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A Compact Design of UWB Monopole Antenna with Dual Notched Bands for WiMAX Applications

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A compact conformal coplanar waveguide-fed (CCF) ultra-wideband (UWB) monopole antenna with dual notched bands at 3.25-3.85 GHz and 5.25-5.85 GHz for worldwide interoperability for microwave access (WiMAX) applications is presented in this paper. The evolution of the proposed antenna structure is presented in a stepwise manner with the incorporation of a parasitic element and a PIN diode. In the proposed structure, the bandwidth enhancement and band notch are realized by an asymmetric design, which has two I-shaped stub lines parallel to the feed line and two semicircles on both sides of the feed line. The notch is achieved by applying the parasitic element parallel to the patch and placing a PIN diode between the parasitic element and the antenna patch. The volumetric size of the antenna is 24×22×0.035 mm^3. The proposed structure attains an operating band (VSWR $\leq$ 2) ranging from 3.1 to 10.6 GHz with a gain close to 3.95 dBi, along with significant efficiency and symmetrical radiation patterns. Parasitic elements are used to improve directivity or gain and reduce the back lobe. By choosing the parasitic elements, different resonant modes can be excited nearby each other, which can provide a wider bandwidth. The proposed antenna is low profile and is designed to be used as a transceiver in UWB communication for WiMAX applications.

Keywords: Worldwide interoperability for microwave access (WiMAX), Coplanar waveguide (CPW), Conformal CPW fed (CCF) antenna.

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1. INTRODUCTION

The current revolution in electronic circuits has forced antenna researchers to create smaller, lighter and less expensive structures. These requirements have led to the creation of several antenna frames, among which the printed microstrip patch antenna (MPA) has attracted attention in recent years. MPA is widely used in several applications, including mobile communication, satellite communication, radars, GPS applications, the automobile industry, radio frequency identification (RFID), telemetry, aerospace, etc. [11, 12]. MPA in its traditional form has certain limitations such as bandwidth, polarization reversal and large structure. MPA can provide good gain, small size, wide bandwidth, flexibility, simplicity of design, etc. In particular, bandwidth, polarization and radiation patterns are becoming the most significant features that affect antenna applications in modern wireless communication systems. MPA for applications such as mobile and compact electronic devices must be physically small in order to be implanted in devices and be broadband in nature. The improvement in bandwidth and multi-frequency operations in an integrated antenna has become a challenge for antenna designers. Numerous techniques have been implemented in earlier reported works to extend bandwidth such as using thick substrates, stacked patches, shorting pins, active and passive devices, feeding mechanisms, and impedance matching network [11-13].

The ultra-wide band (UWB) signal frequency band is from 3.1 to 10.6 GHz, or the bandwidth of the signal is more than 500 MHz as per the Federal Communication Commission (FCC) [1, 8, 13]. UWB systems have a number of benefits like low operating power level, high data rates, high capacity, complexity, etc. [2, 12, 13].

But when UWB systems give us accessibility, they have some problems at the same time. One problem is interference between the UWB frequency and other communication systems like wireless local area network (WLAN, 5.15-5.825 GHz), worldwide interoperability for microwave access (WiMAX, 3.3-3.7 GHz), HIPERLAN/2 (5.15-5.35 GHz, 5.47-5.725 GHz), IEEE802.11a (5.15-5.35 GHz, 5.725-5.825 GHz) [3, 9]. So, antennas with band notched characteristics and UWB nature in these existing bands are desirable.

In this work, a compact UWB monopole antenna structure with dual notched bands at 3.25-3.85 GHz and 5.25-5.85 GHz for WiMAX applications is proposed. In the proposed design, bandwidth enhancement and band notch are realized.

The UWB antenna design is mainly composed of an asymmetric structure that has two different I-shaped stub lines parallel to the microstrip feed line and two semicircles on either side of the feed line region and cuts in the patch. To obtain band notched characteristics at 3.25-3.85 GHz and 5.25-5.8 GHz, one PIN diode is connected to the parasitic element along the patch and thereby a lower notch is achieved. The next step is to etch defects in the patch, which leads to excitation of a higher frequency band. The proposed antenna has a stable and good omnidirectional pattern throughout the whole operating frequency band, which authenticates the proposed design concept and research ideas.

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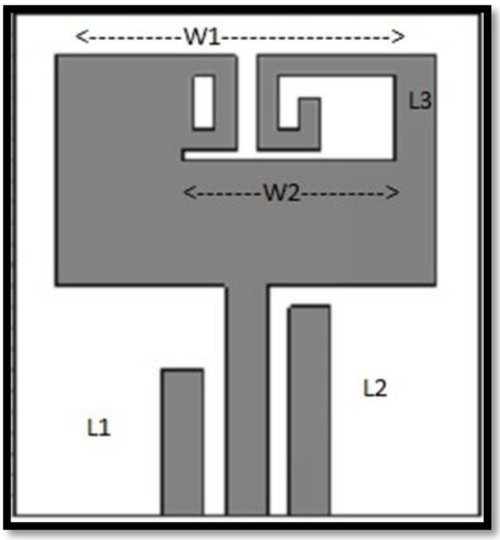
This research paper primarily contains three parts. First, the design evolution of the proposed UWB antenna structure and the simulation results. Second, the antenna evolution with dual notched bands at 3.2-3.85 GHz and 5.25-5.85 GHz for WiMAX applications and its key parameters are analyzed. In the third section, simulation results of final designs are presented systematically.

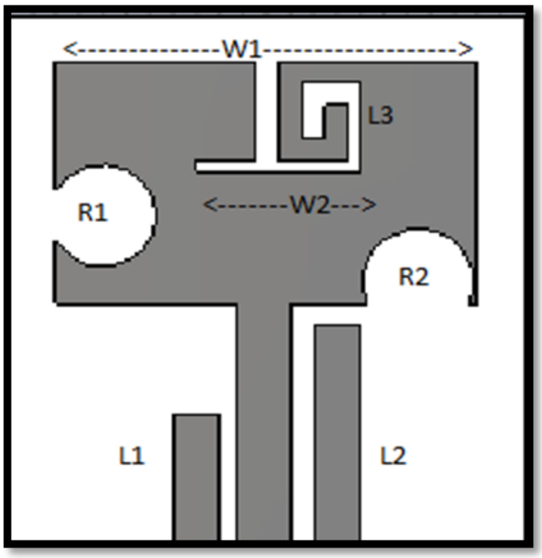
2. ANTENNA CONFIGURATION AND RESULT

The design structure of the proposed antenna along with the physical parameters are shown in Fig. 1. The antenna structure geometry lies in the *XY* region over a finite ground region. The substrate height (*h*) is very small as compared to the free space wavelength (λ_0), and for its use in modern communication systems the dimension of the square patch is restricted to 22×24 mm^2. The primary structure consists of copper as the patch and ground, having dimensions 24×22×1.59 mm^3. The substrate made of FR-4 material is used with a thickness of 1.59 mm, relative permittivity of 4.4 and loss tangent of 0.02. The coplanar waveguide (CPW) feed is used in the geometry.

In the simulation of the antenna structure, finite element method-based CST microwave studio has been used. The design of a conformal CPW fed (CCF) UWB antenna is depicted in Fig. 1. In CPW feeding, the side plane of the conductor is grounded, and the center strip transmits the signal. The benefit of the CPW fed slot antenna is its wideband characteristics. So, the CPW fed slot antenna is an extremely effective and promising antenna feeding technique for wideband wireless antenna applications [5]. Fig. 1a (antenna-1) has a primary square patch asymmetric structure, which is inspired by the work reported in [4]. Fig. 1a (antenna-1) shows the initial design of the CCF antenna, where a 50 Ω microstrip feed line 2 mm wide and 11 mm long is applied. The optimized parameters are illustrated in Table 1. This antenna structure provides the reflection coefficient below – 10 dB in the frequency range of 3.6 to 9.5 GHz.



a



b

Fig. 1 – (a) Antenna-1 and (b) Antenna-2 with CCF line

Table 1 – Optimized parameters (in mm) of Fig. 1a for antenna-1

*L*1	*L*2	*W*1	*W*2	*L*3
5	10	18	14	6

To further improve the performance, the proposed antenna structure is modified by etching two semicircles on the patch with radii *R*1 and *R*2 on both sides of the antenna, as shown in Fig. 1b. Taking all other parameters constant as per the initial structure, the variation of the radii *R*1 and *R*2 is shown in Table 2. The frequency response of this modified antenna is much better than that of the antenna presented in Fig. 1a. This antenna structure provides the reflection coefficient below – 10 dB in the frequency range of 3.1 to 10.6 GHz.

Table 2 – Effect of semicircle radii (*R*1 and *R*2)

Constant parameter (radius)	Varying parameter (radius)	BW (GHz)
*R*2 = 3 mm	*R*1 = 1.9 mm	3.2-10.4
	*R*1 = 2.5 mm	3.1-10.6
	*R*1 = 2.3 mm	3.15-10.5
*R*1 = 2.5 mm	*R*2 = 2.2 mm	3.1-10.5
	*R*2 = 3 mm	3.1-10.6
	*R*3 = 2.6 mm	3.1-11.0

Table 3 – Optimized dimensions (in mm) for antenna-2

*L*1	*L*2	*W*1	*W*2	*L*3	*R*1	*R*2
5	10	18	14	6	2.5	3

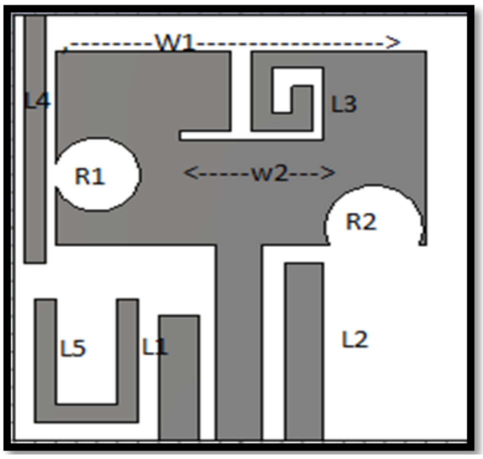
3. MODIFIED RING STRUCTURE WITH PARASITIC ELEMENT AND PIN DIODE

The antenna structure is additionally amended by applying a parasitic element, as shown in Fig. 2a (antenna-3), and placing one PIN diode, as shown in

Fig. 2b (antenna-4), between the parasitic element and the antenna patch. The antenna design in Fig. 2b (antenna-4) is finally our proposed design for WiMAX. An I-shaped parasitic strip is positioned parallel to the patch to introduce a notched band for WiMAX [7]. Parasitic elements are used to improve directivity or gain and reduce the back lobe. By choosing parasitic elements, different resonant modes can be excited nearby each other that can provide a wider bandwidth. A parasitic element has dimensions of 14×2 mm². In Table 4, the optimized dimensions of antenna-4 are shown.

Table 4 – Optimized dimensions (in mm) of antenna-4

*L*1	*L*2	*W*1	*W*2	*L*3	*R*1	*R*2	*L*4	*L*5
6	8	18	14	6	2.5	3	14	7



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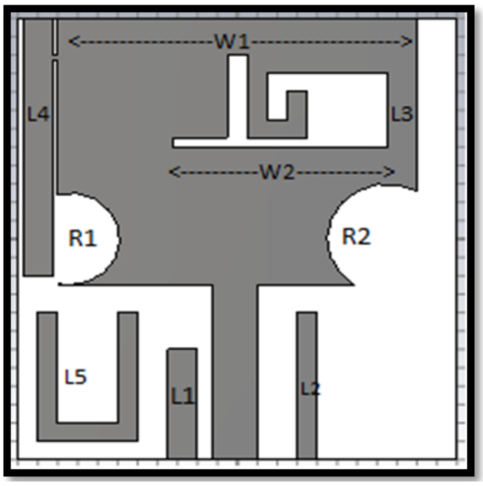


b

Fig. 2 – (a) Antenna-3 and (b) antenna-4, CCF UWB antenna for WiMAX applications

This antenna in Fig. 2a is then modified into the antenna in Fig. 2b for better radiation characteristics; in this design, a PIN diode is placed between the parasitic element and the patch. The simulated result of the variation of the reflection coefficient (S_{11}) for the designed structure with respect to frequency is shown in Fig. 3, taking all other parameters constant as per the structure in Fig. 2a.

A PIN diode changes the slot length. It works as a short circuit and current flows in the circuit. When using a PIN diode, an antenna resonates at different frequency bands. In this structure, a PIN diode is used, it covers two frequency bands [6, 10]. This antenna structure provides the reflection coefficient below – 10 dB with dual notched bands at 3.25-3.85 GHz and 5.25-5.85 GHz for WiMAX. Table 5 shows the effect of the PIN diode in the ON/OFF state.

Table 5 – Effect of the PIN diode in the ON/OFF state

PIN diode state	First frequency band (GHz)	Second frequency band (GHz)
OFF	3.09-4.56	5.11-5.378
ON	3.25-3.85	5.25-5.85

4. RESULTS AND DISCUSSION

The final structure of the proposed CCF UWB antenna for WiMAX applications is shown in Fig. 2b. With reference to the final design, it is observed that the proposed antenna structure has band notched characteristics at frequencies of 3.25-3.85 GHz with a center frequency of 3.5 GHz and at frequencies of 5.25-5.85 GHz with a center frequency of 5.4 GHz with optimized parameters, the result is shown in Fig. 3.

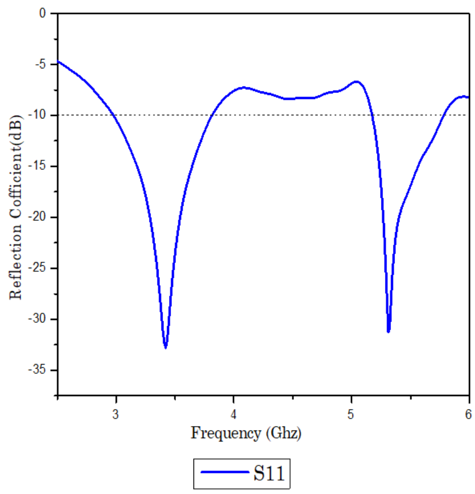
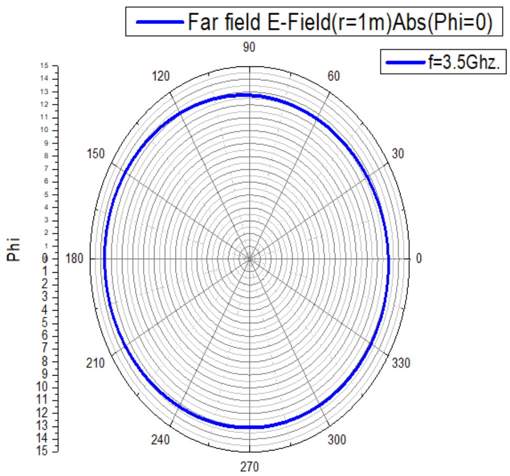


Fig. 3 – Simulated reflection coefficient (S_{11}) vs. frequency (GHz) of the design with a PIN diode and a parasitic element



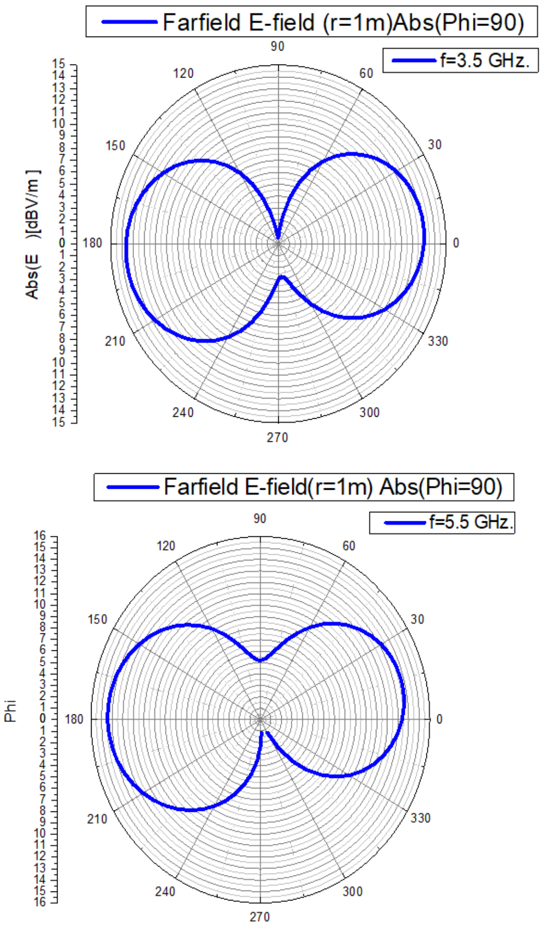


Fig. 4 – Variation of the *E*- and *H*-plane elevation patterns at 3.5 and 5.4 GH

In Fig. 4, the simulated *E*-plane and *H*-plane radiation patterns for the proposed antenna at two different frequencies of 3.5 and 5.4 GHz are shown. It is observed that the *E*-plane is almost omnidirectional in nature for both resonant frequencies. However, the *H*-plane pattern is bidirectional in nature with an angular width of 88.7° at a frequency of 3.5 GHz and 87.0° at a frequency of 5.4 GHz.

5. CONCLUSIONS

In this work, a compact conformal CPW-fed (CCF) UWB antenna for WiMAX applications has been designed. The elementary structure of the proposed antenna design is an asymmetric one, which has two I-shaped stub lines parallel to the feed line and two semicircles on both sides of the feed line. The notch is achieved by applying a parasitic element parallel to the patch and placing a PIN diode between the parasitic element and the antenna patch. By placing these elements, an UWB antenna with dual notched bands at 3.2-3.85 GHz and 5.25-5.85 GHz for WiMAX applications is obtained. To verify the performance of the final antenna structure, several simulated results between frequency and reflection coefficient are studied and analyzed. Compared to other UWB antennas for WiMAX applications, the proposed antenna structure is simple and convenient to design. The proposed antenna structure also has some other attractive features such as good band-edge selectivity, small size, independent reconfigurable structure, which are not related to the radiation pattern and have little effect on the radiation performance of the proposed antenna design.

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Компактна конструкція несиметричної UWB антени з двома режекторними смугами для додатків WiMAX

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У статті представлено компактну конформну несиметричну антену надширокосмугового (UWB) діапазону з компланарним хвилеводним живленням з двома режекторними смугами 3,25-3,85 ГГц і 5,25-5,85 ГГц для додатків WiMAX. Еволюція запропонованої антенної структури представлена поетапно з включенням паразитного елемента та PIN діода. У пропонованій структурі розширення смуги пропускання та режекція смуг реалізуються асиметричною конструкцією, яка має дві I-подібні заглушки, паралельні лінії живлення, та два півкола з обох боків лінії живлення. Режекція досягається шляхом застосування паразитного елемента паралельно патчу антени та розміщення PIN діода між паразитним елементом і патчем антени. Об'ємний розмір антени становить 24×22×0,035 мм^3. Запропонована структура досягає робочого діапазону (VSWR ≤ 2) в інтервалі від 3,1 до 10,6 ГГц з коефіцієнтом підсилення, близьким до 3,95 дБі, разом із значною ефективністю та симетричними діаграмами спрямованості. Паразитні елементи використовуються для поліпшення спрямованості або посилення/зменшення задньої пелюстки. Вибираючи паразитні елементи, можна збуджувати різні резонансні моди поруч одна з одною, що може забезпечити більш широку смугу пропускання. Пропонована антена є низькопрофільною і призначена для використання в якості приймально-передавального пристрою для UWB зв'язку у додатках WiMAX.

Ключові слова: Технологія широкосмугового доступу в мікрохвильовому діапазоні (WiMAX), Копланарний хвилевод (CPW), Конформна антена з компланарним хвилеводним живленням CPW.