 dB and a VSWR below 2, excluding the stopband spanning from 3.38 GHz to 3.83 GHz. The highest radiation efficacy of 91.76% is achieved within the operating band. The maximum gain and directivity values of 3.17 dBi and 3.9 dBi are recorded at 6.05 GHz. The stopped band shows a breakdown in the return loss and VSWR performances, along with a sudden drop in gain, directivity, and efficiency, proving the designed antenna's band eliminating capability. The effective operation of the designed notch filter element makes it a promising candidate for the WiMAX EMI-free UWB applications.

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