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## Compact UWB monopole antenna with reconfigurable band notches using PIN diode switches

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Titre : Antenne monopôle UWB compacte avec encoches de bande reconfigurables utilisant des interrupteurs à diode PIN

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Résumé : Cet article présente une nouvelle antenne monopôle compacte reconfigurable avec deux caractéristiques d'encoche de bande commutables pour les fréquences de 3 à 4 GHz et de 5 à 6 GHz. Les rejets de bande sont réalisés en utilisant une fente en forme de U de longueur  $\lambda/2$  dans la partie principale et une plaque parasite en forme de U de longueur  $\lambda/4$  dans le plan arrière. Dans la conception proposée, deux fréquences d'encoche de bande peuvent être sélectionnées électroniquement à l'aide d'interrupteurs à diode PIN. Par conséquent, quatre états différents sont obtenus. Le rejet de bande couvre les technologies WiMAX, HIPERLAN/2 et IEEE 802.11a. L'antenne reconfigurable conçue, de dimensions  $22 \times 22 \times 1$  mm<sup>3</sup>, fonctionne sur la bande de fréquences entre 2,98 et 11,6 GHz pour un VSWR inférieur à 2.

Mots-clés : antenne monopôle UWB compacte, encoches de bande reconfigurables, interrupteurs à diode PIN, antenne monopôle compacte reconfigurable, rejets de bande, fente en forme de U, plaque parasite en forme de U, WiMAX, HIPERLAN/2, IEEE 802.11a, fréquence de 3 GHz à 4 GHz, fréquence de 5 GHz à 6 GHz.

# Compact UWB Monopole Antenna with Reconfigurable Band Notches Using PIN Diode Switches

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**Abstract**—A novel compact reconfigurable monopole antenna with two switchable band notch characteristics for 3-4 GHz and 5-6 GHz frequencies is presented. Band rejections are realized by using a U-shaped slot with  $\lambda/2$  long in the main patch and a U-shaped parasitic patch with  $\lambda/4$  long in the back plane. In the proposed design two band notch frequencies can be selected electronically using PIN diode switches. Therefore, four different states are achieved. The band rejection covers WiMAX, HIPERLAN/2 and IEEE 802.11a technologies. The designed reconfigurable antenna sized of  $22 \times 22 \times 1 \text{ mm}^3$ , operates over the frequency band between 2.98 and 11.6 GHz for VSWR < 2.

**Keywords**—Band rejection, monopole antenna, PIN diode, reconfigurable antenna, UWB antenna.

## I. Introduction

In recent years, due to increasing number of global wireless standards in close proximity to one another especially in ultrawideband (UWB) radios, the interference among the users increased and the performance of the affected radios decreased. To overcome this problem, it is desired to design UWB antennas with band-notched characteristic and reconfigurable capability [1]–[3]. A reconfigurable antenna which has tunable fundamental characteristics, including operating frequency band and impedance bandwidth uses different electrical or electromechanical switches such as varactor diodes, PIN diodes and RF-MEMS. Although electromechanical switches (MEMS) have benefits of high quality and low loss, but they require expensive facilities. In contrast, antennas that use the electrical switches such as varactor and PIN diodes are simpler to fabricate [4].

Some of the techniques that are used to design UWB antennas with band rejection characteristics have been stated as below: using different shaped slots on the radiating patch [5]–[7], embedding parasitic elements [8], [9] in antenna structure and using split ring resonators [10], [11]. However, these methods have some weaknesses, that the rejected band can not be changed after fabrication [3].

In this paper, a novel UWB reconfigurable monopole antenna with four switchable states is demonstrated. By embedding a U-shaped slot in the main patch and inserting a switching structure in the middle of the slot, switchable band-notch characteristics for WiMAX 3.5 GHz is achieved. The second band notched characteristics for HIPERLAN/2 (5.15–5.35 GHz, 5.470–5.725GHz) and wireless local area network (IEEE 802.11a, 5.15–5.35 GHz, 5.725–5.825 GHz) protocols in proposed design is realized by adding a U-shaped parasitic

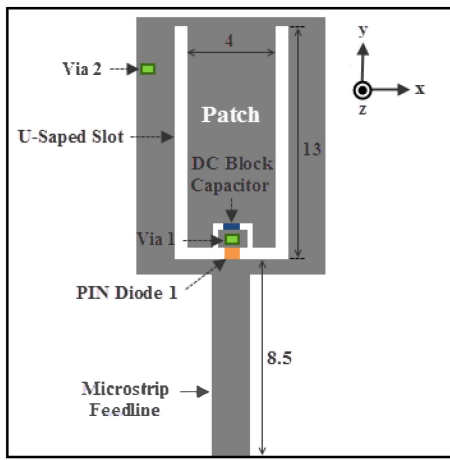
patch in the back plane, then it is cut into two parts which is connected by a PIN diode. Details of the antenna design are described, and both experimental and simulated results are demonstrated.

## II. Antenna Topology

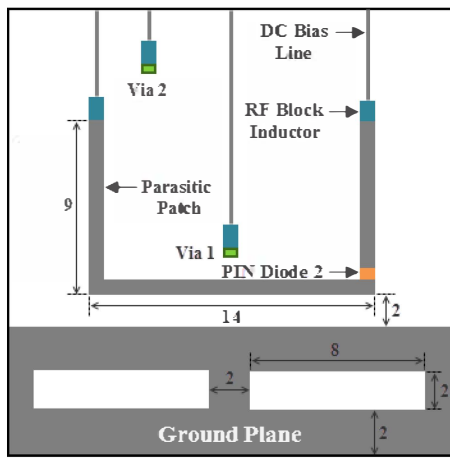
Fig. 1 depicts the configuration of proposed reconfigurable antenna, which consists of an  $8 \times 13.8 \text{ mm}^2$  rectangular patch with a U-shaped slot, a U-shaped parasitic patch and a rectangular ground plane (GND) with length of 6 mm. The proposed antenna is printed on a low cost FR4-epoxy substrate with  $\epsilon_r = 4.4$ ,  $\tan(\delta) = 0.024$  and compact dimension of  $22 \times 22 \times 1 \text{ mm}^3$ . The width and length of the microstrip feed line are fixed at  $W_f = 1.86 \text{ mm}$  and  $L_f = 7.8$ , respectively to achieve 50- $\Omega$  characteristic impedance (Fig. 1). The feed line is terminated with a standard 50-ohm SMA connector. For impedance bandwidth enhancement two rectangular slots are added in the GND and are also symmetrical with respect to the longitudinal direction. The U-shaped parasitic patch consists of two parallel segments in y-axis direction with 9 mm length and a third segment with 14 mm length. As shown in Fig. 1, the U-shaped parasitic patch is positioned 2 mm from the rectangular GND. In the proposed antenna, the rectangular patch can excite the fundamental resonant frequency and the U-shaped parasitic patch is used as a parasitic resonator, electrically coupled to the main patch.

In order to achieve the band-notched characteristics in two bands, two techniques are used which have been stated as below: embedding the U-shaped parasitic element in backplane and using U-shaped slot in the main patch. By using the PIN diodes, the U-shaped slot and parasitic patch respectively can be shortened. The width of the U-shaped slot and U-shaped parasitic patch strips are set approximately to 1 mm. The total length of U-shaped slot and U-shaped parasitic patch are  $\lambda/2$  and  $\lambda/4$ , respectively [1].

Two methods exist to simulate PIN diodes: In first method, the PIN diodes were modeled as a metal tape (tape lengths corresponding to the diode lengths) in the ON state and to eliminate the tape from the model in the OFF state; and in second method, PIN diodes were modeled as a resistor/capacitance in the ON/OFF state, respectively; In this design, the second method is used. Due to the technical datasheet of the HPND-4005 [12], PIN diodes are simulated as a 4.7- $\Omega$  resistor and 0.017-pF capacitor in the ON and OFF states, respectively. With the method used in proposed design



(a)



(b)

Figure 1. Geometry of proposed reconfigurable antenna; (a) top view, (b) bottom view (Unit: mm).

to eliminate the frequencies, the antenna can have four states of reflection coefficients. The exact place for the PIN diodes along the U-shaped slot and U-shaped parasitic patch are selected somehow to change the U-shaped slot and parasitic patch lengths without any effect to resonance frequency to 50 ohm. Due to extreme simulations with different switch positions exact positions found for diodes. In first switching structure, a 100 pF DC blocking capacitor is placed between the metal strip and radiating patch to maintain the RF connection of the PIN diode and also to isolate the RF signal from the DC currents [13]. In proposed design, the metal strip inside the U-shaped slot and radiating patch are connected with vias to the ground plane. Also, four inductors are used in the antennas structure as RF blocks inductors to isolate the RF currents.

### III. Results and Discussion

The performances of proposed antenna have been investigated to find optimized parameters using Ansoft™ high frequency structure simulator software [14]. Thin Bias wires

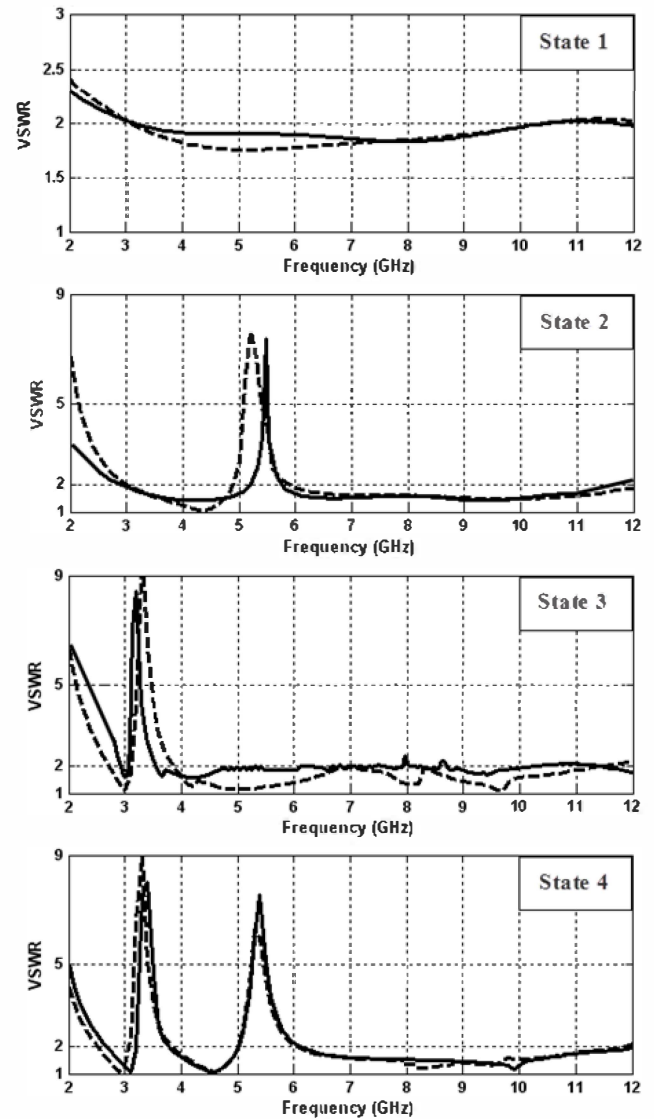


Figure 2. Simulated and measured VSWR of the proposed antenna for different switching states. (Solid line: measured, dashed line: simulated).

with thick insulation were used to bias PIN diodes. A series resistor was placed before the power supply in order to protect PIN diodes. The SMA connector of the antenna is connected to a DC blocker to protect network analyzer against DC currents. In explaining the work process of proposed reconfigurable antenna, four states of proposed antenna are defined as follows (Fig. 2):

In **State 1** (When diode 1 is on and diode 2 is off), It is observed that proposed antenna has a 118% (3.89:1, 2.98-11.6 GHz) impedance bandwidth without any rejection bands. Fig. 2 shows that simulated and measured VSWR of antenna is less than 2 across the whole UWB range;

**State 2** (When all diodes are on), the rejection band is determined by the U-shaped parasitic patch with total length of  $\lambda/4$ . As shown in Fig. 1, one PIN diode (PIN 2) is used to electrically connect and disconnect the two segments of U-shaped parasitic patch at right corner. The measured results in Fig. 2 show that, when PIN diode 2 is “on”, the segments of

U-shaped parasitic patch is connected. Therefore, two parallel segments start to resonate at 5.4 GHz. It is observed that proposed antenna in this state has a band rejection at 5-6 GHz with covering HIPERLAN/2 (5.15–5.35 GHz, 5.470–5.725GHz) and wireless local area network (IEEE 802.11a, 5.15–5.35 GHz, 5.725–5.825 GHz) protocols;

**State 3** (When all diodes are off), the rejection band is determined by the U-shaped slot with total length of  $\lambda/2$ . For switchable characteristics of this slot, PIN diode 1 (Fig. 1) positioned in the middle of the U-shaped slot to connect and disconnect the slot. From Fig. 2, it is observed that when PIN diodes 1 is “off”, U-shaped slot effects on the radiation mechanism and creates rejection in 3-4 GHz bands;

and **State 4** (When diodes 1 and 2 are off and on, respectively), the rejection bands are determined by the both total U-shaped slot and U-shaped parasitic patch length, and are centered at 3.5 GHz and 5.3 GHz, respectively;

TABLE I Different states of the proposed antenna with simulated and measured rejected bands

Diodes	D1	D2	Rejected Band (MHz) Sim./Meas.
State 1	on	off	0
State 2	on	on	5004-5968/4956-5992
State 3	off	off	3102-3850/3072-3966
State 4	off	on	3100-4000/2963-3969 & 5000-6123/5056-6035

The surface current distribution at **State 3** presented in Fig. 3(a) shows how the U-shaped slot with total length of  $\lambda/2$  in main patch resonates at 3.3 GHz and how this rejection behavior is off when the slot is shorted in Fig. 3(b), with PIN diode 1. The surface current in inner and outer side of U-shaped slot in main patch has opposite directions [1]. For this reason these currents cancel each other and antenna will not radiate at 3.3GHz and a frequency band notch is created. When the U-shaped slot is shorted by the PIN diode at center of slot (Fig.3b), the total length of the slot is divided in two, therefore, U-shaped slot cannot support the resonating currents at rejected band [1]. Also, when the second PIN diode (in back plane, Fig.1) is on, two parallel stubs of U-shaped parasitic patch in back plane are connected and the currents flow through these stubs [5.4GHz current distribution at **State2** is presented in Fig. 3(c)], consequently, they resonate at 5.4GHz and create a band notch. By turning this diode off, the band rejecting effect will be eliminated [Fig. 3(d)].

#### IV. Conclusion

A novel compact reconfigurable monopole antenna with two switchable band notch frequencies for UWB applications is introduced. The antenna combines two famous methods with switchable characteristics to reject 3.5 GHz WiMAX, HIPERLAN/2 and WLAN frequency bands. Measured and simulated results validate the proposed reconfigurable antenna which can be a good candidate for future developed UWB technologies.

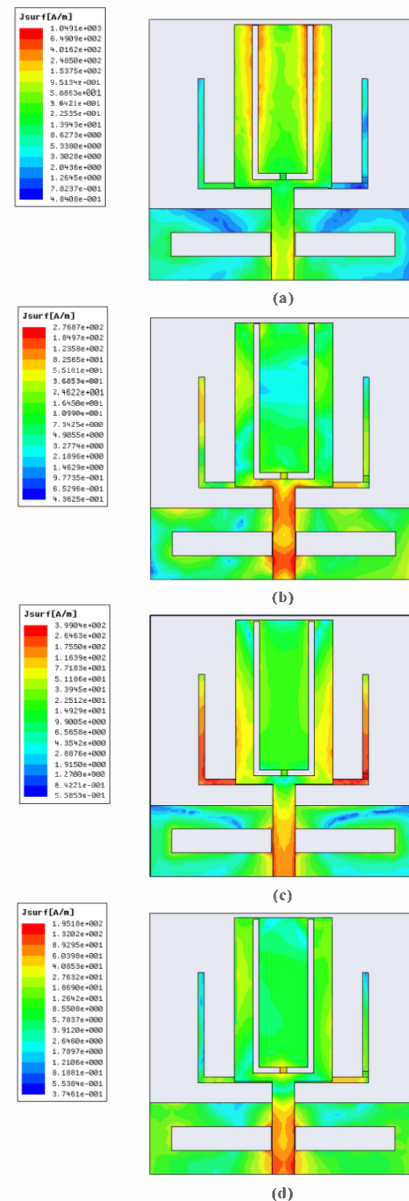


Figure 3. Surface current distribution (a) open U-shaped slot at 3.3 GHz, (b) shorted U-shaped slot at 3.3 GHz, (c) shorted U-shaped stub at 5.4 GHz, (d) open U-shaped stub at 5.4 GHz.

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