

Reconfigurable Band-Notched Slot Antenna Using Short Circuited Quarter Wavelength Microstrip Resonators

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Abstract—In this paper, a CPW feed ultrawideband (UWB) slot antenna with a single reconfigurable notched band is proposed for overlay cognitive radio (CR) systems. The proposed antenna utilizes two symmetrical short circuited quarter wavelength resonators at the top layer and close to the ground to create a single notch. The switching reconfiguration is achieved by changing the length of resonators to prevent the interference to the primary users that are operating in the wireless local area network (WLAN) band at 5.725–5.825 GHz and the international telecommunication union (ITU) band at 8.05–8.4 GHz. The center frequency of the notched band can be tuned by selecting the length of the resonators, which is achieved by employing two ideal switches. Moreover, the proposed antenna has been fabricated and tested. The experimental data confirmed that the proposed design can selectively have a band notch over the two existent desired bands.

1. INTRODUCTION

With the highly increasing demand for wireless communications, the radio frequency (RF) spectrum has become a scarce resource. The lack of available spectrum for accommodating modern services in combination with the under utilization of currently allocated spectrum has fueled the research area with alternative views on communications to that of the former years. Software defined radio (SDR) and cognitive radio (CR) were proposed and emerged to enhance the management and the utilization efficiency of the crowded RF spectrum. CR is a smart wireless communication system where the SDR platform constitutes one of its fundamental building blocks [1]. CR has the ability to sense, adapt and utilize temporarily inactive spectrum, which is referred to as a spectrum hole [2]. In a CR overlay paradigm, the antenna function at the CR device should be able to operate over the whole UWB range, for sensing and locating the bands that are being active by primary users, but should also be capable of producing band notches in its frequency response to avoid the interference to these primary users [3].

To avoid the interference with the existing narrow systems using traditional method, a bandstop filter should be incorporated in the UWB system structure which will increase the complexity and size of the whole system. Accordingly, the reconfigurable band-notched antennas become attractive and play a vital role in communication purposes to overcome the interference without using bandstop filters. The reconfiguration of the UWB antenna enables the antenna to avoid the transmission at single, dual, or multiple frequency bands. The UWB antennas with the rejection of single band [4–6], dual bands [7–9], multiband [10], and reconfigurable bands [11] have been presented and investigated [4–11]. Some of the recently used approaches include using electromagnetic band-gap (EBG) structure [12, 13], defected ground structure (DGS) [14], etching different slots on the patch or the ground [15, 16], employing a band-reject filter into the feed line of the antenna [17], Varactor diodes [18], optical switches [19], PIN

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diodes [20], and rotational motion using a stepper motor [21]. Slots in the radiator have been widely implemented to obtain tunable notched-bands. For example, in [3], an ideal switch was employed inside the radiator to achieve switching for different band-notches by adjusting slot length. However, the reduction levels in the gains at the notched bands are relatively low (approximately 6 dB suppression), and the antenna has a size of $40 \times 40 \text{ mm}^2$. Besides, the measured radiation patterns have some distortions and magnitude fluctuations due to the use of slots and an ideal switch inside the radiator patch. In a similar way, using three slots inside the radiator to obtain dual band-notch characteristics is investigated in [7] and [8]. However, the rejection levels are quite low. Pattern distortions and low rejection levels are main challenges in designing reconfigurable band notched antennas for CR systems. To avoid the effect of the distortions in the radiation patterns of the passband frequencies and to improve the rejection level, the employed band-notched resonant structures such as resonators and slots are preferred to be placed as far away from the radiator as possible.

In this work, a CPW-fed planar monopole antenna with reconfigurable band-notch characteristics is presented and discussed. Using quarter wavelength resonators in the top layer has some advantages, such as simple design, stable radiation pattern, high rejection level, and simplicity in tuning the center frequency of the notched band. Furthermore, the use of a quarter wavelength resonator needs less space to be implemented than the case of employing half wavelength resonators [17]. The proposed approach is based on electrically tuning the produced resonant frequency of the notched-band by altering the length of the quarter wavelength microstrip resonator using two ideal switches to avoid the transmission at the active primary user's bands operating in the wireless local area network (WLAN) band at 5.725–5.825 GHz and the international telecommunication union (ITU) service at (8.025–8.4 GHz). In Section 2, the theory, design parameters, and simulation results of the proposed antenna are explained and discussed. Section 3 is devoted to the proposed fabricated antenna experimental results and discussions. A summary of the work is followed.

2. PROPOSED RECONFIGURABLE SINGLE NOTCHED-BAND CPW-FED SLOT ANTENNA

The layout of the proposed antenna consists of a CPW feed and a rectangular radiating element in the top layer as shown in Fig. 1(a). The slot antenna structure is designed on an RO3003TM substrate with a dielectric constant of 3, $\tan \delta = 0.0013$ and thickness of 0.762 mm. The rectangular radiating element has a size of $L_2 \times W_2 \text{ mm}^2$ while the slot has a length of L_{slot} and width of W_{slot} . The 50 ohms CPW feed line has a width of W_1 and length of L_1 while the gap has a width of 0.2 mm. A quarter wavelength resonator is printed beside the slot edges at the top layer and connected to the ground plane. For a symmetrical structure, two identical resonators are used in the two sides. Because of the fringing effects, the resonator length L_r (L_{r1} in OFF state and L_{r2} in ON state) electrically looks greater than the physical dimension and extended by Δ_r on the open circuited side as shown in Fig. 1(c). The effective length of the microstrip resonator ($L_{r,\text{eff}}$) determines the fundamental resonant frequency f_o and the harmonics [22]. The resonant frequency of the notch can be approximately calculated using

$$f_{\text{notch}} = \frac{kc}{4 * L_{r,\text{eff}} \sqrt{\varepsilon_{\text{eff}}}}, \quad L_{r,\text{eff}} = L_r + \Delta_r \quad (1)$$

where $k = 1, 2, 3, \dots, c$ is the velocity of the light in free space, and ε_{eff} is the effective permittivity. To achieve tunability, the notch frequency can be electrically tuned by using switching devices like ideal switches or PIN diodes to change the length of resonator.

Use ideal switches to tune between two fixed lengths of the resonator. When the switch is ON, the length and width of the resonator are L_{r2} and W_r , respectively, while the length of the resonator is L_{r1} in the OFF state of the switch, as shown in Fig. 1(c).

3. PARAMETRIC STUDY OF THE NOTCHED-BAND

The center frequency of the notched band, bandwidth, and rejection level are significantly controlled by the length and width of the short circuited quarter wavelength resonator. Fig. 2(a) illustrates the simulated VSWR for different length values of the resonator using the transient solver in the Computer

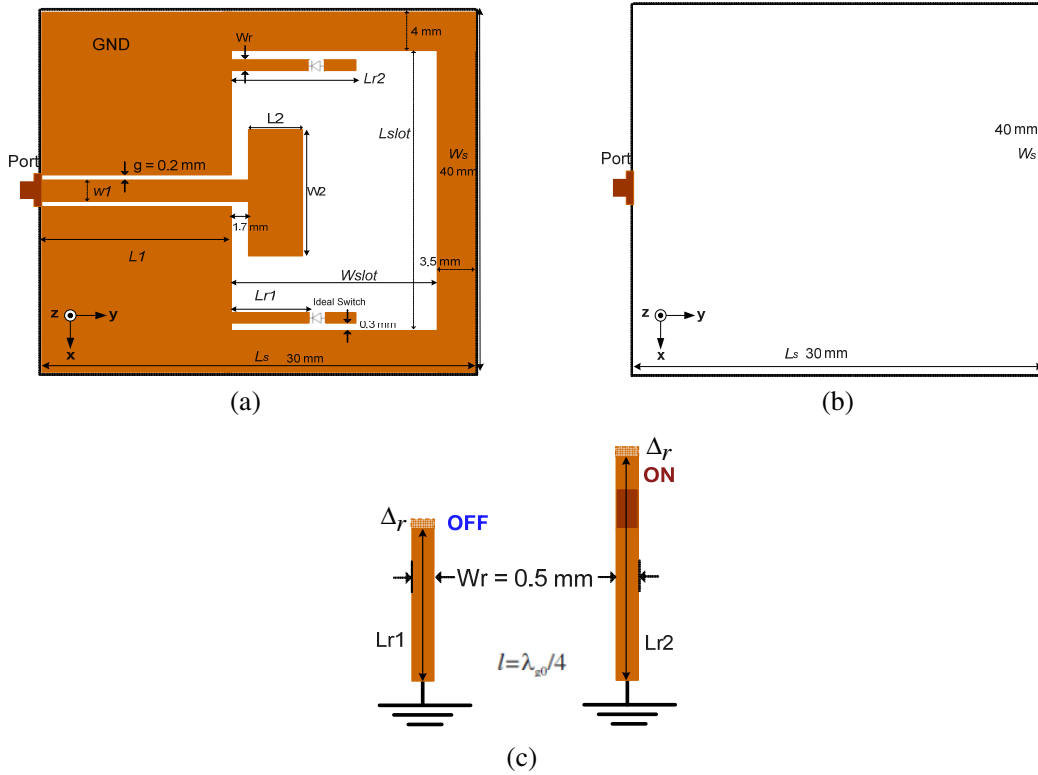


Figure 1. Schematic of the proposed UWB notch antenna. (a) Top view. (b) Bottom view. (c) Short circuited quarter wavelength resonator in ON and OFF states.

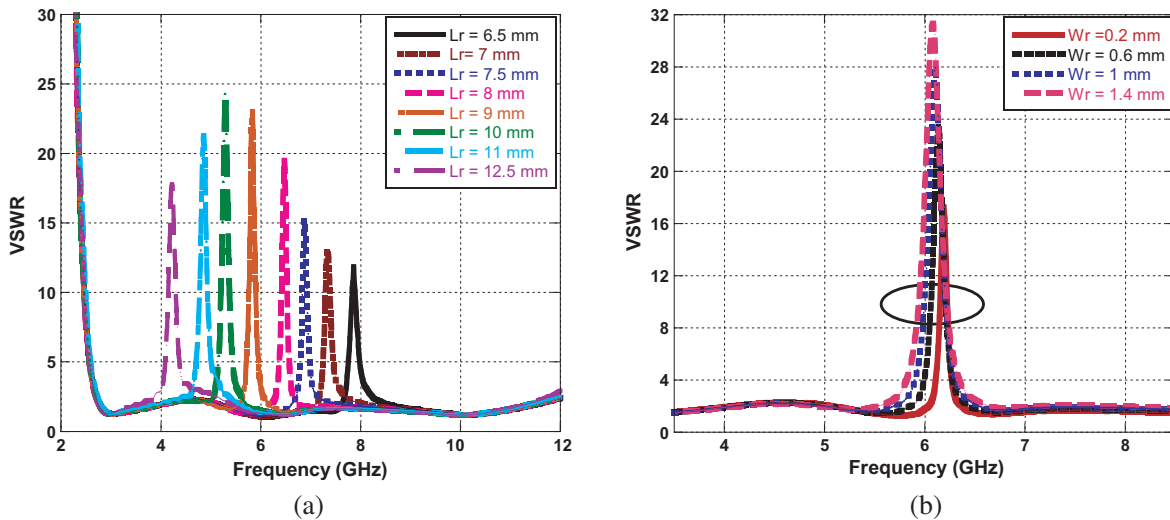


Figure 2. Simulated VSWR for various values of the resonator length and width. (a) Length study at fixed width of 0.8mm. (b) Width study at fixed length of 8.5mm.

Simulation Technology (CST) Microwave studio [23]. To explore the effect of the length of the resonator, the parametric study was done for the resonator with a fixed width of 0.8mm. By varying the length of the resonator L_r from 6.5 to 12.5mm, the center frequency of the notched band is easily tuned as shown in Fig. 2(a). Fig. 2(b) shows the variation of the notch bandwidth, when changing the width of the resonator W_r from 0.2 to 1.4mm while the length of the resonator remains constant at 8.5mm. It

is observed that the width of the resonator affects the notch bandwidth extremely. For example, a large width of the resonator results in a wide bandwidth and vice versa while the length of the resonator controls the center frequency of the notched band. It is observed from these graphs that the center frequency and bandwidth of the notch can be easily adjusted by controlling the length and width of the resonator, respectively, to the desired bands based on the results of the parametric studies and the theoretical calculations using Equation (1).

Table 1 contains the optimized design parameters of the proposed antenna at the desired bands where the antenna has total dimensions of length $L_s = 30$ mm and width $W_s = 40$ mm.

Table 1. The summary of the optimized antenna parameters.

Parameters	Values (mm)
radiating element length (L_2)	6.5
radiating element width (W_2)	11.5
Rectangular slot length (L_{slot})	32
Rectangular slot width (W_{slot})	13.5
CPW feed line width (W_1)	2.8
CPW GND length (L_1)	13
CPW feed gap width (g)	0.2
Resonator width (W_r)	0.5
Resonator length in OFF state (L_{r1})	5.7
Resonator length in ON state (L_{r2})	8.65

Moreover, the UWB antenna without the resonator is also simulated and fabricated as a reference antenna. Fig. 3(a) shows the simulated VSWR of the proposed antenna and the reference UWB antenna. The results show that the antenna can selectively tune between two notched bands which cover the WLAN (5.725–5.825 GHz) and ITU service (8.025–8.4 GHz) to avoid the transmission at the active primary users that are operating at these bands. Compared to the theoretical calculations using Equation (1), the notch frequency experiences a percentage error of 3.4% in the ON state and percentage error of 2.5% in the OFF state. Fig. 3(b) shows the simulated realized gains of the proposed band-notched antenna and the reference antenna without the resonators. The results show that the proposed band-notched antenna has more than 10 dB decrease at the center frequencies of the notches.

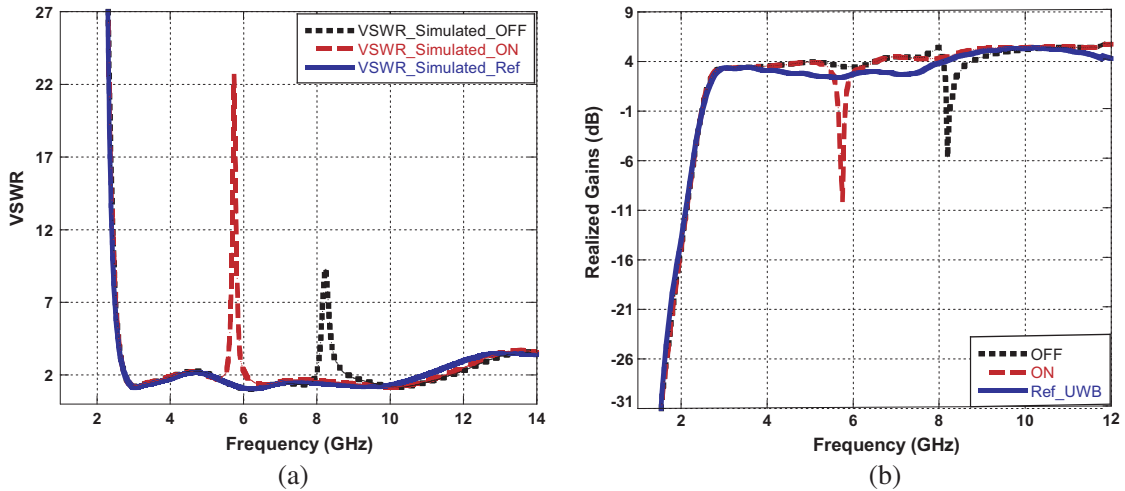


Figure 3. Schematic of the proposed UWB notch antenna, VSWR, and realized gains. (a) Simulated VSWR. (b) Realized gains.

4. EXPERIMENTAL RESULTS

The proposed reconfigurable band-notched antenna is fabricated and measured to validate experimentally the approach of achieving tunable single band-notch operation using short circuited quarter wavelength resonator. Photographs of the top and bottom views of the fabricated antenna are shown in Fig. 4. The notch frequency can be tuned by incorporating two ideal switches to switch between two different lengths of the resonator. The two ideal switches are realized by metallic strips between the two sections of the resonator in the ON state while they are considered as no connections in the OFF state. The $|S_{11}|$ parameter and VSWR measurements are performed using Anritsu 37269D vector network analyzer.

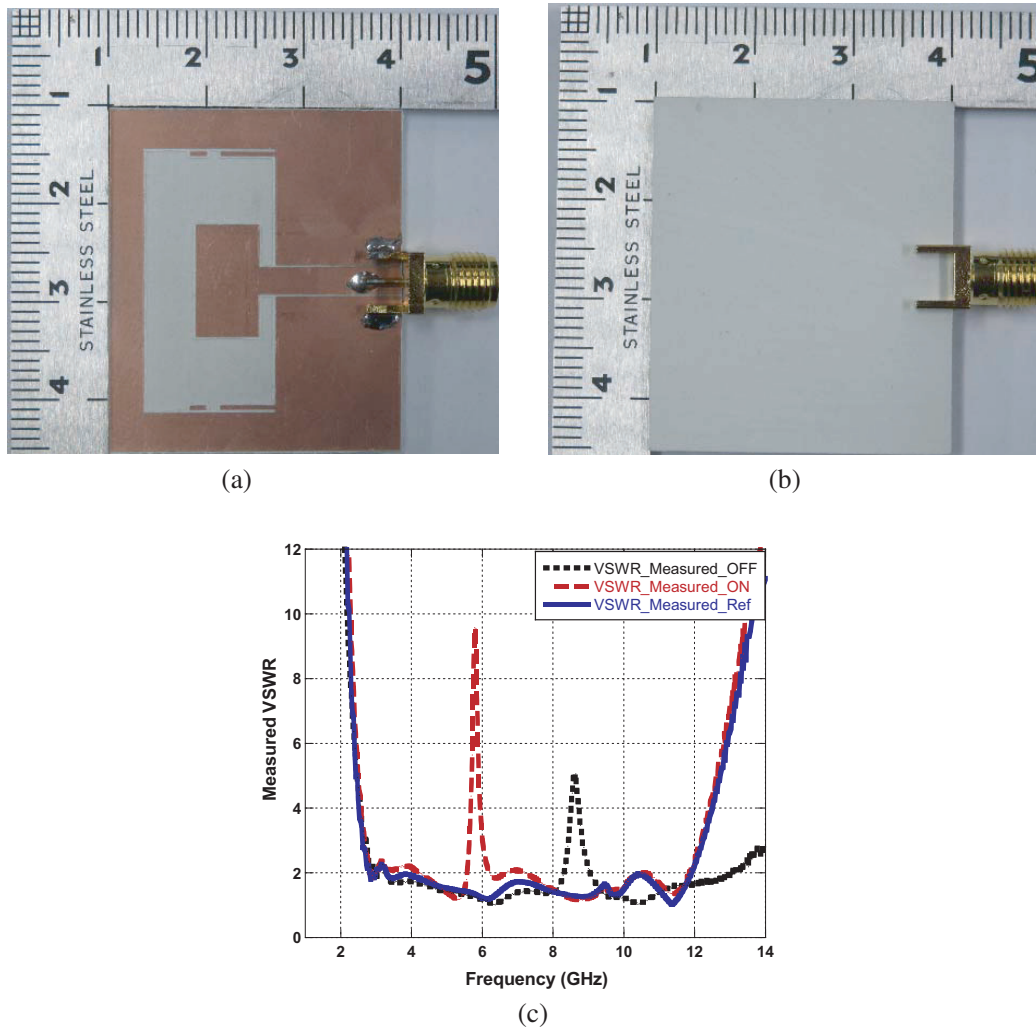


Figure 4. Photograph of the proposed fabricated CPW-fed UWB antenna and VSWR. (a) Top view. (b) Bottom view. (c) Measured VSWR.

The fabricated reference UWB antenna provides a measured band of 9.1 GHz from 3.05 to 12.15 GHz. The proposed fabricated antenna works in the UWB range with a notched band at the WLAN (5.725–5.825 GHz) in the ON state and a notched band at the ITU (8.025–8.4 GHz) band in the OFF state of the switch as shown in Fig. 4(c). However, an acceptable small differences in the central frequencies between the simulated and measured data are found. The differences could be attributed to the fabrication tolerance, soldering, and coaxial cable effects.

Figure 5 shows a comparison between the simulated and measured normalized radiation patterns

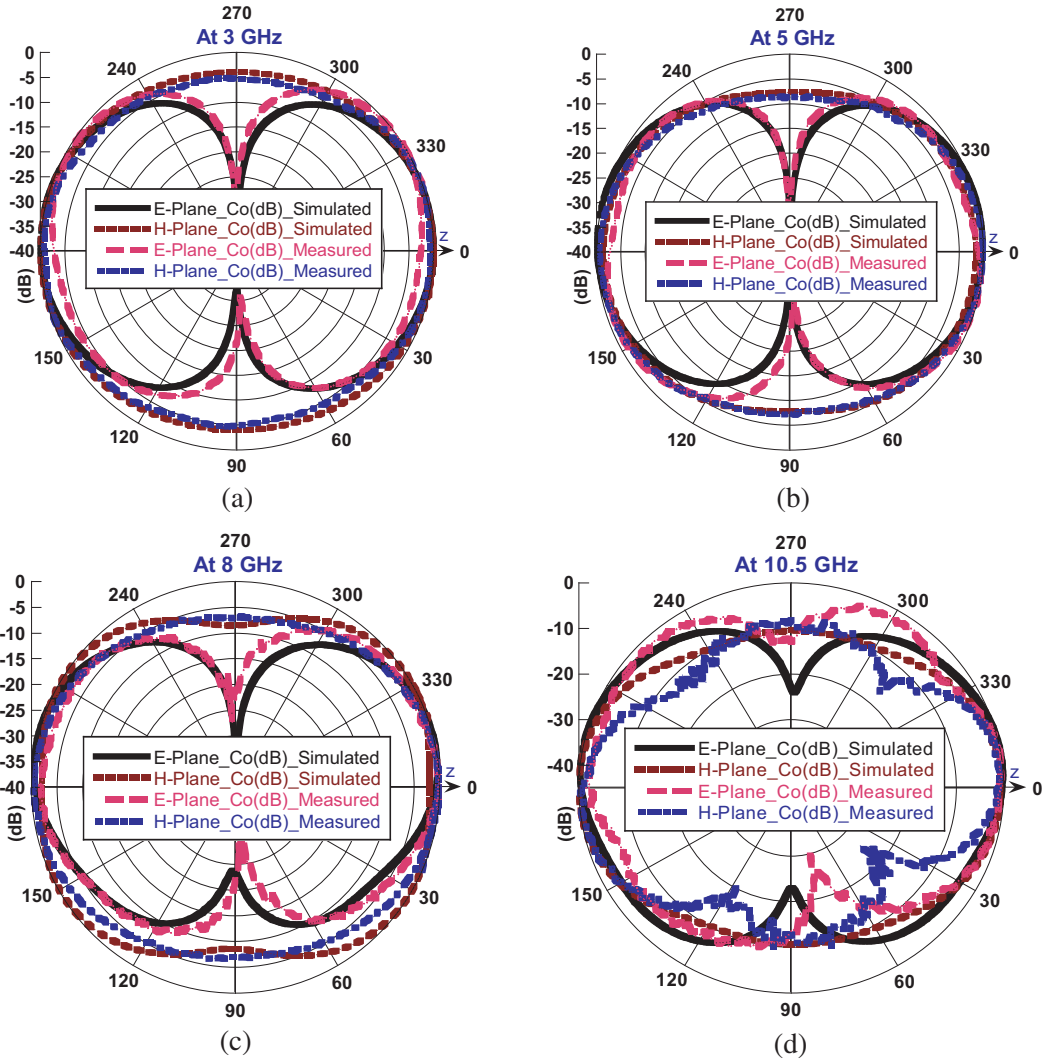
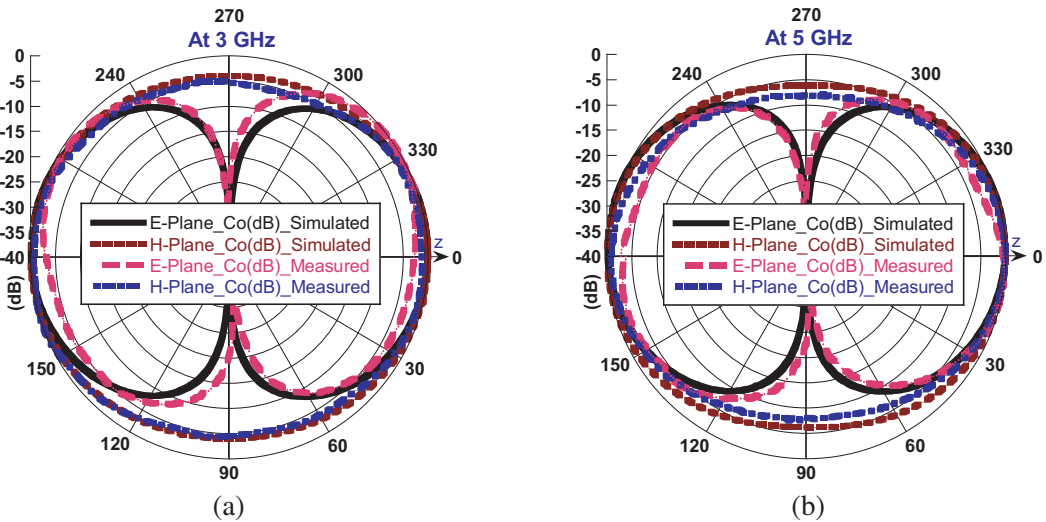


Figure 5. The proposed antenna simulated and measured normalized radiation pattern results when the switch is ON state. (a) At 3 GHz. (b) At 5 GHz. (c) At 8 GHz. (d) At 10.5 GHz.



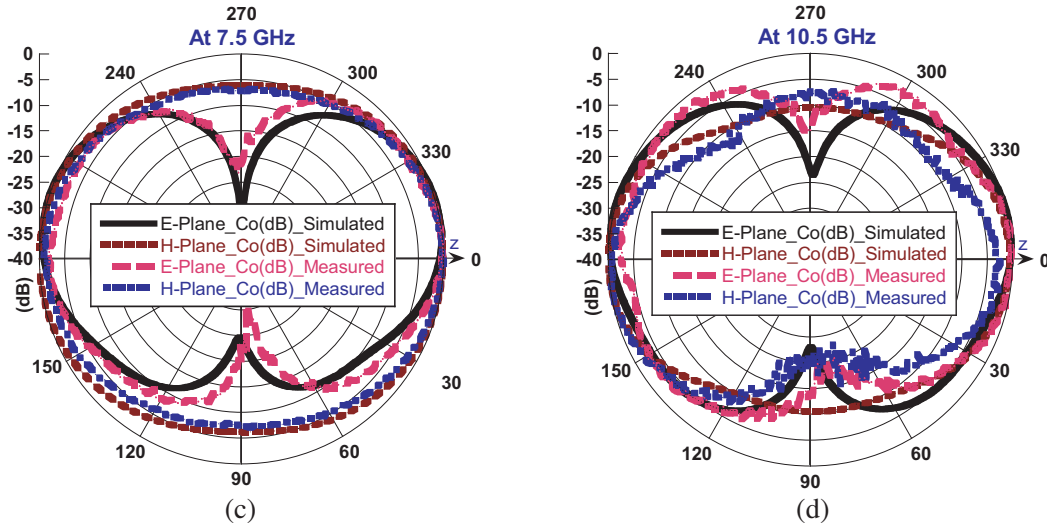


Figure 6. The proposed antenna simulated and measured normalized radiation pattern results when the switch is OFF state. (a) At 3 GHz. (b) At 5 GHz. (c) At 7.5 GHz. (d) At 10.5 GHz.

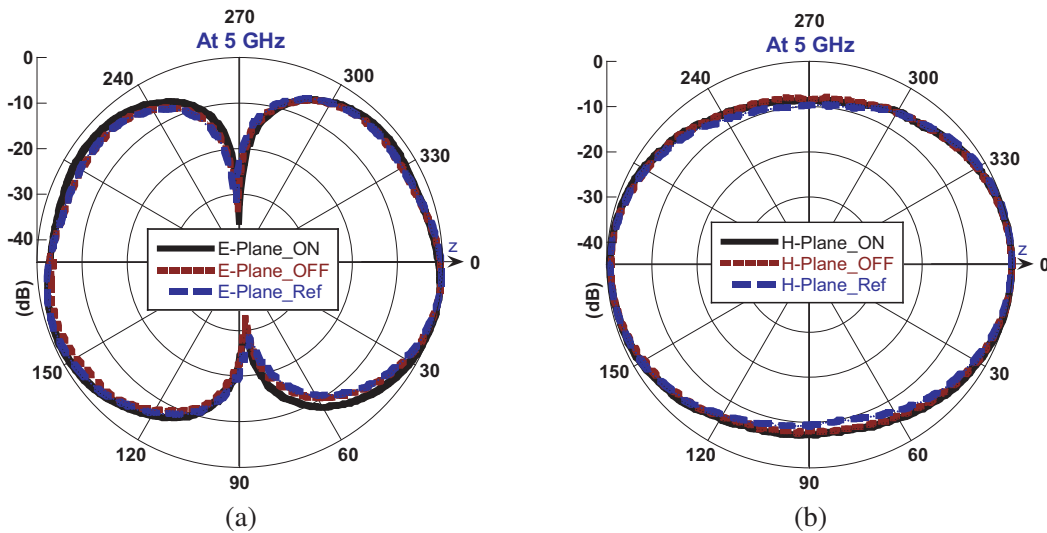


Figure 7. The reference and the proposed antenna measured radiation patterns when the switch is ON and OFF. (a) Measured *E*-planes. (b) Measured *H*-planes.

of the proposed band-notched UWB antenna when the switch is ON at selected frequencies (3, 5, 8, 10.5 GHz). It is obvious that the patterns in the *E*-plane (*yz*-plane) and *H*-plane (*xz*-plane) are stable over the whole operating frequency range and confirm the desired beams of two-sided directional pattern.

For more investigations of the antenna performances, the measured normalized radiation pattern results of the proposed antenna, when the switch is OFF at selected frequencies (3, 5, 7.5, 10.5 GHz) over the operating band, are plotted and compared to the simulated patterns in Fig. 6. These results show that the patterns in the *E*- and *H*-planes are steady over the whole operating band with a good agreement. The proposed antenna exhibits stable measured radiation patterns compared to the measured patterns in [3] which uses the same type of switches.

To explore and investigate the effect of the quarter wavelength resonator on the radiation patterns, the measured normalized radiation patterns of the proposed antenna without (reference antenna) and with the resonator at 5 GHz when the switch is OFF and ON are plotted in Fig. 7. Obviously, the measured results with and without the resonator do not show any significant differences.

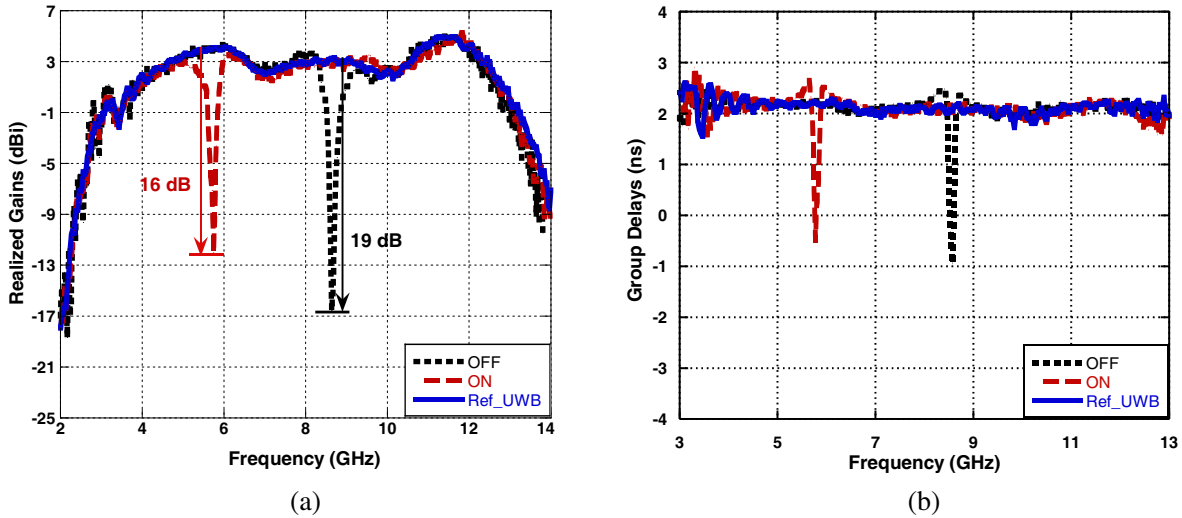


Figure 8. Realized gains and group delays of the proposed band-notched antenna in ON and OFF states. (a) Measured realized gains. (b) Measured group delays.

The measured realized gains (at front side) in the ON and OFF states of the switch are depicted as a function of frequency in Fig. 8(a) and compared to the realized gain of the reference antenna. The results show that the antenna exhibits two sharp gain decreases at the desired bands (more than 16 dB) in the ON and OFF states of the switch, and the rejection levels are larger than the results shown in [3] and [7]. The measured group delays of two identical antennas in the face-to-face orientations with a separation distance of 54 cm to analyze the dispersion for the two cases of the switch are shown in Fig. 8(b). The results show flat group delays except at the notched bands while the group delay of the reference antenna is constant and steady over the entire frequency band of operation. Therefore, the proposed antenna is convenient for transmitting and receiving UWB pulse with a very small distortion.

5. CONCLUSIONS

In this paper, a design of a frequency reconfigurable band-notched antenna with good rejection levels for overlay CR applications is presented, fabricated, and measured. In this simple antenna design, a reconfigurable band notch at two desired bands is successfully achieved by using a short circuited quarter wavelength microstrip resonator. The switching technique has been accomplished by incorporating two ideal switches attached to the resonator to choose between two different lengths of the resonator which corresponds to band notch at WLAN (5.725–5.825 GHz) and at ITU (8.05–8.4 GHz). The proposed antenna is experimentally validated. Moreover, the measured and the simulated results are presented, compared, and discussed. Excellent agreement is found between the measured and simulated data. Furthermore, the radiation patterns are very stable over the operating frequency range.

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