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MULTI-STATE UWB CIRCULAR PATCH ANTENNA BASED ON WiMAX AND WLAN NOTCH FILTERS OPERATION

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ABSTRACT
This paper presents a multi-state reconfigurable UWB circular patch antenna with two notch filters. The two notch filters can be implemented using U-shaped and J-shaped slots embedded on the patch for WiMAX and WLAN frequency bands rejection. In order to add reconfigurable characteristics to the patch antenna, two copper strips are placed on the slots to represent the ON or OFF switching state of an ideal Pin diode. By using this simple switching technique, the current distribution of the patch changes and enables the antenna to have four modes of operation. The achieved results demonstrate that the antenna can function over the entire UWB working frequency range (3.1 GHz to 10.6 GHz) in one of the switching configurations. On the other hand, it rejects one or both WiMAX (3.13 – 3.7 GHz) and WLAN (5.15-5.85 GHz) frequency bands in the other three switching configurations. The antenna is simulated using electromagnetic simulation software CST Studio Suite. The obtained results were experimentally validated and good agreement was observed.

Key words: UWB Patch Antenna・ Reconfigurable・ Band Stop Filter・ Multi-State・

INTRODUCTION

The continuous development of wireless communications systems and the increasing request of multifunctional antennas have attracted the mind of researchers for the last ten years. Different methods of wireless communications were the basis of Ultra Wide Band (UWB) technology. In London, the first set up for UWB communications system was in 1896 to connect two post offices mail, the distance was more than a mile apart between them (Nikookar and Prasad, 2009). In 1960, the U.S. armed forces was introduced a contemporary UWB system made use of radar, stealth communication and pulse transmissions to conceal imaging (Kartik and Ramesh, 2014). And because of this, UWB has triggered a huge investment in antenna design with new opportunities and challenges for antenna architects.

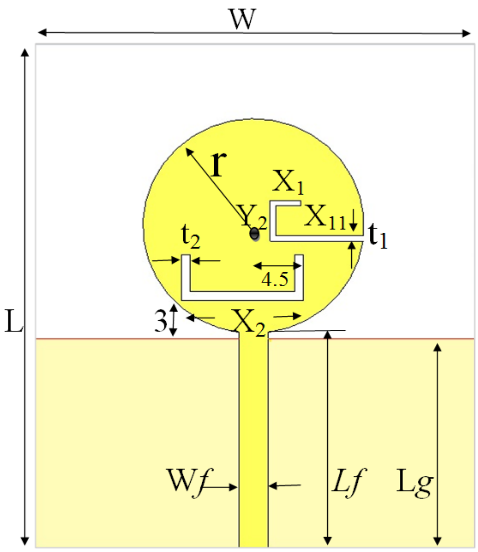
A interference of electromagnetic interference (EMI) with some narrowband on UWB applications is the most defeat problem so, UWB system require to discrete band-stop filters to reject these unwanted frequency bands. The first challenge in UWB antenna design is reaching the wide bandwidth while maintaining good radiation efficiency with a less manufacturing complexity and high gain. For the last decade, researchers have approached the subject area in a number of different ways. A numerous slot configurations embedded in the radiation patch or the ground plane are the most common approaches to realize the rejection of unwanted frequency bands, to reduce the antenna size and to enhance the antenna performance (Liuand Kao, 2006), (Zaker et al, 2009), (Awaleh et al, 2014).

Reconfigurable antennas have recently received strong interest in many applications such as mobile and satellite communication (Yang and Elsherbeni, 2012). Reconfigurable antenna is mostly required in applications where changing operating modes are desired like multimode wireless communication and cognitive radio networks. The most common way of achieving reconfigurable antenna characteristics is to use RF switching components where the ON and OFF states of the switch affects the current distribution of the antenna patch. Two copper strips are employed in this antenna design for proof of concept. The copper strips are embedded on two notch structures, which are conventionally designed for WiMAX and WLAN frequency bands rejection. The proposed antenna can operate on four modes and this gives additional capability and functionality in any multimode and UWB communication systems.

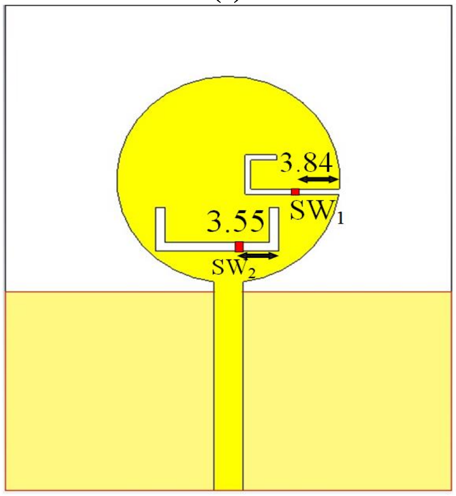
ANTENNA DESIGN AND CONFIGURATIONS

Patch antenna for WiMAX and WLAN notch filters

An UWB antenna for WiMAX and WLAN bands rejection was designed and proposed in (Abdulhasan et al, 2015). Figure 1(a) illustrates the schematic of the circular patch microstrip UWB antenna with two notch structures (J-shaped and U-shaped slots) to realize band rejection characteristics at 3.15-3.7 GHz and 5.15-5.85 GHz respectively. The achieved results for this antenna design demonstrate a good notch filtering performance over the entire working frequency band (3.1 GHz to 10.6 GHz) except notched bands WiMAX and WLAN. On the other hand, the antenna distinguishes are fixed and inflexible. Therefore, a reconfigurable or multifunctional UWB circular patch antenna for WiMAX and WLAN notch filters are proposed in this paper.



(a)



(b)

Figure 1: Geometry of the UWB circular patch antenna (a) Fixed UWB circular patch antenna with notch filters (b) Proposed reconfigurable UWB patch antenna configurations.

Reconfigurable UWB circular patch antenna

The two notch filters on the proposed reconfigurable UWB circular patch antenna with are sketched in Figure 1(b). The circular patch antenna has a radius (r), thickness (t) and embedded slots for desired frequency band filtering. The patch antenna was printed on a standard FR4 substrate having thickness of 1.6 mm, substrate relative permittivity (ε_r = 4.4) and dielectric loss tangent (tanδ = 0.019). The antenna is excited using microstrip line feed with good impedance matching (Allen B. et al, 2007). The antenna substrate and ground plane sizes equal (47×40 mm^2) and (19.6×40 mm^2) respectively.

Two copper strips of (0.5 ×0.8 mm^2) and (0.5 × 0.5 mm^2) are integrated on the slots. The copper strips are used to represent four operation states through ON or OFF switching state of an ideal Pin diode. The presence of copper strip on the slot indicates the switch is ON (short) while the absence of copper strip represents switch OFF state (open). This easy switching technique enables the antenna to show multifunctional capabilities and characteristics.

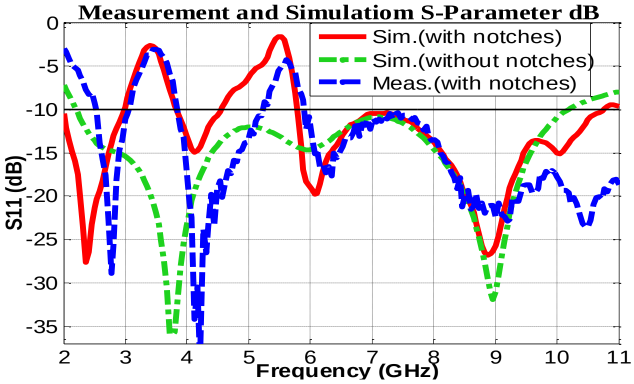
To calculate the overall dimensions of a patch antenna structure, the general mathematical expressions of circular patch antenna at a specific resonance frequency can use (Balanis, 2005), (Abdulhasan et al, 2015). Table 1 summarizes the optimized antenna physical parameters and main features.

Table 1: Important design parameters of the antenna.

Parameter	Value
Frequency range	3.1 GHz to 10.6 GHz
Antenna dimensions	L = 47 mm, W= 40 mm, L_g = 19.6 mm, Wg= 40 mm, Wf= 2.6 mm, Lf = 20.3 mm, r = 10 mm, t=0.035
Optimised slot dimensions	X_{11} = 8.5 m, Y_1 = 3.8 mm, X_1 = 2.8 mm, t_1= 0.5 mm, X_2 = 11 mm, Y_2 = 4.2 mm, t_2 = 0.8 mm.
Substrate	FR4: ε_r = 4.4, h = 1.6 mm, tan δ = 0.019

RESULTS AND DISCUSION

The antenna is designed and simulated using CST Microwave Studio software. First, the fixed UWB circular patch antenna loaded with U-shaped and J-shaped notches were fabricated and measured. The U-slot contributes to WLAN band rejection while the J-slot results WiMAX frequency notch. The reflection coefficient value (S_{11}) of less than -10 dB and VSWR of less than 2 are obtained over the whole design frequency range (3.1-10.6 GHz) except WiMAX (3.15-3.7 GHz) and WLAN (5.15-5.85 GHz) rejected frequency bands as illustrated in Figure 2.



(a)

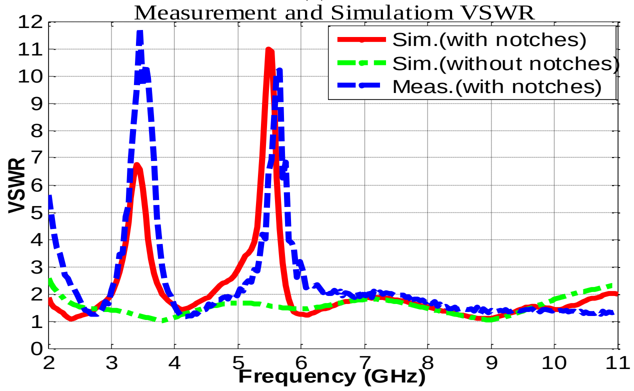


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Figure 2: Fixed UWB circular patch antenna S-parameter performance (a) Measured and Simulated return loss

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curves (with and without notches) and (b) Measured Simulated VSWR curves (with and without notches).

The scattering parameters of the antenna are measured using Vector Network Analyzer. The antenna return loss and VSWR are recorded and sketched with the comparison of the simulated results. The obtained results show that the antenna input impedance had good matching over all the desired bands. It is also observed that the adjusted U-shaped slot length is larger than the J-shaped slot length, hence achieves bigger band reject (5.15 GHz – 5.85 GHz). Secondly, the proposed reconfigurable UWB circular patch antenna are fabricated and measured. This is to test the performance of the antenna while using copper strips, which work as switches to control the slots operation. The geometry of the slots are adjusted to reach the desired frequency band rejections with VSWR > 2 and S_{11}> -10, using the following equations (Ajay et al, 2015).

$$L_1 \approx \frac{c}{4 f_{notch}\sqrt{\varepsilon_{eff}}} \quad (1)$$

$$L_2 = \frac{\lambda_g}{2} \quad (2)$$

$$L_2 = \frac{c}{2 * f_{notch} * \sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (3)$$

Where
L_1: is the length of the J-shaped notch,
L_2: is the length of the U-slot,
f_{notch} : is the notch frequency,
c : is the speed of light,
λ_g: is the guided wavelength of the desired notch frequency,
ε_{eff} : is the effective dielectric constant of the substrate.

The total optimized U-slot and J-slot lengths are equal to 17.8 mm and 14.1 mm respectively. As shown in equations (1) and (2), the U-slot length is equivalent to half wavelength while J-slot length equals quarter wavelength of the desired notch frequencies. Therefore, placing copper strips in the slots decrease the slot lengths, hence causing the slots to be non-responsive to the desired notch frequencies. Four different switches configurations are considered and their descriptions are summarized in Table 2.

Table 2: Proposed antenna switches configurations.

Configurations	Switch state		Band rejection
	S1	S2	
Conf. 1	ON	ON	Passes all range
Conf. 2	OFF	OFF	WLAN and WiMAX
Conf. 3	OFF	ON	WiMAX
Conf. 4	ON	OFF	WLAN

Figure 3 shows the photograph of the fabricated antenna. The reflection coefficient (S_{11}), voltage standing wave ratio (VSWR) and gain performances of all the four switches configurations are investigated. The antenna operates over the entire working frequency band when both switches are ON. In contrast to that, WLAN and WiMAX frequency bands are rejected when both switches are in OFF state while turning ON one switch stops only the desired frequency band. Figure 4 and 5 illustrate the simulated and measured s-parameter results and VSWR of the switch-controlled UWB patch antenna respectively.

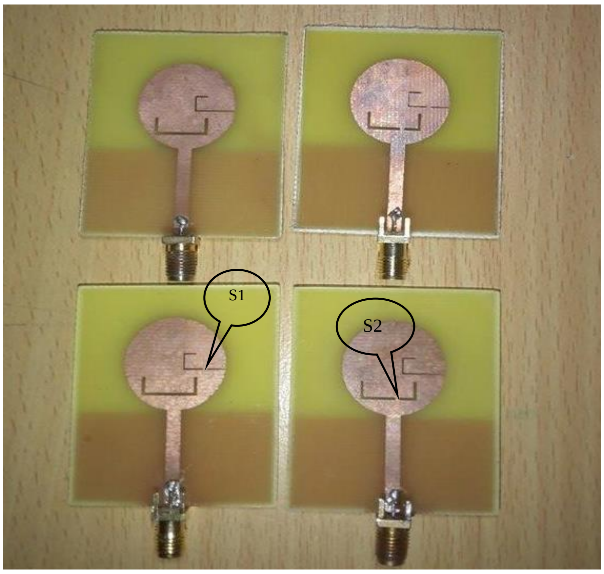
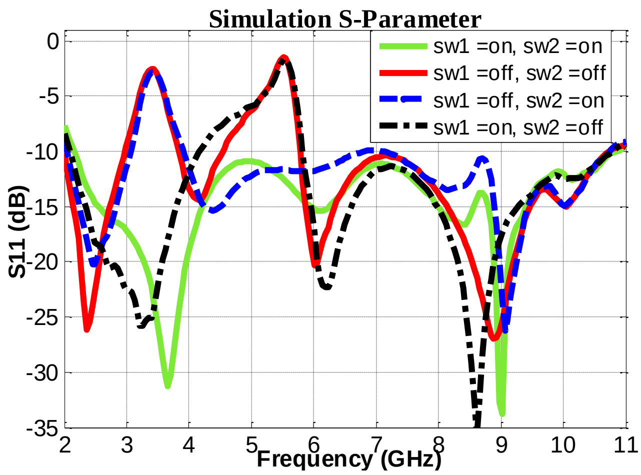


Figure 3: Fabricated UWB circular patch antenna with U and J shaped notches and switch-controlled patch.

The simulated antenna gain over the entire working frequency band with all the four switching configurations is shown in Figure 6 High gain antenna performance (above 5 dB) is demonstrated over the entire UWB frequency range except at the notch frequency bands. Finally, the reconfigurable UWB patch antenna has far-field radiation patterns are plotted by using CST Microwave studio software at 4 GHz, 7 GHz and 10 GHz frequencies in both ON and OFF switching states.



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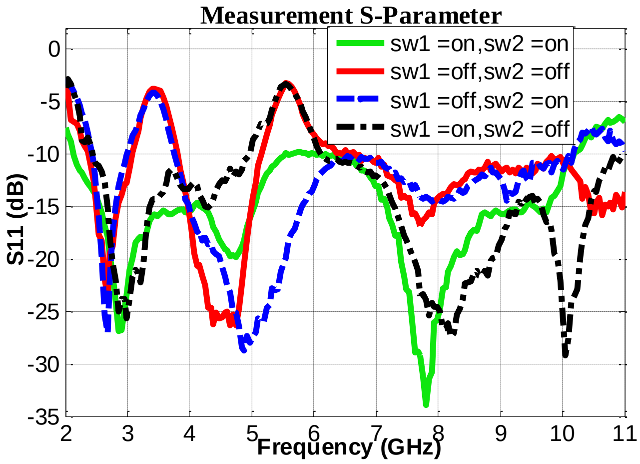
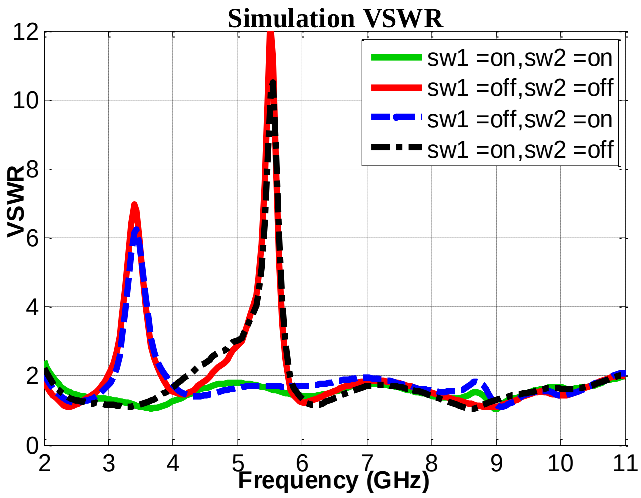


(b)

Figure 4: Reflection coefficient responses of the reconfigurable UWB patch antenna (a) Simulated results (b) Measured results



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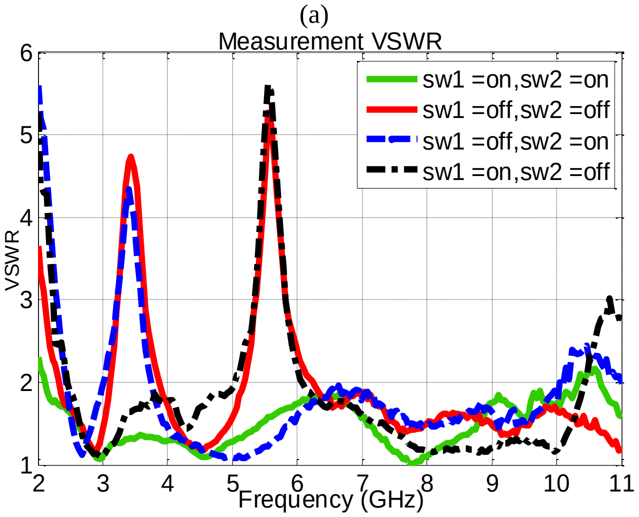


(b)

Figure 5: The proposed reconfigurable UWB patch antenna VSWR performances (a) Simulated (b) Measured.

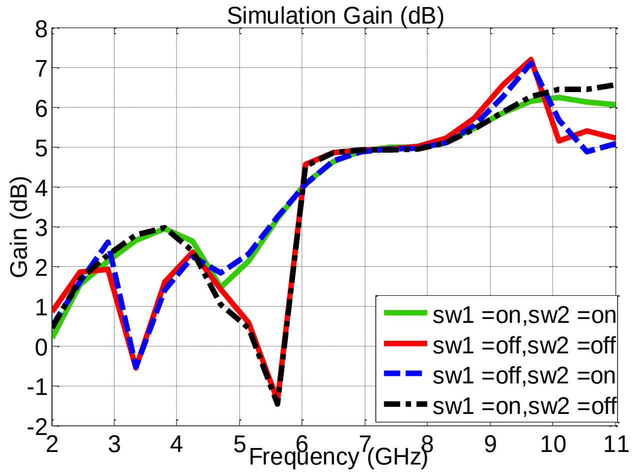
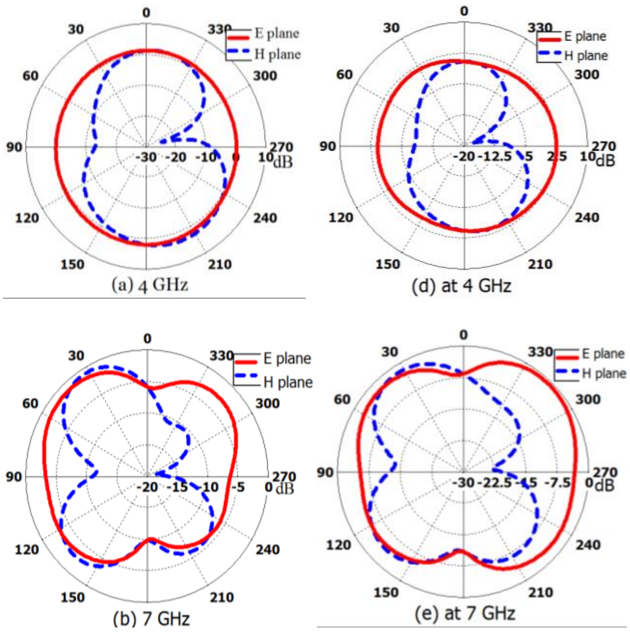


Figure 6: Simulation aantenna gain performance over the entire UWB frequency range.

Figure 7 shows the simulated H-plane (y-z plane) and E-plane (x-z plane) radiation patterns of the antenna. The obtained overall radiation patterns in the E-plane are nearly Omni-directional which is the requirement for UWB wireless communication applications. Moreover, the antenna H-plane patterns are significantly distorted, especially in higher frequencies. The H-plane pattern degradations can be due to some feed-line reflections and leaked electromagnetic waves. In contrast, the antenna preserves high gain (above 5 dB) at the other UWB operating frequency band.



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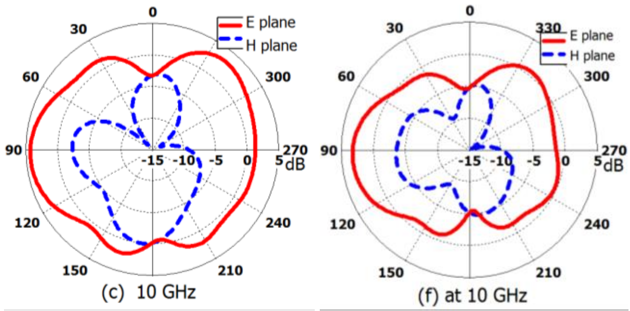

Figure 7: Far-field radiation patterns for the antenna's E-plane and H-plane (a), (b) and (c) ON state of the two switches (d), (e) and (f) OFF state of the two switches.

CONCLUSION

A multifunctional reconfigurable UWB circular patch antenna have been designed and measured. Two copper strips representing as four different switches configurations are placed in the slots embedded on the patch. The additional functionality and capability of the reconfigurable antenna is thoroughly investigated. The slot dimensions and switches positions were optimized to achieve UWB antenna characteristics as well as desired frequency band rejections. The achieved results show that the proposed antenna has good performances in terms of gain, reflection coefficient and radiation patterns for the entire working frequency range except the desired notched frequency bands.

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